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Development of a Facility for Studies on Intensity Based Sound Power and Sound Transmission Loss Measurements

Junping Li

A thesis

in

The Centre

for

Building Studies

Presented in Partial Fulfilment of the Requirements
For the Degree of Master of Engineering
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ABSTRACT

The sound intensity technique is a new measurement technique in acoustics and offers a better alternative to measure the sound power level of noise-generating objects or the sound transmission loss of building partitions. No standards have been established for these measurement methods, and this work is intended to contribute towards their establishment.

An automated measurement facility for both sound power and sound transmission loss tests has been constructed and one dimensional and three dimensional intensity tests were undertaken to commission the facility.

Investigations were carried out on the influence of some dominant measurement parameters whilst various experimental errors are investigated in detail.

Existing draft standards on sound power measurement are discussed and some recommendations for change are proposed; in addition recommendations towards a sound transmission loss standard are presented.

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TABLE OF CONTENTS

Chapter 1

Chapter 2

Chapter 4

Chapter 5

Chapter 6

Appendices

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

A_a : Room absorption; [Sabin, m^2]

V : Volume of room; [m^3]

I : Sound intensity; [watt/m^2]

t : Time; [s]

p : Sound pressure; [Pa]

$\hat{u}$: Medium particle velocity vector; [m/s]

I_r : Intensity in r direction; [watt/m^2]

ω : Angular frequency; [rad/s]

ρ : Density of medium; [Kg/m^3]

Δr : Spacing of intensity microphones; [m]

Im : Imaginary part of a quantity;

$\{G_{12}\}$: Cross spectral density of signal 1 and 2;

∇ : Gradient operator;

u_r : particle velocity in r direction; [m/s]

r : Distance between sound source and microphone probe; [m]

P_A : Pressure measured by microphone A; [Pa]

P_B : Pressure measured by microphone B; [Pa]

I_m : Measured intensity; [watt/m^2]

I_t : True intensity; [watt/m^2]

k : Wave number;

IL_{error} : Error on sound intensity level; [dB]

Φ : Phase between two channels; [rad.]

f : Frequency; [Hz]

Φ_{error} : Phase error between two channels; [rad.]

p_t : True pressure; [Pa]

I_{re} : Residual intensity; [watt/m^2]

p_{re} : Residual pressure; [Pa]

p_{amb} : ambient barometric pressure; [mbar]

$p_{amb,0}$: Standard ambient barometric pressure; [1013mbar]

T : Temperature; [k]

T_0 : Standard temperature; [k]

W : Sound power; [watt]

s : Measurement surface;

$\hat{n}$: Unit normal vector;

TL : Sound transmission loss; [dB]

W_i : Incident sound power; [watt]

W_t : Transmitted sound power; [watt]

$\sigma 1$: Radiation efficiency of a vibrating surface;

ρc : Characteristic impedance of medium; [rayl, Pa·s/m]

$\hat{u}_n$: Normal particle velocity; [m/s]

SWL_i : Incident sound power level; [dB]

SWL_t : Transmitted sound power level; [dB]

p_{rms} : Root mean square pressure; [Pa]

A : Panel area; [m^2]

SPL_{int}: Incident sound pressure level; [dB]

SIL_t : Transmitted sound intensity level; [dB]

S : Area of measurement surface; [m^2]

n, N : Number of measuring points;

SIL_i, SIL_j : Individual sound intensity level; [dB]

L_A : Area correction factor for TL test; [dB]

L_c : Sum of other correction factor for TL test; [dB]

λ : Sound wavelength; [m]

L_{WH} : Waterhouse correction for TL test; [dB]

S_1 : Internal surface area of reverberation room; [m^2]

V_1 : Volume of reverberation room; [m^3]

I_{ni} : Individual normal intensity at point i; [watt/m^2]

A_i : Individual surface area for segment i; [m^2]

SIL_s, $\overline{L}_i$: Average surface intensity level; [dB]

SPL_i : Individual sound pressure level at point i; [dB]

SPL_s, $\overline{L}_p$: Average surface pressure level; [dB]

σ : Sample standard deviation;

x_i : Value of sample i;

$\overline{x}$: Sample mean;

PII : Pressure-intensity index; [dB]

L_p : Pressure level; [dB]

L_i : Intensity level; [dB]

Er_{tot} : Total error; [dB]

Er_{random} : Random error; [dB]

Er_{system} : Systematic error; [dB]

Er_{phase} : Phase mismatch error; [dB]

$\overline{L}_{|in|}$: Unsigned surface intensity level; [dB]

I_0 : Reference intensity; [10^{-12} watt/m^2]

Ld : Dynamic capability index; [dB]

p_0 : Reference sound pressure; [$2 \cdot 10^{-5}$Pa]

$\overline{L}_{I,BO}$: Average surface intensity level with background noise only; [dB]

L_W : Sound power level; [dB]

δ : Convergency index; [dB]

Ld_{TL} : Dynamic capability index for TL tests; [dB]

CHAPTER 1

INTRODUCTION and LITERATURE REVIEW

1.1 Introduction

Modern buildings require high noise-isolating performance for the building enclosures; in addition internal noise sources require to be suppressed.

To accommodate these requirements, two acoustic quantities must be determined, namely, the sound transmission loss of a panel in order to indicate the ability of the panel to reduce transmitted noise levels, and the acoustical power of a sound source to determine its ranking amongst others as well as its subjective characteristics.

The conventional method for determining the transmission loss of a partition[1] requires a test facility including two vibration-isolated reverberation rooms having the following typical properties: the volume of each room must be greater than 80 m^3 for 125Hz as the lowest frequency tested; the dimensions of the two rooms should not be the same, nor should their dimensions be in certain ratios; the room absorption in each room should be no greater than $A_\alpha=V^{2/3}/3$ where A_α is the room absorption in metric sabines and V is the volume of the room. These requirements restrict the availability of such facilities because the market generally does not support their wholly commercial operation. Furthermore, this measurement method cannot give the spatial distribution of transmission loss over the partition, but instead yields an 'integrated' or overall acoustic energy transmission. Therefore, important diagnostic information of the panel is lost and detailed analysis of the panel properties is impossible.

The method traditionally used to measure sound power[2] also requires a test facility, either a reverberation room or an anechoic(hemi-anechoic) room. This requirement is especially restrictive when the noise source to be measured cannot be moved either because it is too large or too heavy, or if the movement will change the characteristics of the source. Sound power can be measured in a free field provided it is an obstruction-free outdoor condition and the movement of the source is possible; the technique, however, is still limited to fair weather condition.

During the last decade, the intensity measurement technique has become practical. This new measurement technique in acoustics offers an alternative method for sound transmission loss and sound power measurements. This technique releases the restrictive facility requirement in the case of sound power measurement and reduces the facility requirement for the transmission loss test, since in the intensity measurement technique one can measure the sound power in situ and measure the transmission loss using only one reverberation room. In addition, one may also obtain detailed information of the source or panel emission characteristics.

Due to its relative newness, standards on transmission loss and power measurements by the intensity technique have not yet been established, although there are draft standards[3][4] on sound power measurement. The best measurement procedure, instrumentation requirements and analysis guidelines on transmission loss measurement are still in the research stage, while the draft standards for sound power measurement are still being validated.

1.2 Literature Review

Numerous researchers have worked on the applications of the sound intensity technique. Most have contributed to the area of sound power measurements: the comparison of sound power obtained by the traditional method and the intensity technique; the influences of parameters on accuracy; possible error sources; estimates of the errors and discussions of indicators and so on. A few papers have discussed transmission loss measurements: some parameter analysis, possible corrections for better accuracy etc. While these works give some suggestions, standard guidelines have not been established.

1.2.1 Sound Power Measurement

The pioneering experiments on the application of sound power radiated by complex sources using the intensity technique can be traced back to the early 1970s. Van Zyl, Burger among others[5][6] in South Africa used their self-made pressure velocity intensity meter to measure the sound power.

Hodgson[7], in 1970s, used a pressure microphone and an accelerometer to measure the surface intensity of a large centrifugal chiller to establish the total A-weighted sound power level. He confirmed that the intensity technique is suited to sound power determination of large machine in situ where the surrounding pressure field is likely to be very complicated.

Thompson and Tree[8] analyzed the errors within the two microphone intensity technique in 1975. At that time, the two pressure microphone technique to measure intensity had become the superior approach over other intensity measuring methods.

Elliott[9] in 1981 described two error sources within the two microphone intensity technique, namely, finite separation error and phase mismatch error. He explained these errors in detail and also mentioned the error due to the interference effects at the microphone.

Kaemmer and Crocker[10] studied the feasibility of using surface intensity measurements for the determination of sound power as a tool for noise source identification with an experiment on a circular cylinder. They conclude that the intensity technique compares well with the reverberant room method for determining sound power and is also able to measure radiation efficiency and velocity.

G. Hubner[11][12][13] described some indicators for sound power measurement such as range of applicability for instrumentation system, an indicator for reactivity of a steady parasitic noise field, an indicator for a strong parasitic direct field under approximate free field conditions, indicators for the non-uniformity of parasitic noise and source field, an indicator for the time dependence of a parasitic noise and an indicator for accuracy of sound power determination.

Wu and Crocker[14] derived a general formula for the sound intensity normal to a plane measurement surface caused by a plane distribution of monopole sources under the assumptions that the level of the background noise is much lower than the level of source and the measurements are made in the far field of the sound source. They simulated the sound power and did some parametric analysis from which they found:

(a) when the measurement surface(not enclosing the source) has unit area, the estimation error on the sound power decreases with an increase in the measurement distance and an increase in the number of sound intensity measurements.

(b) when the measurement surface is a surface enclosing the source, the estimation error depends on the total number of intensity measurements over the surface, and does not depend on the measurement distance or the number of measurements over each unit area. Although these conclusions only apply to ideal situation, an experiment was done which confirmed the first conclusion.

Jacobsen[15] examined the random error expression[16] of spectral intensity estimates in terms of coherence determined with a frequency analyzer and derived a more general formula. In another article[17], he applied the formula to sound power determination and dealt with both discrete point sampling and continuous scanning technique. He found that random errors depend on (1) the acoustical environment;(2) the directivity of the sources; and (3) the total averaging time. Unfortunately, little use is found for this kind of estimation if digital filtering instruments are used.

Tandon[18] tested, for a known sound source, the repeatability of sound intensity measurements and the influence of some measurement parameters such as the distance from the source, scanning pattern and speed, configuration of points and point density, on sound power determination. He found that the point method is slightly better than the scanning method, fairly accurate results are obtained at larger measurement distance from the source, better results are obtained if sufficient number of points are taken in the point method and if a slower speed and a smaller gap between sweeps is used in the scanning method.

R. Hickling[19] applied the intensity technique to measure the A-weighted sound power of vehicles. He found, from the power spectra, that the peak of the spectra occurred at frequencies corresponding to the orders of excitation of components of the vehicle power train. He concluded that it has diagnostic value because it identifies noisy components and provides a quantitative measure of their contribution to the total sound power of the vehicle.

1.2.2 Sound Transmission Loss Tests

Application of the sound intensity technique to sound transmission loss tests has not been referred to as frequently as the sound power application.

Crocker[20] et al compared the TL test results by FFT intensity technique with the conventional suite method and the results agree well with each other except at low frequencies. They also found the results by the intensity technique compare well with the theoretical mass law at frequencies below 2000Hz.

Halliwell and Warnock[21] also compared the TL results from the intensity technique with the conventional method. They found if the receiving room is quite reverberant, then an additional influence known as the Waterhouse[22] effect must be considered.

Guy and De Mey[23] undertook a detailed investigation to validate the TL tests by the intensity technique with respect to the conventional method. Preliminary investigation were also undertaken to test the influence of absorbent material in the reception room, the influence of averaging time, the measuring mesh size and the measuring distance from the panel. The analytical capabilities of the intensity method were exploited to determine the influence of lining the sill or niche of the test panel with absorbent material. They also demonstrated that the intensity technique can be used to identify the existence of untoward sound transmission paths as part of measurement procedure. In another article[24], they explored the effect of lining the sill or reveal with absorbent material with regards to sound transmission loss.

Van Zyl and Erasmus[25] investigated the practical requirements for sound transmission analysis in a reactive field by the sound intensity technique. Supported by their experimental findings, they proved that practical intensity meters can be used effectively in performing sound transmission analysis in highly reactive receiving rooms such as reverberation chambers.

Minten, Cops and Wijnants[26] compared the sound transmission loss obtained with the intensity technique and the conventional method with the theoretical model of Statistical Energy Analysis and found they are in good agreement. They also confirmed that the phase mismatch is a good quantity to evaluate the accuracy of the intensity measurement results, and the Waterhouse factor corrects the difference at low frequencies to a great extent.

Van Zyl, Erasmus and Anderson[27] presented a formula to calculate the practical transmission loss with the intensity technique containing additional terms to account for the size of the measurement surface, boundary interference effects and calibration mismatch. They investigated the practical implications of the conditions relating to the shape and absorption contents of the measurement surface.

Vercammen, Martin and Cornelissen[28] studied the complication concerning the possibility of a measurement deviation in a highly reactive environment caused by absorption at the receiving side of the partition wall and derived corrective terms to accommodate this situation.

1.2.3 Source Location and Fault Diagnosis

Reinhart and Crocker[29] applied the intensity technique to a diesel engine for source identification purpose. They compared the measurements with a traditional method, the lead-wrapping method, and concluded that the acoustic intensity technique has advantages over the traditional approach because measurements by the acoustic intensity technique are more repeatable, can be done in situ and need a less expensive facility.

Birembaut et al[30] estimated the acoustic power emitted by different zones of a synchronous belt employed in many mechanical equipments using integration of the normal component of acoustic intensity. They also located the sources of noise by using vector components of the intensity. They confirmed that intensity mapping can be a quick and powerful tool to extract in a very complex acoustic field. The information obtained is of great interest to understand the noise generation mechanism.

Jones and Porter[31] provided a good example of the application of sound intensity measurement to the identification, quantification and rank ordering of noise sources in an industrial compressor plant installation, together with analysis of the implication for the selection of noise control measures.

Wagstaff and Henrio[32] used the selective two microphone technique with a dual channel frequency analyzer to obtain the contributions from each source in a multi-source environment. This technique was found valid even when the acoustic intensity level is lower than the background level.

Besides the above-mentioned literature, some references concerning general aspect of the intensity technique are of interest:

S. Gade[33] gave a clear description of the theoretical concept of sound intensity. He showed how it makes a distinction between the active and reactive parts of sound fields and how sound intensity can be measured over a wide frequency range by a specially designed probe consisting of a pair of closely spaced pressure microphones. Two different principles of signal processing, digital filtering and the use of the Fast Fourier Transform(FFT) technique, were discussed. Various error sources were also outlined.

Tandon[34] did a general review of the two-microphone method for intensity measurements. The principles, measurement errors, instrumentation and the applications of sound intensity technique were described.

Jacobsen[35] presented a number of normalized, energy-related local and global indicators of the sound field which can be derived from the signals of an intensity probe. These indicators can help the experimenters in evaluating and interpreting experimental data.

Loyau and Pascal[36] proposed the use of flux lines, tangential to the intensity vectors, to represent graphically acoustic vectors. Nevertheless, the representation of the three dimensional vectors still remains difficult.

Fahy[37] has written the first book dealing systemically with the sound intensity technique. Although as the author stated that "sound intensity measurement is an area of physical metrology which is still undergoing rapid development", a systemic review of current knowledge is of great convenience to many researchers in this field.

1.3 Objectives

This work is designed to develop and validate a sound intensity based one dimensional and three dimensional measurement facility; then, the facility is to be used to develop or examine standard criteria with respect to sound power measurement and the measurement of sound transmission loss.

CHAPTER 2

THEORY and TEST FACILITY

2.1 Theory of Intensity Measurement

2.1.1 p-p Method and p-u Method

The sound intensity, I, is a vector quantity which is the net flow of the acoustic energy in unit time on a unit area. It is the time averaged product of the instantaneous sound pressure p and the corresponding instantaneous particle velocity $\hat{u}$ at the same position[38]:

$$I = \frac{1}{t}\int_0^t p\hat{u}\,dt = \overline{p\hat{u}} \qquad (2.1)$$

Thus for intensity assessment a need exists to simultaneously measure the sound pressure level and the particle velocity. This may be achieved separately as in the case of a 'p-u' device, or a 'p-p' device, where 'p' indicates a pressure measurement and 'u' indicates a particle velocity measurement.

In a 'p-u' device, like the Type 216 'p-u' intensity probe by Norwegian Electronics in Norway[39], the two output signals from a pressure microphone and an ultrasonic particle velocity microphone are multiplied to give the component of intensity in the direction of the microphone axis, while in the 'p-p' device, particle velocity is inferred from pressure measurements.

2.1.2 Digital Filtering Method and FFT method

Currently, the 'p-p' measurement is more commonly used than the 'p-u' approach. In the 'p-p' approach, there are two different methods which can be employed to measure intensity, namely, the Fast Fourier Transform(FFT) method or the direct Digital Filtering method.

It can be proven that intensity can be obtained from the imaginary part of the cross-spectral density, $\mathrm{Im}\{G_{12}\}$, between two closely spaced microphones using a dual channel FFT analyzer[40]. In this case, the intensity in the r direction I_r is calculated as

$$I_r = \{\frac{1}{\omega\rho\Delta r}\}\mathrm{Im}\{G_{12}\} \qquad (2.2)$$

where

ω is the angular frequency,
ρ is density of the medium,
Δr is the spacing between two microphones.

At the Centre for Building Studies, a direct Digital Filtering 'p-p' intensity measurement system is employed and in consequence attention will be confined to this technique.

In this technique one must infer the particle velocity. This is achieved after consideration of Newton's second law:

$$\nabla p = - \rho \frac{\partial \hat{u}}{\partial t} \tag{2.3}$$

where

∇p is gradient of pressure p, $[\partial p/\partial r]$
ρ is the density of the medium,
$\partial \hat{u}/\partial t$ is the acceleration of the particle motion.

Consequently,

$$u_r = - \frac{1}{\rho} \int \frac{\partial p}{\partial r} dt \tag{2.4}$$

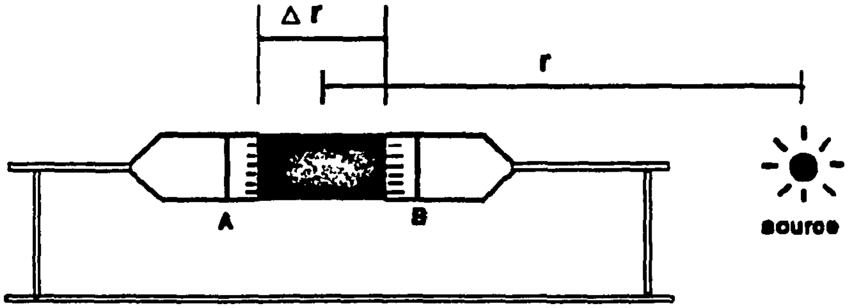


Fig.2.1 Finite Difference Approximation of Pressure Gradient

If the finite difference technique is used to approximate the differentiation, we can have the estimate of particle velocity along the r direction as(see Fig.2.1)

$$u_r = - \frac{1}{\rho \Delta r} \int (p_B - p_A)\, dt \qquad (2.5)$$

This approximation is valid as long as Δr is relatively small compared with the sound wavelength concerned.

Thus, we have the so-called direct Digital Filtering intensity method[41]

$$I_r = - \frac{1}{2\rho \Delta r} \overline{(p_B + p_A) \int (p_B - p_A)\, dt} \qquad (2.6)$$

where the pressure is taken as the mean value of the two pressures from microphone A and B, the bar is the time averaged notation.

The foregoing approximation makes it possible that two ordinary pressure microphones can measure the intensity along an axis joining the centres of the microphones.

Although this technique is perhaps the most widely used method among three intensity measurement approaches[42], it however has a number of inherent error sources and subsequent restrictions in use which must be identified.

2.1.3 Error Sources in Intensity Measurement

Because the direct 'p-p' intensity technique involves an approximation for the particle velocity, errors are inevitable and a review of the possible errors is necessary in order to estimate error bounds.

a. Finite Difference Approximation Error

This systematic error always occurs because it is inherent in the intensity measurement theory which in turn is due to the approximation of the pressure gradient by a finite pressure difference. Assuming the intensity magnitudes at two microphone positions are the same, then the approximated intensity I_m is related to the true intensity I_t for a sinusoidal sound wave propagating along the axis joining the two microphones with spacing Δr by the expression[43]

$$\frac{I_m}{I_t} = \frac{\sin(k\Delta r)}{k\Delta r} \tag{2.7}$$

where k is the wave number.

It is clear that this error is severe at high frequencies and the intensities are always underestimated.

If we take the fact into consideration that the magnitudes of the two intensities are different at the two microphone positions, then the bias error due to this effect must be considered. For a spherical wave, from a point source, the relation between the measured intensity I_m and the true intensity I_t is given by[44](see also Fig. 2.1)

$$\frac{I_m}{I_t} = \frac{1}{[1 - (\Delta r/r)^2/4]} \tag{2.8}$$

where

Δr is the spacing between the two microphones,
r is the distance between the sound source and the centre of the microphone spacing.

It can be seen that if $r>2\Delta r$ this error is less than 0.3dB. It is only significant when the microphone probe is very close to the sound source.

Hence, the total error by the finite difference approximation can be combined as

$$IL_{error} = 10\mathrm{Log}\{(\frac{\sin(k\Delta r)}{k\Delta r})(\frac{1}{[1 - (\Delta r/r)^2/4]})\} \tag{2.9}$$

b. Error due to Instrumentation Phase Mismatch

The phase mismatch between the two microphones and between the two channels of the instrumentation causes an error. The phase, Φ in radians, between the two microphone signals p_A and p_B is[45]

$$\Phi = \frac{I}{(p^2/\rho\Delta rf)} \tag{2.10}$$

where

p is the sound pressure,
I is the measured intensity,
f is frequency,
Δr is the spacing,
ρ is density.

To have valid measurement results, the phase error Φ_{error} must be much smaller than the phase Φ.

After the derivation, the difference between the dB levels of the measured intensity and the true intensity IL_{error} is expressed as[46]

$$IL_{error} = -10 \log(1 - \frac{I_{re} p_t^2}{p_{re}^2 I_{me}}) \qquad (2.11)$$

where

I_{re} is the residual intensity,
p_{re} is the pressure,
I_{me} is the measured intensity,
p_t is the measured pressure which is assumed to be measured correctly.

The residual intensity and pressure are measured in a perfect reactive sound field in which, theoretically and ideally, the intensity is zero.

The phase mismatch error is critical for small values of microphone spacing Δr and/or at low frequency.

c. Calibration Error

This error is due to the instrumentation bias and usually is compensated by adjusting the instruments through a standard calibration procedure before the measurements. A post-test calibration is also recommended so that a check can be made to confirm that the instrumentation system worked well during the test.

d. Error due to Ambient Conditions

If the atmospheric pressure and ambient temperature are not in standard conditions on which the instrumentation calibration are based, a slight error will be caused.

The error due to the ambient pressure can be given as

$$IL_{error} = 10 \log(p_{amb}/p_{amb,0}) \tag{2.12}$$

where

p_{amb} is the ambient pressure,
$p_{amb,0}$ is the standard ambient pressure as 1013mbar.

The error due to ambient temperature variation is based upon changes in the velocity of sound in air, it is calculated as

$$IL_{error} = 10 \log(T/T_0) \tag{2.13}$$

where

T is the ambient temperature in K,
T_0 is reference temperature, 293K.

The standard relative humidity for the calibration is 65%.

e. Sound Source Error

This is caused by the source level instability and can be assessed by continuously monitoring the source level.

f. Statistical Error

This random error is the sum of the errors caused by random selections of the measuring parameters such as the averaging time for data acquisition, number of measuring pc [illegible] measuring surface, and the influence of the sound field.

This error is difficult to predict before tests but may be assessed by the repeatability of the test results.

2.1.4 Applications of Intensity Technique

The sound intensity technique is a very useful device for engineers. Although it does not give the answer how to reduce the noise, it does offer an effective way to evaluate the sound source, sound field and efficacy of noise control measures. Its uses are still being realised but some are reviewed below.

a. Sound Power Measurement

If a steady state sound source emits sound power W, the power equals the integration of the normal sound intensity I along an enclosing surface s of the source, i.e.,

$$W = \int_S I \cdot \hat{n} \, ds \qquad (2.14)$$

Therefore, by measuring the normal intensities about the enclosing surface area of the source, the sound power can be calculated even in the presence of sources outside the enclosing surface, although in this instance there should be no absorbent surfaces located within the enclosing surface.

b. Sound Transmission Loss Test

The sound transmission loss TL is defined as the level of the ratio of the incident sound power W_i and transmitted sound power W_t of a panel.

$$TL = 10 \operatorname{Log}\{W_i/W_t\} \qquad (2.15)$$

Theoretically, by measuring the sound intensity and area at each side of the panel, one can get the TL. In practice, the incident sound power has to be derived from the sound pressure measurement in a diffuse field as explained later.

c. Source Location and Fault Diagnosis[47]

By choosing a close enclosing surface of a sound source and measuring the sound intensity at different parts of the surface, one can rank the order of the source at individual locations and take noise control measures accordingly.

Similarly, one can know the distribution of the transmitted intensity on a panel. Furthermore, using three dimensional intensity measurements, by tracing back along the directions of the intensities, one can find the fault of a panel or the most dominant part of the source. The source location or fault diagnosis can normally be proceeded along with a sound power measurement or a transmission loss test.

d. Sound Absorption Measurement[48]

The sound intensity technique may be used to determine the net sound power entering a source-free volume. Thus, the absorbed sound power by an absorbent material might be determined by measuring the intensity on a hypothetical surface enclosing the test specimen. However, the incident power has to be inferred from measuring pressure in an ideal sound field. Also, the test specimen must be quite absorbent, otherwise, significant errors can occur. Absorption measurement by the intensity technique is not yet at a practical application stage and more research is needed.

e. Specific Acoustic Impedance Measurement[49]

The specific acoustic impedance is the ratio of the complex amplitudes of sound pressure and particle velocity for a frequency at a point in a sound field. The normal surface specific acoustic impedance is of most importance as it represents the reflective/absorptive material properties.

Since the intensity meter can measure the pressure p and infer the particle velocity $\hat{u}$, one can feed the output signal from the intensity meter into a FFT analyzer and get the transfer function $p/\hat{u}$ which is the impedance.

f. Other Applications

The intensity technique can be applied to other parameter evaluations, for example, radiation efficiency.

The radiation efficiency, $\sigma 1$, of a vibrating surface is a measure to rank the effectiveness with which a vibrating surface generates sound power W as defined as[50]

$$\sigma 1 = W/\rho c S \overline{<\hat{u}^2_n>} \qquad (2.16)$$

where

ρc is the characteristic impedance,

$\overline{<\hat{u}^2_n>}$ is the space-average mean square normal velocity of the surface S.

The sound power can be measured by the intensity technique and the velocity can be measured by an accelerometer or a velocity microphone or inferred from p-p intensity measurements.

The intensity technique can assist one to take optimum noise control measures by evaluating the sound fields in presence of different control approaches.

2.2 Theory of Sound Transmission Loss Tests

Sound transmission loss TL is the ability of a panel to isolate the sound travelling from one side to the other. The definition of TL is

$$TL = 10 \log(W_i/W_t) = SWL_i - SWL_t \qquad (2.17)$$

where

W_i is the incident sound power in watt,
W_t is the transmitted sound power in watt,
SWL_i is the incident sound power level in dB
SWL_t is the transmitted sound power level in dB.

The sound power is the area integration of sound intensity on an enclosing surface.

In practice, the TL is measured according to the following procedure:

Two vibration and sound isolated rooms are used as source and reception room respectively. The test panel will be located within the wall between the two rooms.

Using a reverberant room as the source room, the sound energy impinging upon the panel is calculated as[51]

$$W_i = (p^2_{rms}/4\rho c)A \qquad (2.18)$$

where

p_{rms} is the time and space averaged sound pressure in the reverberant room,
ρc is the characteristic impedance of the air, typically, ρc=415,

A is the panel area.

Eq(2.18) in dB notation becomes:

$$SWL_i = SPL_{int} - 6 + 10\log(A) \tag{2.19}$$

where

SPL_{int} is the time and space averaged sound pressure level in the source room.

The transmitted sound power level, which is measured on the reception side of the panel, SWL_t is

$$SWL_t = SIL_t + 10\log(S) \tag{2.20}$$

where

S is the measurement surface area which may be different from the area of the panel,
SIL_t is the space and time averaged surface sound intensity level on measurement surface.

To get the averaged surface intensity, two sample schemes can be employed. The point-to-point method is used to measure intensity at fixed discrete measuring points. The microphone is moved from point to point and the time averaged intensity is measured at each point. The scanning method uses the intensity probe to scan the surface. A running average intensity level for each scan with a fixed sample time can then be achieved for the total scanning area. The advantage of the scanning scheme is the speed of measurement and the fact that it may be achieved by manual manipulation of the probe. The disadvantage is that an overall average is achieved and point values are not retained, thus detailed surface examination is not possible. At the Centre for Building Studies, the system developed is that of the point-to-point measurement technique and further discussion will be confined to this.

Since the point-to-point method is used, then

$$SIL_t = 10\log\{(1/n)\ \Sigma 10^{(SILj/10)}\} \tag{2.21}$$

where

n is the number of the measuring points,
SILj is the individual time averaged intensity level at point j.

Rearranging Eq(2.17) and introducing other corrections, we have the TL as follows[52]

$$TL = SPL_{int} - 6 - SIL_t + L_A + L_c \tag{2.22}$$

where L_A=10log(A/S) which is an area correction compensating for differences between the measurement surface and the actual source surface area; L_c is the sum of other corrections, for example calibration, barometric pressure, or temperature corrections.

The reverberant room formulation used to derive the sound power incident on the test object requires amending to consider the energy stored in the boundary interference field. This is known as the Waterhouse effect[53]. The Waterhouse correction factor[54] can be written as

$$L_{WH} = 10\log[1 + \lambda S_1/(8V_1)] \tag{2.23}$$

where

λ is the wavelength,
S_1 is the internal surface area,
V_1 is the volume of the reverberation room.

Ideally, the reception room should have no extraneous sound contributing to the measuring surface, i.e., no noise sources and no reflections from the boundary of the room. In practice, the extraneous noise level must be at least 10 dB below the transmitted noise level.

Theoretically, it is possible that one can measure the sound intensity at both sides of the panel at the same time using two sound intensity meters. This can remove the restriction to use a reverberation room as the source room and perhaps can give a more accurate in situ result because the unique spatial distribution of incident energy is measured. So far no one has used this method to measure the incident power in a transmission loss measurement because most energy is reflected from the surface of incidence and it remains difficult to distinguish it from the reflected energy field. It should be noted that the single reverberant room method does provide definable or "standard" source side incidence;

this is likely to be a requirement of a standards approved technique.

2.3 Theory of Sound Power Measurement

The sound power emitted by a source may be found from the surface integral of normal intensity about the source(Eq.2.14). Using the point-to-point scheme, one can simply choose a surface to enclose the source and divide the surface into n segments, and then measure the normal intensity I_{ni} and the area A_i of each segment. The power is calculated by the following summation:

$$W = \sum_{1}^{n} I_{ni} A_i \tag{2.24}$$

The scanning method, in which the probe scans the enclosing surface, more closely approximates the surface integral evaluation and is time saving compared with the point to point method, but better accuracy is reported of the point method[55] which in addition offers the prospect of more detailed data analysis.

The advantage of the intensity based sound power measurement technique is that no restrictive ambient acoustic environment is needed. The traditional method has to be undertaken in an ideal sound field, thus generally cannot be employed in situ.

With respect to measurements in noisy environment, theoretically, the net contribution from outside sources to the enclosed field are zero provided there is no energy sink inside the field. That is, without sound absorbent material inside the surface, the amount of the sound energy entering the enclosed field will equal that going out from the field. This principle can only be approximated in live sound power measurements, because of influences from the target sound source plus the fact that air absorption within the enclosing surface always exist. However, for many practical purposes accurate results may be obtained invoking the principle.

2.4 Test Facility

2.4.1 Instrumentation System

The instrumentation system established in the Centre for Building Studies is an entirely automated arrangement as shown in Fig. 2.2.

The Bruel & Kjear Type 3360 Sound Intensity Analyzing System[56] is used which comprises the Sound Intensity Analyzer Type 2134(Serial no. 873342), a Display Unit Type 4715(Serial no. 981096) and a Sound Intensity Probe Type 3519(Serial no. 988996). This system enables sound intensity to be measured using a direct digital filtering two-microphone technique. It also enables sound pressure measurement. The analyzed signal is displayed on an 11" monitor in the form of bar graph showing both the signal magnitude and the intensity direction in third octave or octave band.

An Eight Channel Multiplexer B&K Type 2811(Serial no. 1357046) is connected between the Intensity Probe and the Intensity Analyzer which in turn is capable of selecting the signal pairs from different multiplexer channels. This branch connector is imperative for three or two dimensional data acquisition as it makes it possible to switch from one pair of microphones to the other.

Since the intensity measurement generally needs greater data gathering, manual operation would be a cumbersome and time consuming practice, thus application of a computer becomes a necessity. In the present system, an IBM PC computer is employed to control the operation through the GPIB IEEE-488 interface of the Intensity Analyzer.

Two kinds of microphones are used for the measurements. One pair of B&K Type 4165 half inch microphones are used for one dimensional measurements. With 12mm microphone spacing, the valid frequency range for these microphones at this spacing is 125Hz to 5000Hz.

Three pairs of B&K Type 4135 quarter inch microphones (Serial no. 1369549 and 962504; 1369446 and 1369565; 962522 and 1369377) are used in three dimensional measurements. With a 12mm microphone spacing, the useful frequency range is

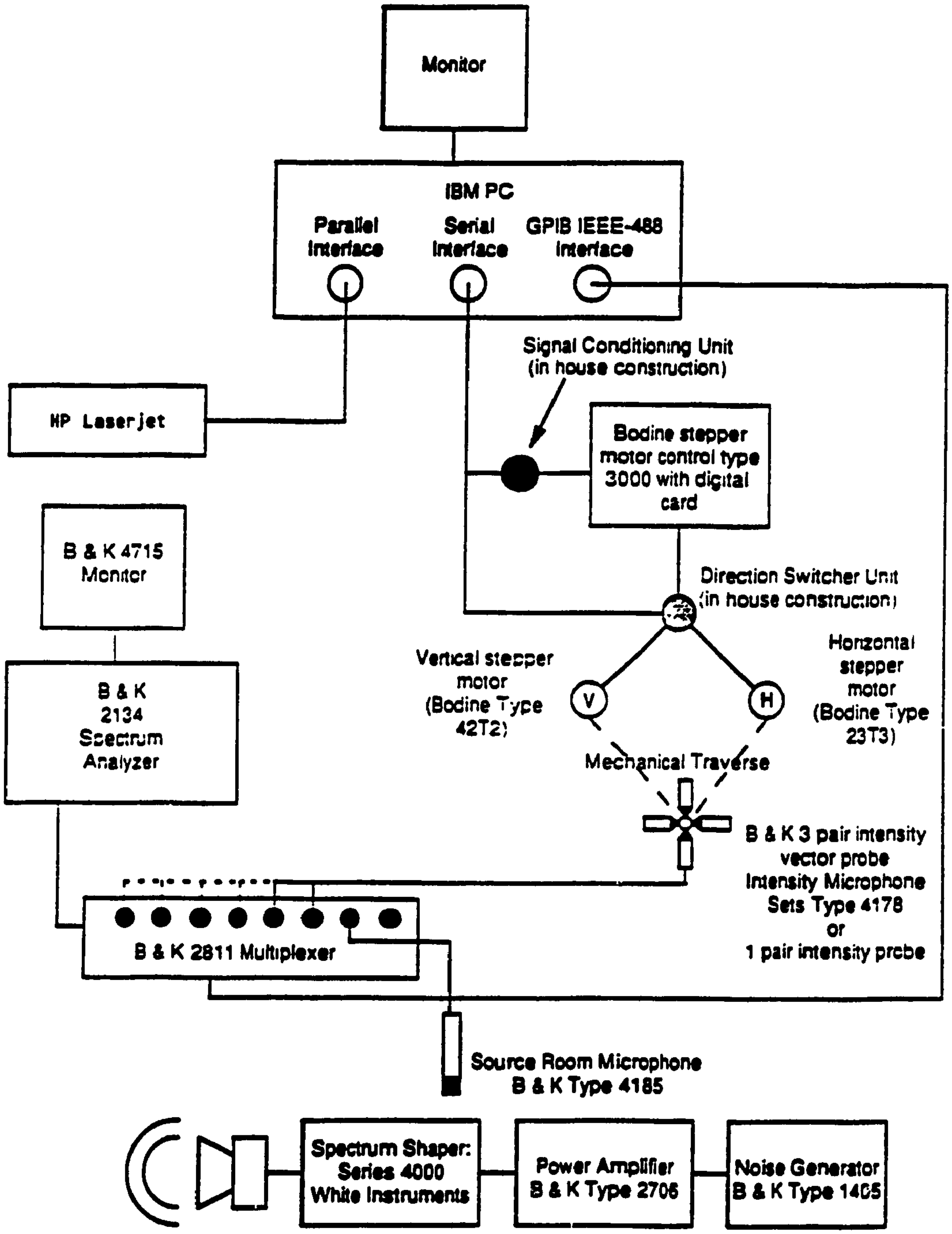


Figure 2.2 : Configuration of Lab Equipment

also 125-5000Hz. The serial numbers are reported here in order to identify the particular X, Y and Z coordinate probe pairs.

A B&K Type 4185 half inch microphone is used in the source room for TL tests.

The sound generation apparatus for TL tests consist of a B&K Type 1405 Noise Generator(Serial no. 503103) with pink noise, a B&K Type 2706 Power Amplifier(Serial no. 612003) to amplify the sound, and a White Instruments Series 4000 Spectrum Equalizer to adjust the spectra of the sound source. Finally the sound is output by an Audio Sphere speaker system.

2.4.2 Probe Traverse System

To move the intensity probe to the desired position manually is also time consuming and not accurate. To overcome this difficulty, an automatic mechanical traverse system has been established using digital control stepper motors. The Series 3000 Digital Motion Control System by the Bodine Electric Company[57] is used to accomplish this task. A horizontal stepper motor Bodine Type 42T2 which enables the probe to move horizontally and a stepper motor Bodine Type 23T3 which moves the probe vertically make the probe move freely as directed by the program codes across a two dimensional surface.

An oscilloscope is used to monitor the motion control signal pulses so that the appropriate working order of the system may be monitored during the tests when the reception room is closed. A motion Direction Switch Unit is connected to the system with LED lamps to indicate the direction of probe movement.

2.4.3 Transmission Loss Test Set-up

In the TL tests, two rooms are used, a source room and a reception room respectively. They are vibration-isolated from each other and from the building structure.

Fig. 2.3 illustrates the room dimensions and internal arrangement. Room A, as the source room, is a 95 cubic meters reverberation room. This room has been qualified as a Reverberation Chamber[58] under the standard ANS S1.21. The speaker sound source was located at the farthest corner from and facing away from the test panel. The ceiling and walls are covered with aluminum sheet to act as sound reflectors. Three stationary diffusers and one rotating vane were used to make the sound field within the chamber more diffuse, in other words, more uniform along different directions and at different locations. A space averaged sound pressure measurement is undertaken by a traverse which scans the core of the chamber thereby minimizing the influence of the boundary.

Room B, as the reception room, is 37 cubic meters volume. It is lined on the surfaces by fibre glass wedges having a

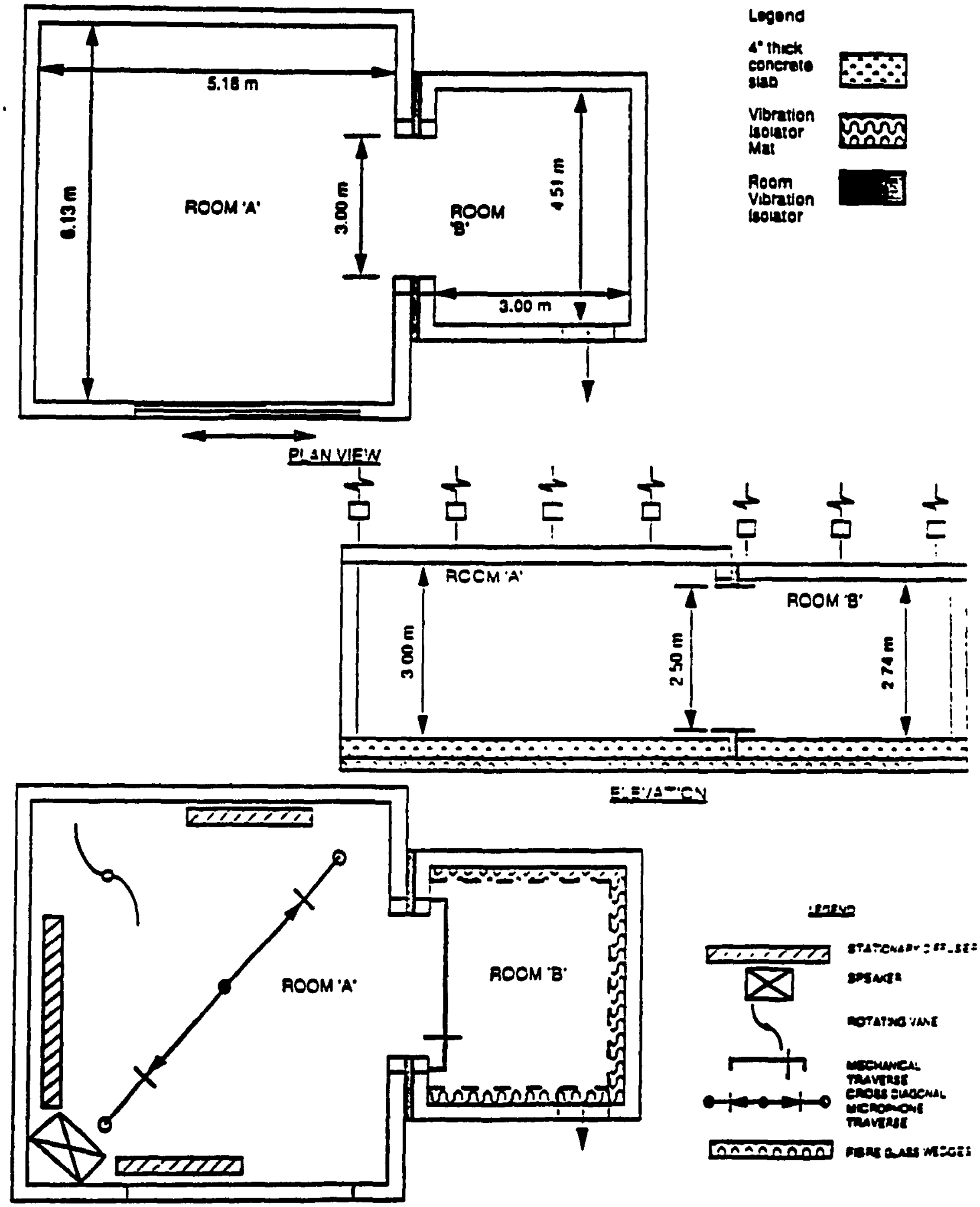
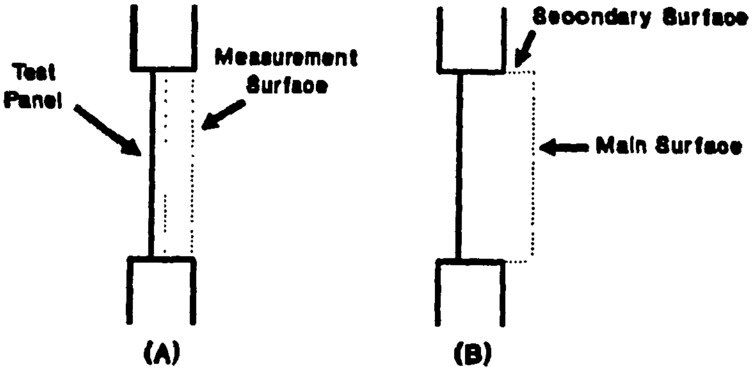


Figure 2.3 : Dimensions and room arrangement of the Acoustic Test Facilities , *Centre for Building Studies*

high absorption over all frequencies of interest; this feature minimizes noise interference from other sources and avoids reflective interferences.

An isolation wall was carefully built between the two rooms so that the sound passing through is limited to its contained test panel. An aperture with dimension 3x2.5 meter was left on the isolation wall to install the test panels. The gap between the edge of the panels and the aperture was well sealed in order to restrict the sound pass through the test panel.

The three measurement surfaces for one and three dimensional tests are chosen as 10, 30 and 40 cm from the panel as shown in Fig. 2.4. Because the 10 and 30cm measurement planes are within the aperture, only a single plane is needed for each measurement surface. However, since



(A) Surfaces 10cm and 30cm from panel
(B) Main surface 40cm from panel

Fig.2.4 Test Panel and Measurement Surfaces Arrangement for TL Tests the 40cm surface is out of the aperture, a peripheral secondary plane has to be added besides a major plane to form an enclosing surface.

2.4.4 Set-up for Sound Power Measurement

Sound power measurements by the intensity technique do not require the use of reverberation or anechoic chambers. However, in the present facility use is made of the hemi-anechoic chamber. When the source is placed within the hemi-anechoic chamber, two benefits can be achieved; the measured data may be used to assess the directivity patterns of the sound source, and the measurement sequence may be semi automated by employing the installed probe traverse system.

A small rectangular sound source with the dimension of 345x235x200 mm was chosen as the test object. Three measurement surfaces were set as 10, 30 and 70 cm respectively

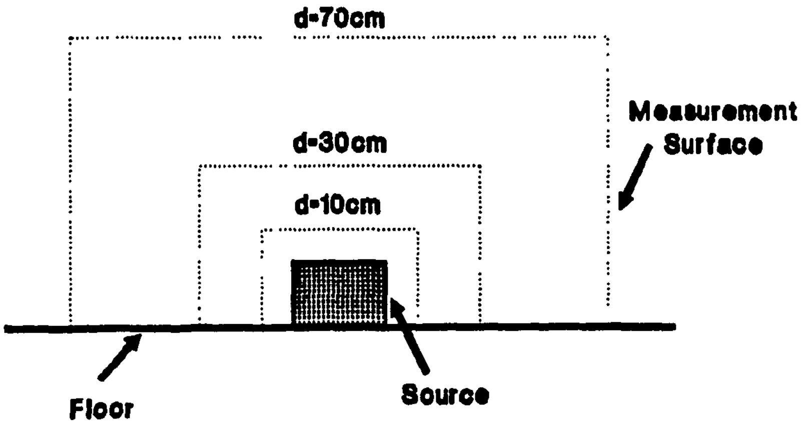


Fig.2.6 Source and Measurement Surface Arrangement for Sound Power Measurements

away from the source faces. Thus, each individual side of the total five rectangular surface has the same distance from the source as shown in Fig. 2.5.

2.4.5 Supporting Softwares

Software routines were designed to control the measurement process and analyze the measured data. They are part of the laboratory development and are particularly designed with respect to the measurement system at the Centre for Building Studies.

The programmes are written in BASIC to serve the following test procedure for both sound power and TL tests:

Stage 1. Instrumentation set-up, calibration and test settings.

Stage 2. Data acquisition and test monitoring.

Stage 3. Data processing and result evaluation.

Several programmes have been created, each specific to a particular application, namely,

(1). POWERA.BAS: sound power measurement for third octave band analysis with option of 1D or 3D tests (see Appendix 2).

(2). POWERB.BAS: sound power measurement for octave band analysis with option of 1D or 3D tests.

(3). POWERC.BAS: sound power measurement data processing programme(see Appendix 3).

(4). BK1DIMA.BAS: one dimensional TL test for third octave band analysis.

(5). BK1DIMB.BAS: one dimensional TL test for octave band analysis.

(6). BK2188B.BAS: three dimensional TL test for third octave band analysis.

(7). BK2188C.BAS: three dimensional TL test for octave band analysis.

(8). ANALYZE.BAS: TL test data processing programme.

(9). RBK1D.BAS: calibration program for 1D and third octave band.

(10). RBK1DA.BAS: calibration program for 1D and octave band.

(11). RBK3D.BAS: calibration program for 3D and third octave band(see Appendix 4).

(12). RBK3DA.BAS: calibration program for 3D and octave band.

The flow charts for sound power measurement procedure, i.e., for the related programmes shown in Fig.2.6 to Fig.2.11 are taken as a representative example, and may be explained as follows.

Fig. 2.6 is an overview for the Stage 1. Three types of activities are involved, User Physical Activity which is accompanied by full instruction or description on the display monitor and the next step is not invoked until prompted by the user; User Response which involves dynamic selections of the test parameters and the options of the parameters are displayed for the user's convenience; System Controlled Events which are accompanied by some visual display message or output to assure the user that something is indeed happening and to allow full test monitoring.

To begin with, the user is asked to check the wiring and the instrument control settings to conform to the prescription of the test. Then, the third octave band or octave band analysis must be selected. After the input of file names for data and information purposes, the user is prompted to consider the option of calibration. Calibration includes pressure and reactivity calibration as illustrated in Fig.2.7. The pressure calibration is furnished by the B&K Type 4220 Pistonphone(Serial no. 578016) with standard 124dB at 250Hz. The reactivity calibration is done in a acoustic coupler like B&K WA0344 or similar reactive field providing devices. During the reactivity calibration, pink noise is used to achieve reactivity measures at all frequencies of interest. Then, the pressures from both channel A and B and intensity are acquired and the pressure-intensity index is calculated. Next, the calculated pressure-intensity index is displayed on the monitor so that the user can check the result. If it is acceptable, the result is saved in a file so that it can be retrieved later to be used as part of the measurement error

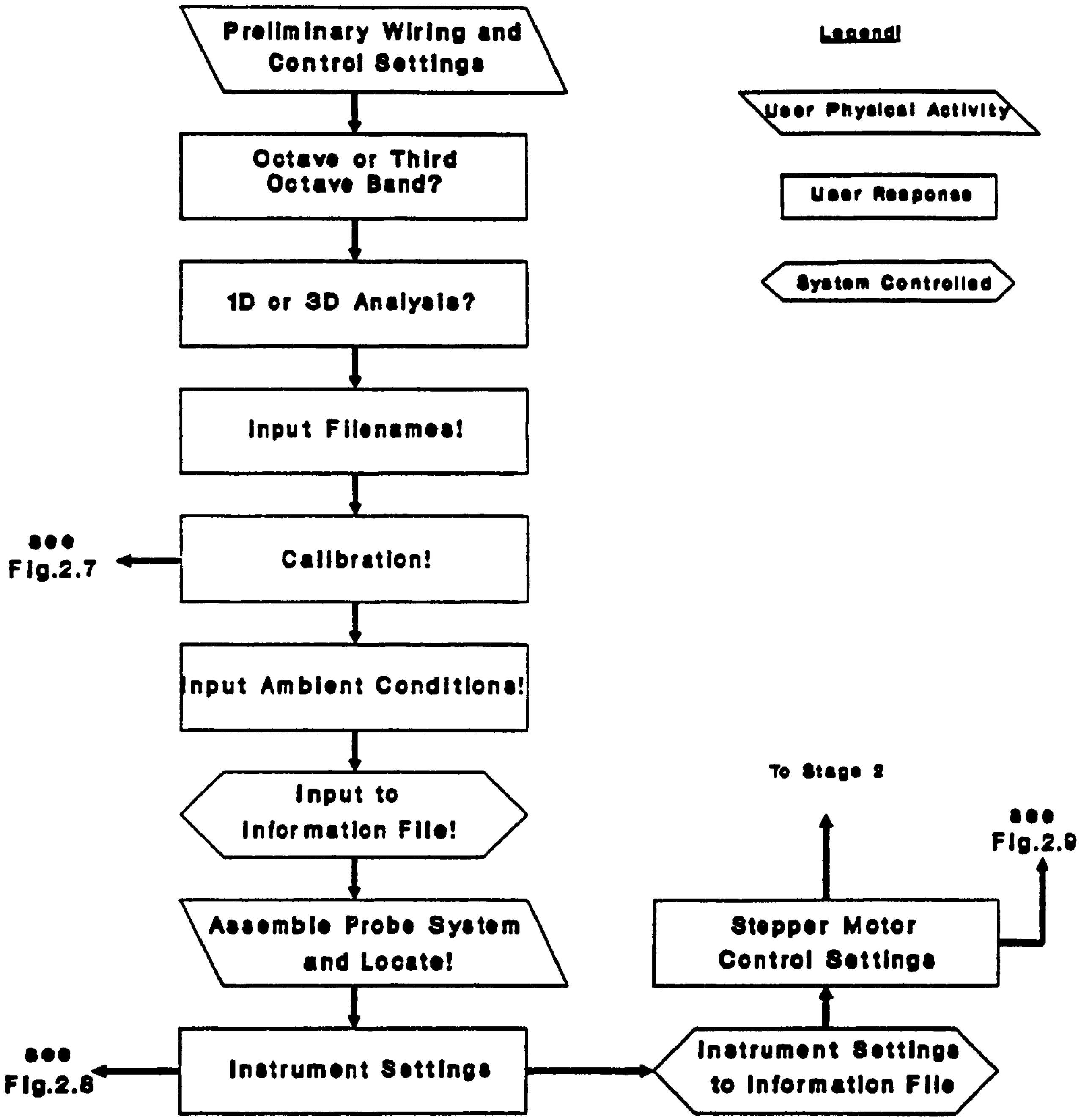


Fig.2.6 Flow Chart of Program for SWL Tests
Overview of Stage 1

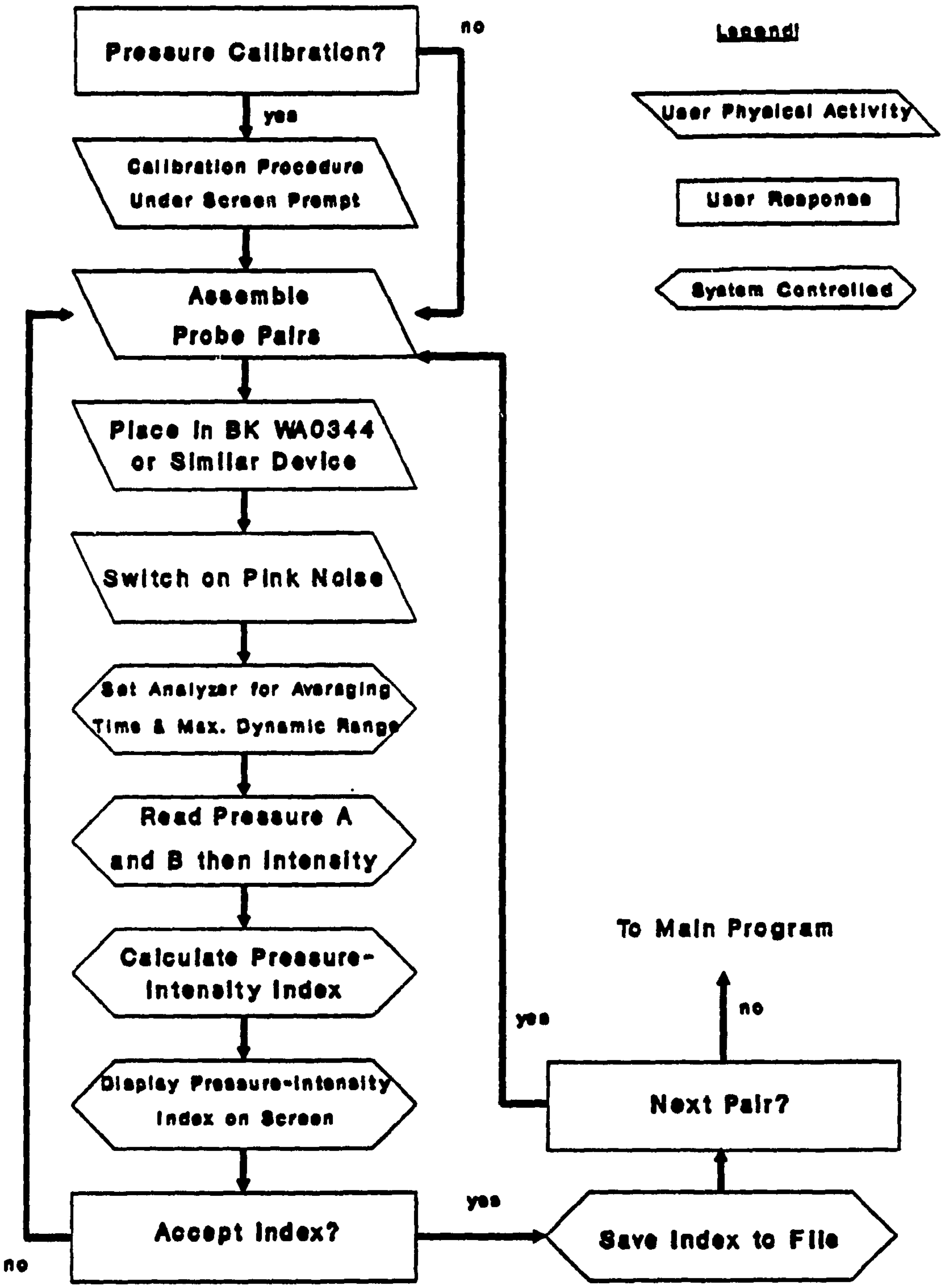


Fig.2.7 Calibration Procedure

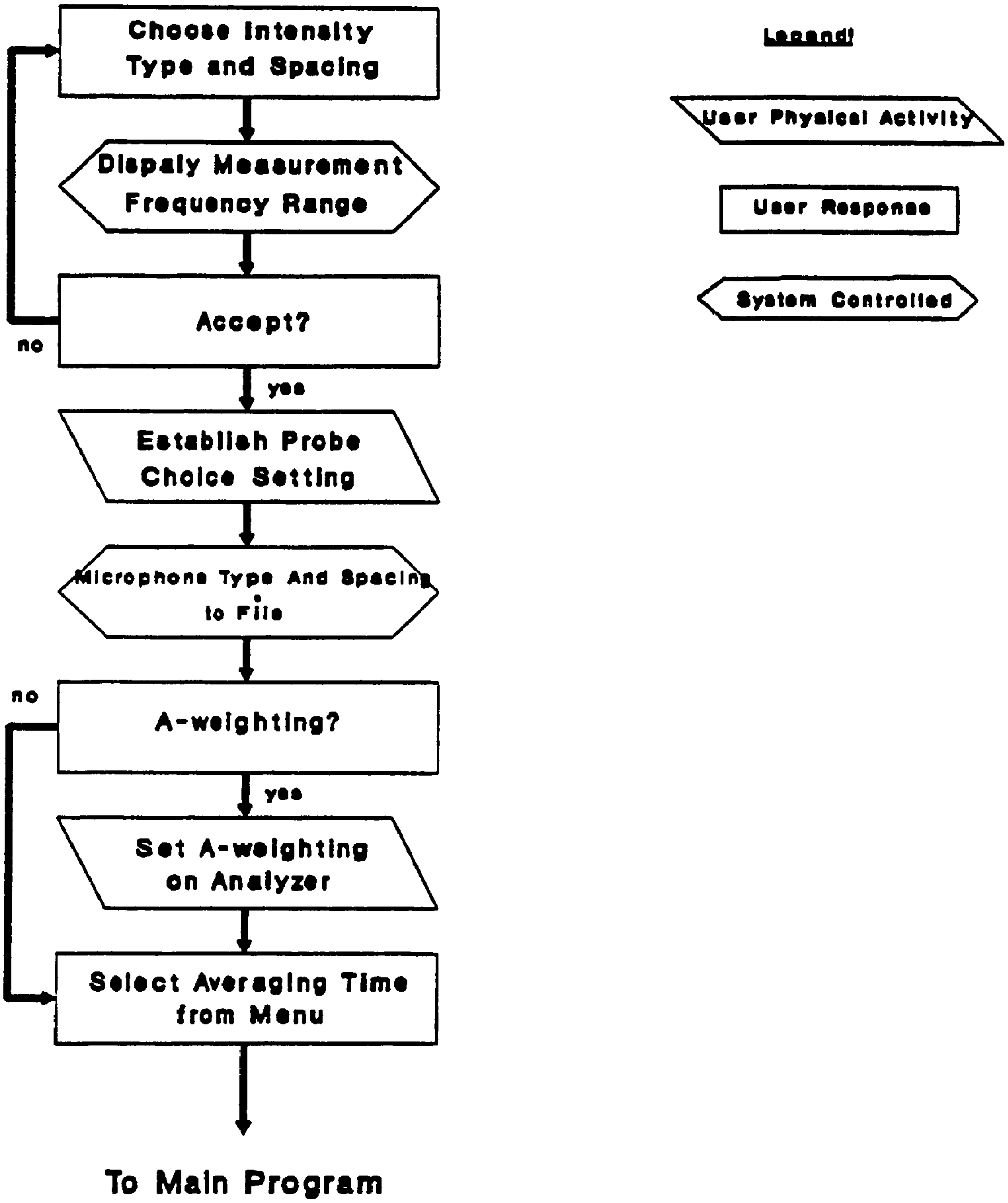


Fig.2.8 Instrument Settings

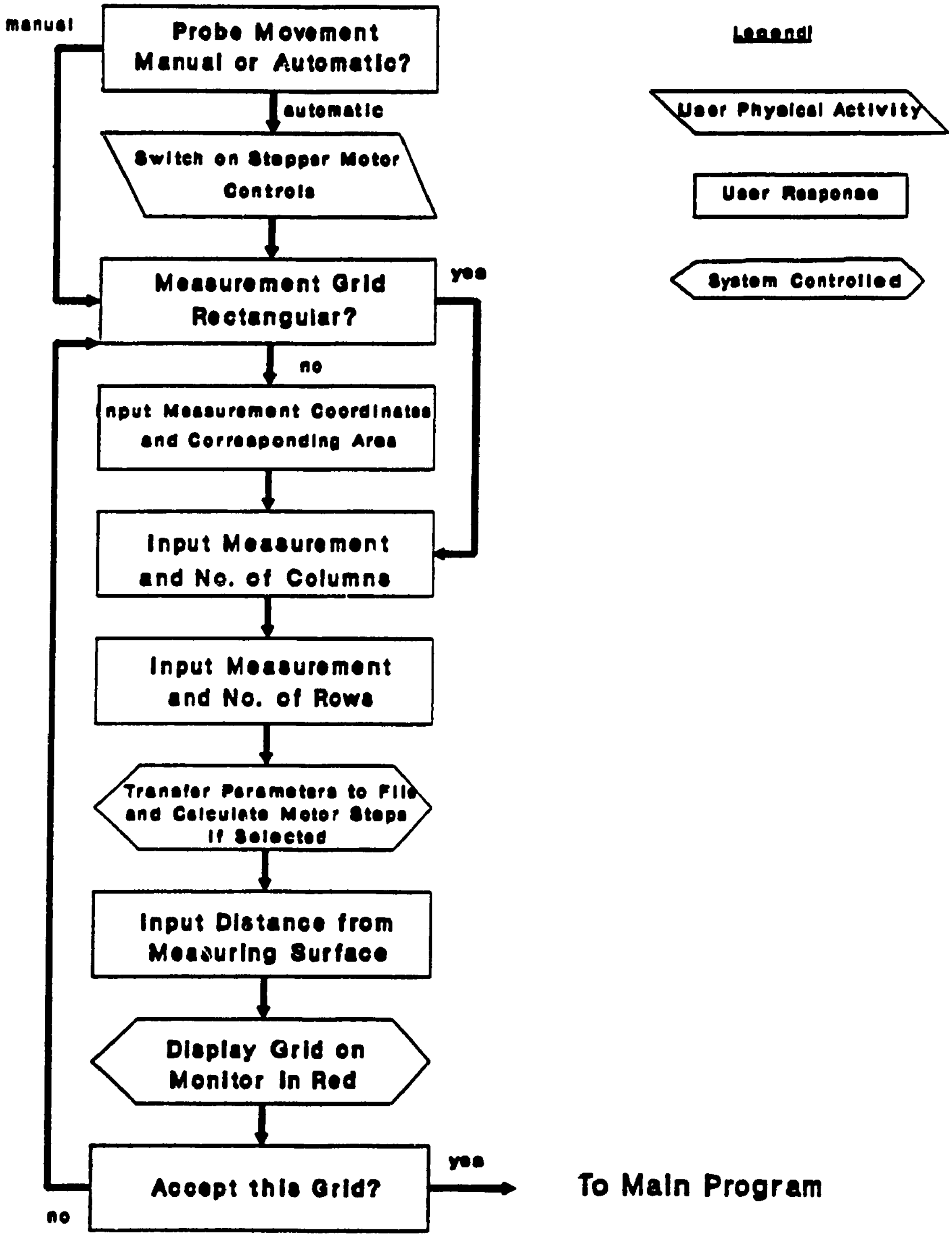


Fig.2.9 Measurement Grid Set-up

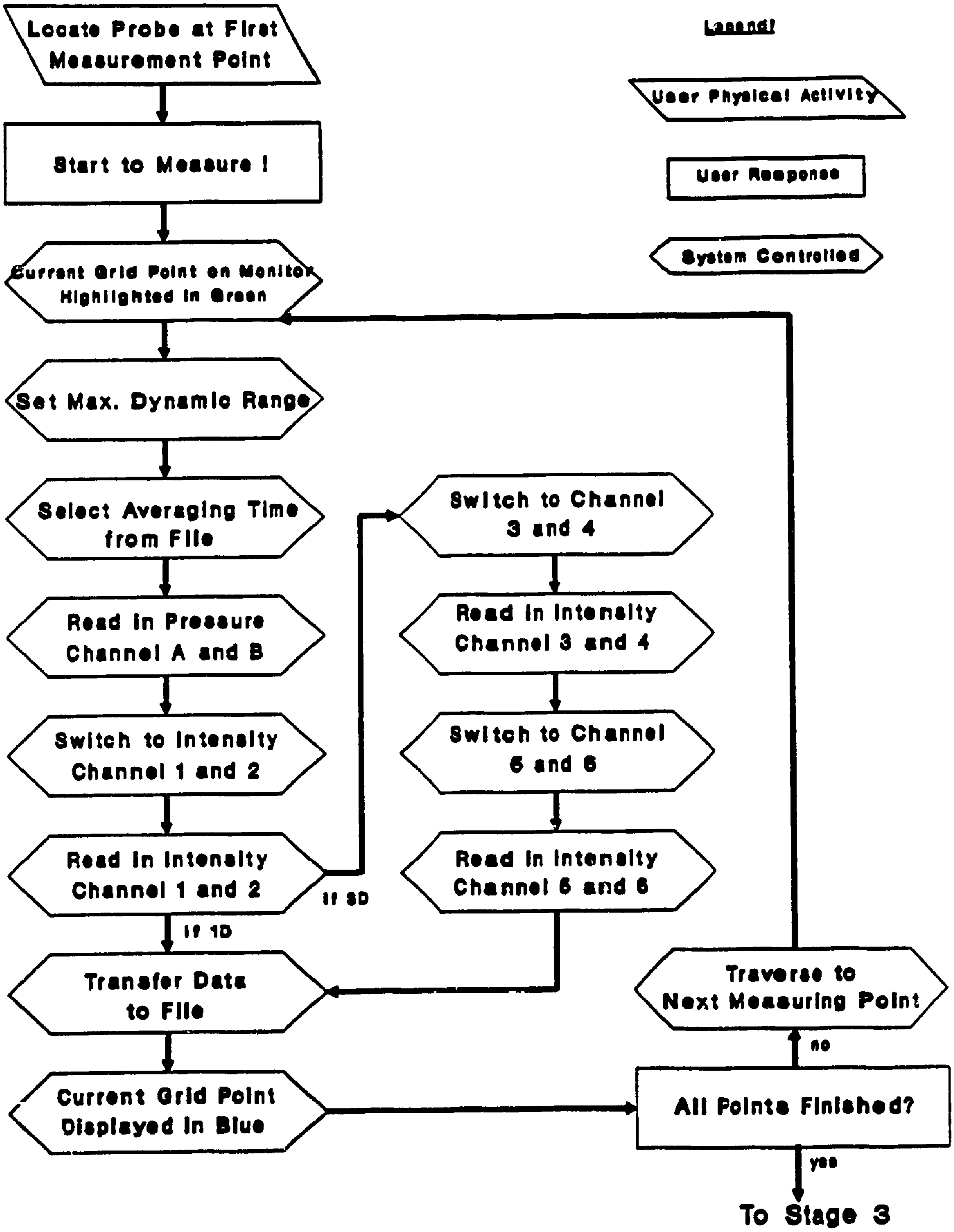


Fig.2.10 Stage 2-Probe Movement & Measurement

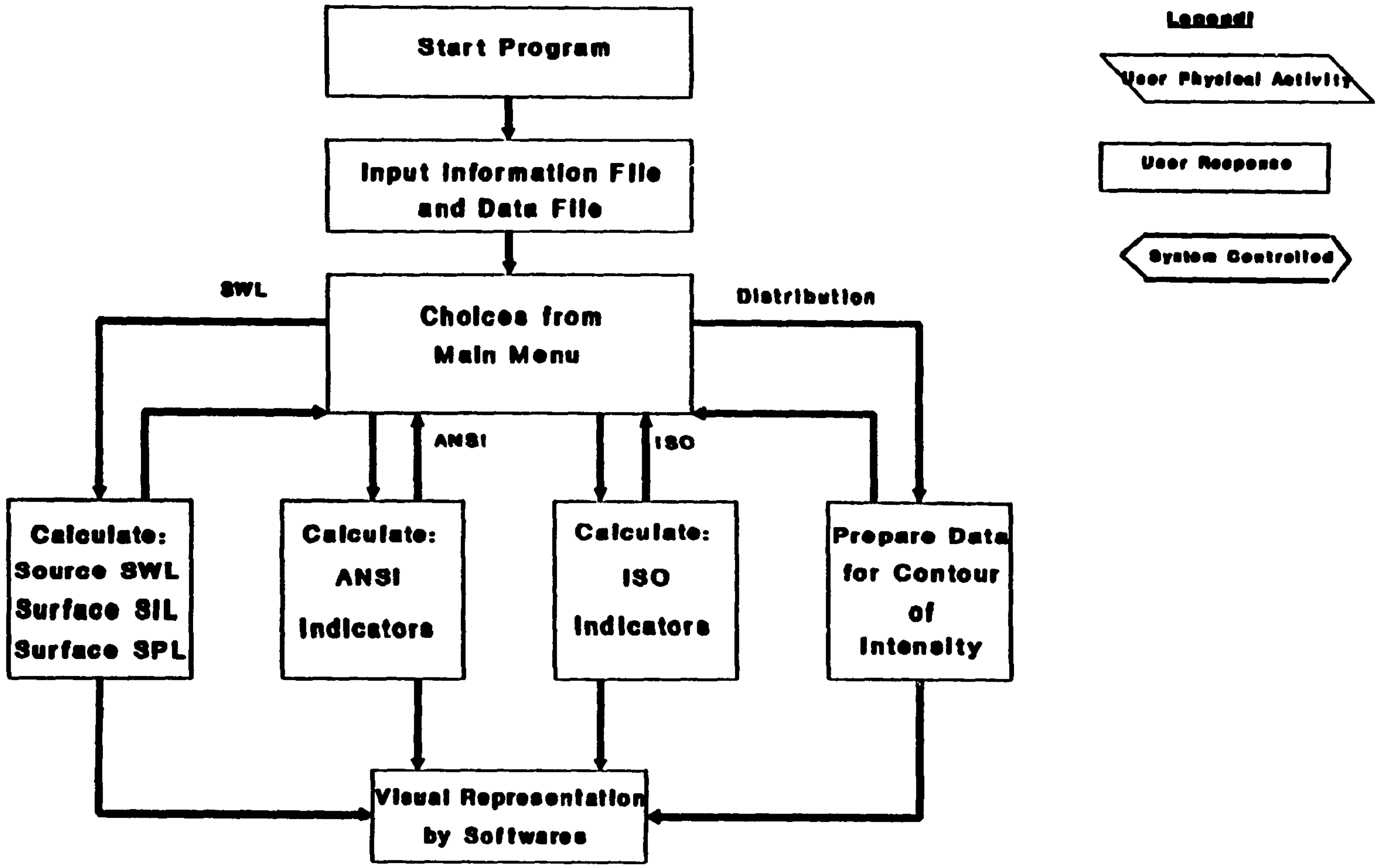


Fig.2.11 Stage 3- Data Processing

estimates, otherwise, the calibration is repeated after appropriate adjustment. If a 3D test has been selected, then the calibration is repeated for other pairs of microphone.

After the calibration, some ambient conditions such as temperature, humidity, barometric pressure as well as test title and date are input. The probe is then assembled and located as appropriate. For TL tests, the source room settings should be activated at this step, for example, switching on the rotating diffuser and microphone traverse and establishing the optimum base level on analyzer for source room after switching the sound source on.

The next step is to choose a number of instrument settings such as microphone spacing and type, these selections dictate the valid frequency range, A-weighting or not and averaging time. Fig.2.8 displays this procedure.

Fig.2.9 displays the stepper motor controls selection. For each measurement surface, one can choose a rectangular plane on which the total measuring points are evenly distributed or the setting of random measuring locations for which the user must define the coordinates and corresponding areas of each segment. For TL tests, a third option is offered to move the probe along the boundary of the test panel. Viewed from the reception room to the test panel, the probe is attached to the close-to-panel end of the probe mount on the traverse apparatus; upon activation the probe moves from left to right and then right to left with an intervening vertically down movement starting from the first point located manually at the upper left corner of the measuring surface. The origin point of the measuring surface coordinate system is chosen as the bottom left corner of the test surface. Once the setting is established, a scale representation of all points is presented to the user on the viewing monitor as a check prior to starting the measurement, it then serves as a progressing guide during the test, with points measured, current position, and points to be measured all displayed in different colours as described later.

The measurement stage is shown in Fig. 2.10. In this stage, the probe movement may be under manual or automatic control. At each measuring point, the optimum base level of the analyzer is first established thus assuring the analyzer is not overloaded. This is accomplished by switching the analyzer to Octave Filter Bandwidth and sensing the overall sound pressure level using 8 seconds linear averages of the spectrum. Then, the sound pressures from both channel A and B and the intensity from each microphone pair are measured and saved to a data file. The test is monitored by using a colour code system for the grid points on the display monitor. Red points are those that have not yet been measured and blue ones are completed points. The point being measured is denoted by green. In addition, when the measurement is taking place at a point, the actual measurement type and multiplexer channels are shown underneath the grid display. The spectrum is simultaneously displayed on the Display Unit Type 4715.

After data acquisition, a data processing stage follows as shown in Fig.2.11. The sound power along with the surface intensity and pressure level, ISO draft standard indicators and ANSI draft standard indicators as well as intensity distribution data can be computed as required. By using appropriate commercial graphical softwares, the results can then be presented visually. Three commercial software routines are used at this stage, SURFER by Golden Software Inc.[59], Harvard Graphics by SPC SOFTWARE PUBLISHING Corporation[60], or AutoCAD by Autodesk Inc.[61].

CHAPTER 3

ANALYSIS OF SOUND POWER MEASUREMENTS

Introduction

Reference has been made in Chapter 1 and 2 to the test facility constructed at the Centre for Building Studies, and to the existence of draft standards for the measurement of sound power via the sound intensity technique. In this chapter the results of sound power measurements are presented by way of validating the measurement facility and procedures, and the data is assessed in accordance with the prescriptions of the draft standards with the objective of commenting upon their functional use. In the process, observations are made which may contribute to modifying the requirements of the draft standards. In this work, the half inch microphone probe system was employed and in particular, microphone No.978221 was close to the source whist microphone 978266 was the farthest from the source; these microphones are designated z1 and z2 respectively.

The test arrangement has been presented in Chapter 2 and is shown diagrammatically in Figure 2.5 and discussed in section 2.4.4.

3.1 Results

The sound intensity on the measuring surfaces at 10, 30 and 70cm from the sound source were measured using 320 evenly distributed points for each test and the sound power levels SWL in dB were calculated from

$$SWL = 10 \, Log\{ \Sigma 10^{(SILi/10)} . Ai \} \qquad (3.1)$$

where

SILi is the intensity level in dB at each point,
Ai is the corresponding area for segment i.

The sound power levels are presented in Fig.3.1 and Table A1-1.1. Good agreement between the result measured at different distance can be seen.

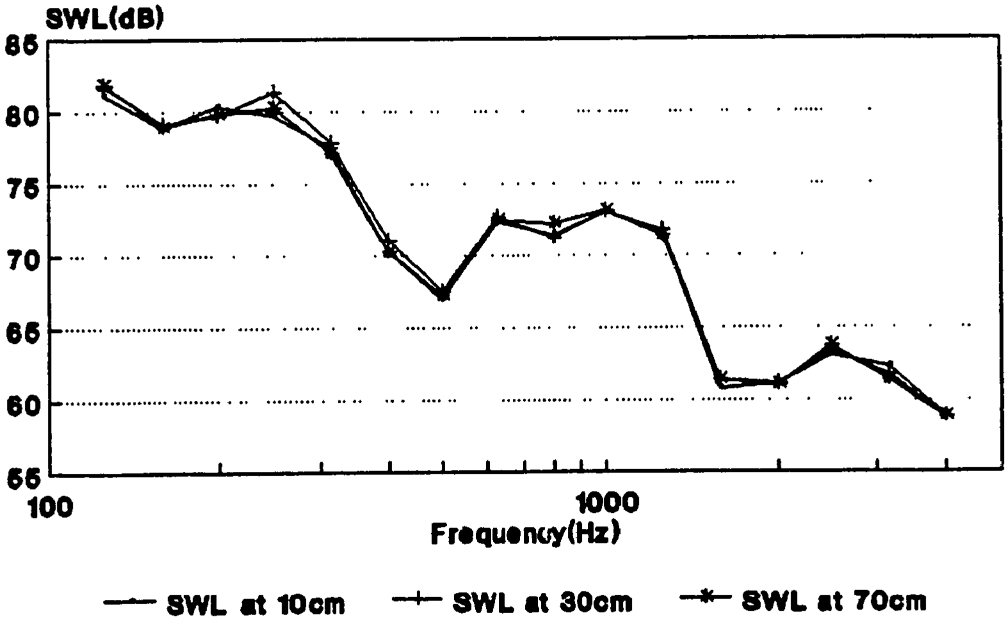


Fig.3.1: SWL at Different Distance

To determine the overall sound power output of the source, the surface average intensity must be calculated. In addition, the surface average sound pressure level must be determined in order to establish standards criterion. These will be discussed in detail later. The surface intensity level SIL_s in dB is computed from the following formula

$$SIL_s = 10 \, \mathrm{Log}\{(1/A)\Sigma 10^{(SILi/10)} \cdot Ai\} \qquad (3.2)$$

where

SILi is the intensity level in dB for segment i,
Ai is the area of segment i,
A is the total surface area.

If every segment has same area, then the formula is simplified to

$$S \qquad 10 \, \mathrm{Log}\{(1/N)\Sigma 10^{(SILi/10)}\} \qquad (3.3)$$

where

N=320 is the total measuring points over the measurement surface.

Similarly, the surface sound pressure level SPL_s can be calculated from individual sound pressure level SPLi for segment i,

$$SPL_s = 10 \, \mathrm{Log}\{(1/A)\Sigma 10^{(SPLi/10)} \cdot Ai\} \qquad (3.4)$$

or from the simplified formula

$$SPL_s = 10\ \mathrm{Log}\{(1/N)\Sigma 10^{(SPLi/10)}\} \quad (3.5)$$

The surface intensity and pressure levels at different distance are plotted in Fig.3.2 and Fig.3.3 and listed in Table A1-1.2 to Table A1-1.4. The trends of both intensity and pressure levels are as expected, i.e., they are attenuated with the increase of the distance from the source.

To ensure that the sound source was consistent for each test, the sound pressure level at a fixed point was measured before each test. The reference point is 280mm away from the corner of the source and 105mm above the floor where the source is placed. The result is shown in Table 3.1.

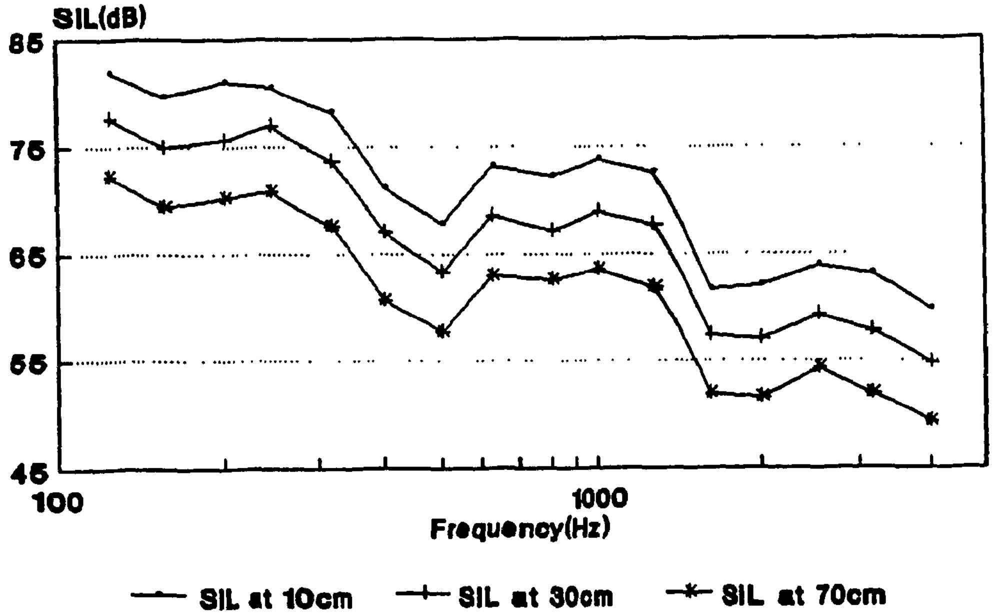


Fig.3.2: SIL for Sound Power Tests

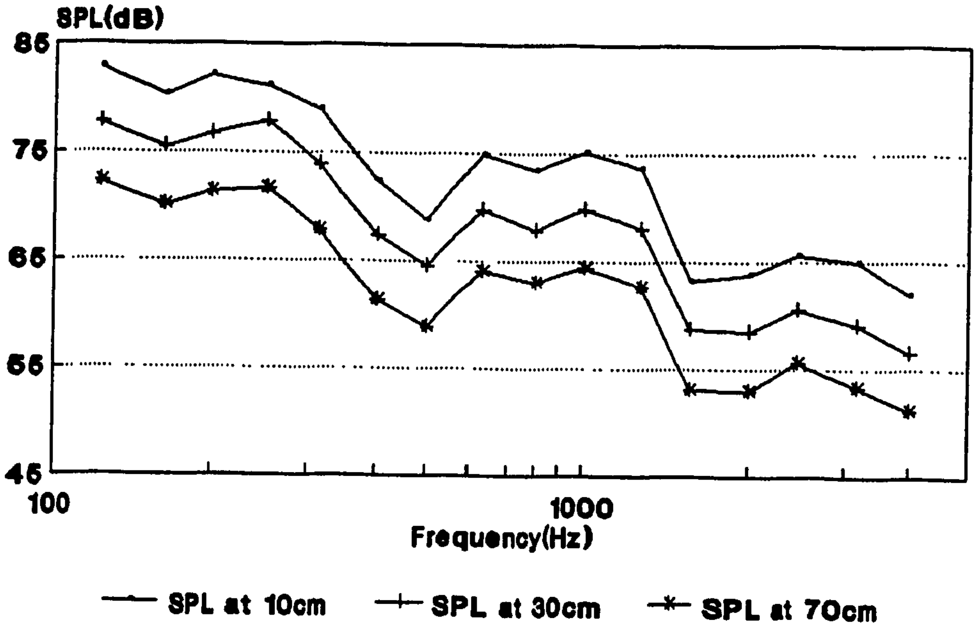


Fig.3.3: SPL for Sound Power Tests

Table 3.1 Sound Source Monitoring Results

Freq.,Hz	SPL1,dB	SPL2,dB	SPL3,dB
125	78.3	78.0	78.3
160	74.6	74.6	74.1
200	77.1	77.3	77.1
250	79.5	79.7	79.7
315	73.7	73.3	73.1
400	65.1	65.0	64.8
500	58.4	59.1	58.4
630	66.2	64.9	66.2
800	67.7	66.6	67.7
1000	75.9	75.2	74.7
1250	70.9	70.5	71.0
1600	57.9	57.9	57.9
2000	60.8	59.4	59.4
2500	59.0	58.7	58.4
3150	60.8	61.0	60.0
4000	57.0	56.0	56.0

The standard deviation σ of the monitored source level is calculated from

$$\sigma = [\Sigma(x_i - \bar{x})^2/(n - 1)]^{1/2} \tag{3.6}$$

$$\bar{x} = (\Sigma x_i)/n \tag{3.7}$$

where

x_i is the sample value which in this case is the monitored source level,
$\bar{x}$ is the mean of the sample values,
n is the sample number.

The variation result is illustrated in Fig.3.4 and Table A1-1.5.

From Figure 3.4, we can see that the source variation is

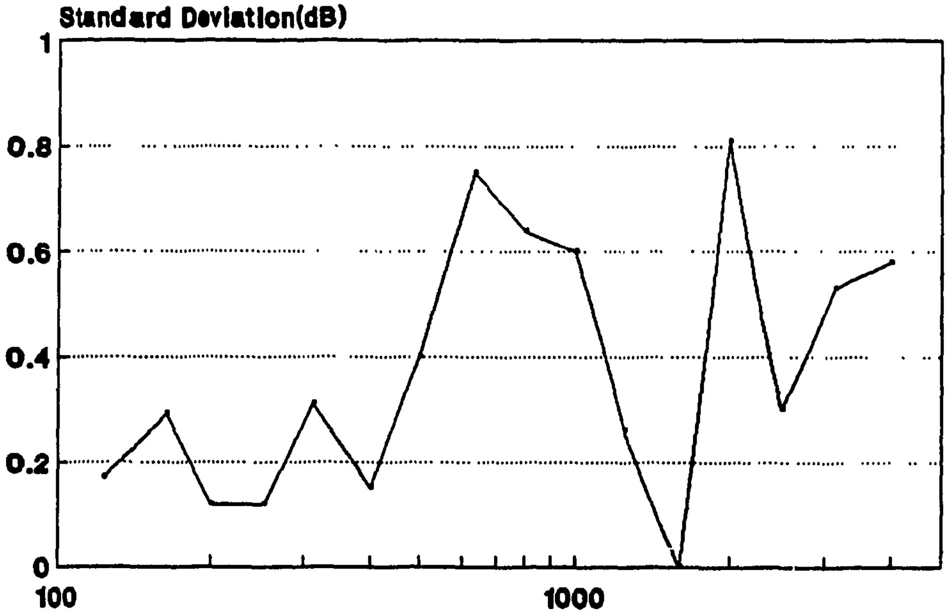


Fig.3.4: Sound Source Monitoring Result

less than 1 dB at all frequencies, from which we conclude that the tests for sound power measurements are for the same source and the power measurement results can be compared with each other. Fig.3.4 is only a rough qualitative descriptor for the source; it cannot be taken as the quantitative description of the source variation, nor as the exact error source for the power measurement results. The error due to the source variation will be reflected as part of the random error.

3.2 Error Analysis

To make the measurement results meaningful and to evaluate the influence of the measuring distance to various error sources, it is necessary and imperative to analyze the errors.

The first error is the unpredicted random error. This error can be designated as the sound power level repeatability standard deviation calculated by equation 3.6 where the sample is the sound power level. They are shown in Fig.3.5 and Table A1-1.6 along with the allowable uncertainty levels proposed in ISO and ANSI draft standards. In the ISO draft standard, there are two levels of uncertainty requirement, the precision level which is for laboratory research purpose and the engineering level which is applied to practical measurements. The ANSI draft standard only refers to engineering applications, thus

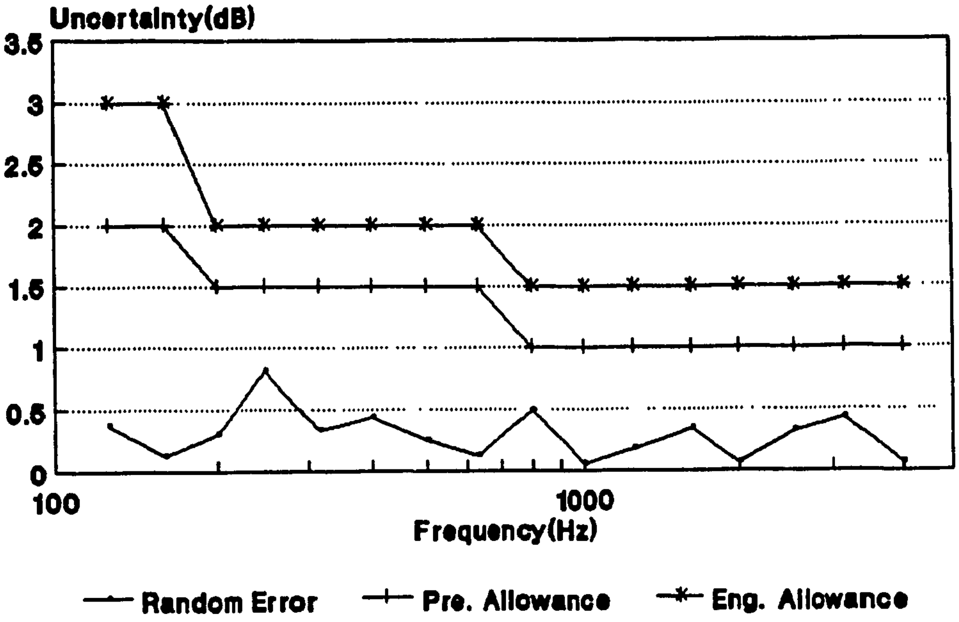


Fig.3.5: Random Error on Power Tests

only the engineering level requirement is proposed. One can see that the error is within the tolerance limits and all errors are less than 1 dB at different frequencies. Therefore, the test results are qualified in this regard. If compliance with standards is not met then the random error can be minimized by careful selection of the measurement parameters, e.g., increasing the number of measuring points and averaging time.

The second error is the phase mismatch error and it can be quantified by equation 2.11. To evaluate the error, the residual pressure-intensity index must be tested. The residual pressure-intensity index is defined as[3]

$$PII = L_p - L_i = 10Log[(p_{re}^2/I_{re})/400] \qquad (3.8)$$

where

L_p is the pressure level,
L_i is the intensity level,
p_{rs} is the pressure,
I_{re} is the intensity.

It is the index measured in a reactive sound field where the intensity is supposed to be zero. The pressure-intensity index is a good descriptor of the instrumentation. A minimum 10 dB difference between the measured pressure and intensity levels must be given by the instrumentation when tested in a reactive field. A standing wave tube is used for the measurement of the residual pressure-intensity index in the present work[62]. The acoustic coupler, B&K WA0344 was modified to fit over the end of the 1" diameter standing wave tube(B&K type 4002). Pink noise was supplied to the tube via

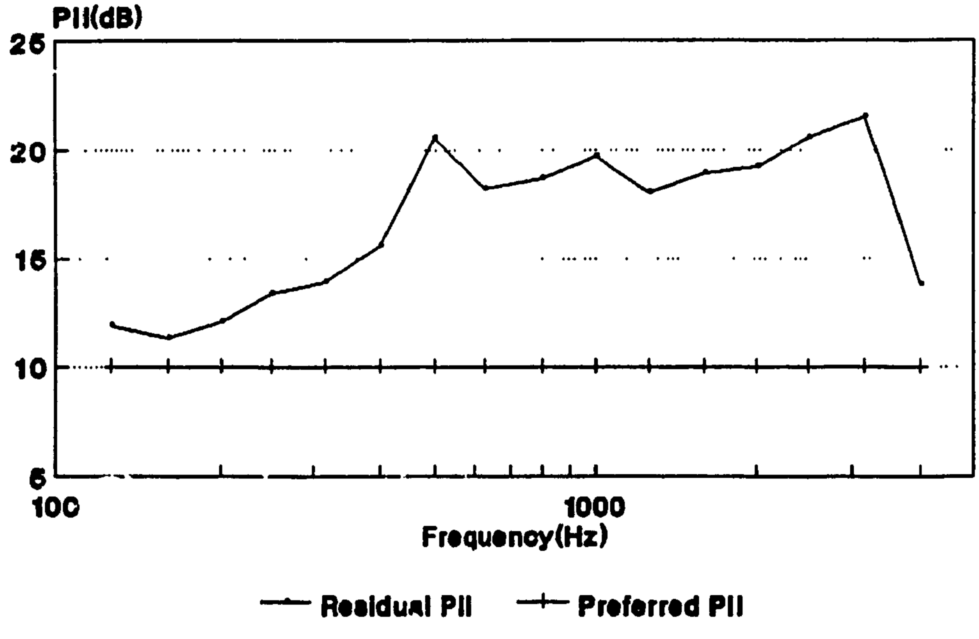


Fig.3.6: Residual PII for Power Tests

the Noise Generator B&K type 1405 and the consequent residual pressure-intensity indices were recorded. Typical results are shown in Fig.3.6 and Table A1-1.7.

From Fig.3.6, it can be seen that all pressure-intensity indices are greater than 10dB. Thus, the instrumentation is qualified in this aspect. Better performance at high frequencies with the exception of 4000 Hz is seen compared to the low frequencies; this is normal and has been discussed in Section 2.1.3, part b.

The phase mismatch errors of the measurements at different distances can now be evaluated according to Eq.(2.11). This error can be evaluated individually using the measured intensity and pressure levels at each point and then an estimate made of the local phase induced error. To assess

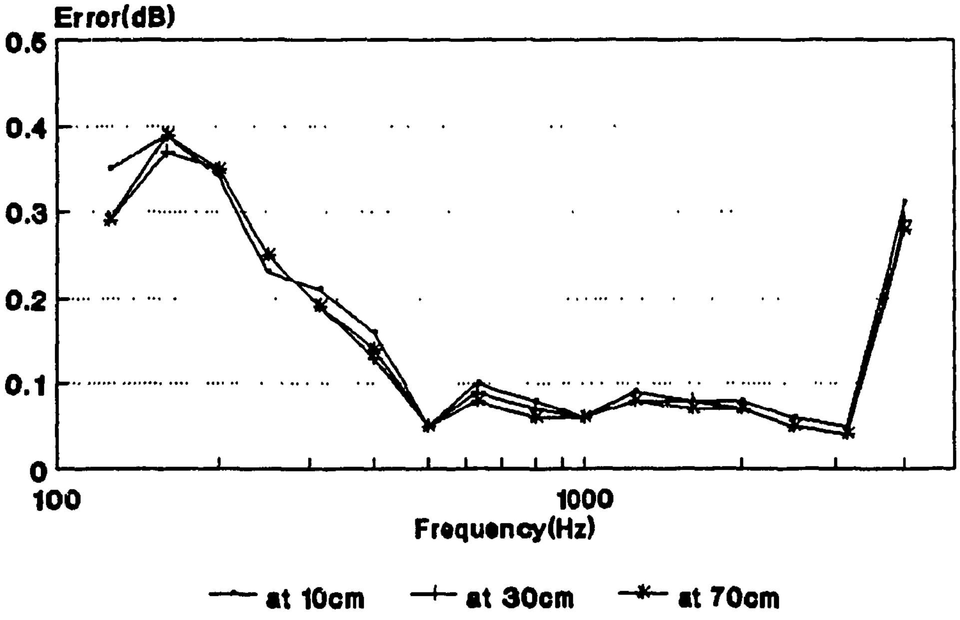


Fig.3.7: Phase Mismatch Error on SWL

the global phase mismatch error for the whole measurement surface, the average surface intensity and pressure along with the residual pressure-intensity index can be used. The calculated global phase mismatch errors are plotted in Fig.3.7 and listed in Table A1-1.2 to Table A1-1.4.

From Fig.3.7, The following observations can be made. First, there is no significant difference between the phase mismatch errors at different distances for the present sound power measurements. Because the pressure-intensity index is stable this suggests that the phase properties of the sound field at different distances are not significantly different for those sources. Second, the phase mismatch is higher at low frequencies than for high frequencies due to the performance of the instrumentation at low frequencies. The poor performance at 4000 Hz is considered as an exception. Thus, it does seem possible to measure accurately at somewhat closer distance to the source.

Another error is the finite difference error. It is a systematic error and cannot be avoided when using the sound intensity technique. For simplicity, the errors are calculated from Eq.(2.9) using the current microphone spacing Δr=12mm. The highest finite difference errors, found at the 10cm measurement surface, are listed in Table 3.2. It can be seen that this error is generally negligible except at the high frequency end where the wavelength begins to approach the microphone spacing.

Table 3.2 Finite Difference Error at d=10cm

Freq.,Hz	Er, dB	Freq.,Hz	Er, dB
125	1.51×10^{-2}	800	-0.67×10^{-2}
160	1.48×10^{-2}	1000	-1.94×10^{-2}
200	1.43×10^{-2}	1250	-3.91×10^{-2}
250	1.35×10^{-2}	1600	-7.42×10^{-2}
315	1.22×10^{-2}	2000	-0.13
400	1.01×10^{-2}	2500	-0.21
500	0.69×10^{-2}	3150	-0.34
630	0.18×10^{-2}	4000	-0.56

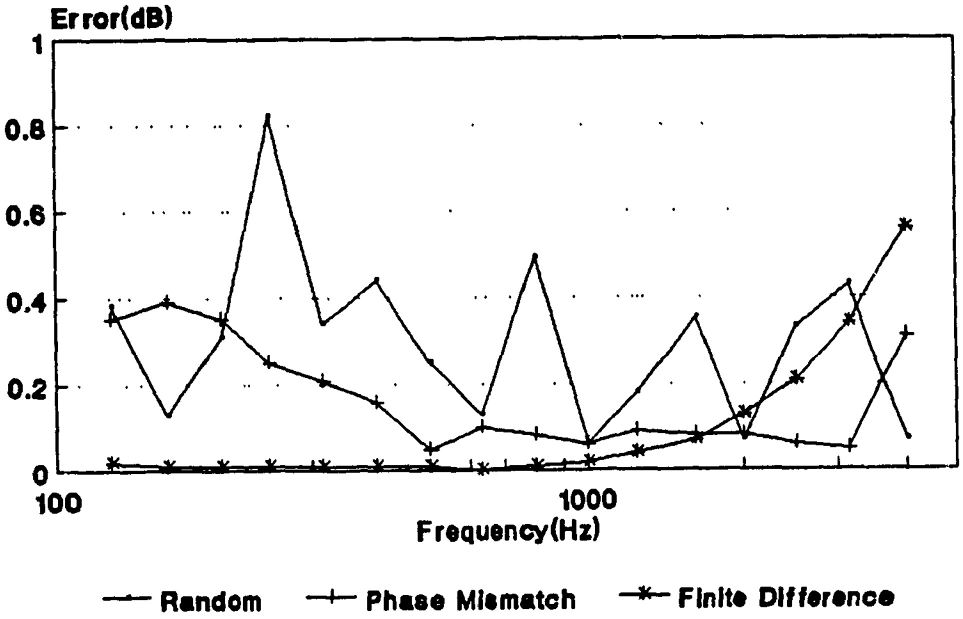


Fig.3.8: Various Errors on SWL Tests

The various error bounds for the power measurements are illustrated in Fig.3.8 where the phase mismatch errors are chosen from the maximum values among the three error spectra at different distances and the finite difference errors are taken as the absolute values of the errors at the 10cm surface. The comparisons show that at low frequencies the random errors and phase mismatch error are the major error sources while at high frequencies all three error types have similar magnitudes. Overall, the test random error is most dominant and control measures for this type of error must be given high priority. Nevertheless, all errors are less than 1 dB.

Finally, the mean sound power levels which are calculated using Eq.3.7 and their total error bounds which are summed as

$$Er_{tot} = |Er_{random}| + |Er_{system,max}| + |Er_{phase,max}| \qquad (3.9)$$

are illustrated in Fig.3.9 and Table A1-1.8.

The highest cumulative error is found as 1.08dB at 250Hz, errors at all other frequencies are less than 1 dB, thus the

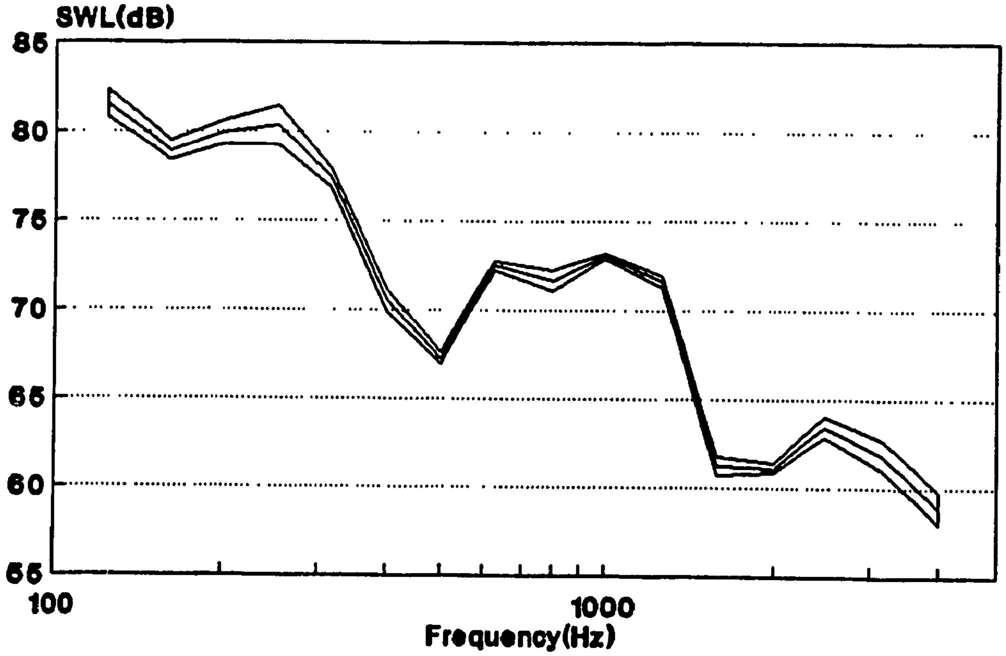


Fig.3.9: SWL & Total Error Bounds

intensity technique and the test instrumentation system used are reliable for sound power measurements.

3.3 Assessment of ISO Field Indicators[1]

In the ISO draft standard[3], four field indicators are designed to evaluate the measurement of sound power. The adequacy of the sound power measurement tested will be evaluated with these indicators as follows.

3.3.1 Surface pressure-intensity indicator F2

This indicator is designed to show the field reactivity and to test whether this factor is within acceptable bounds with respect to the instrumentation employed.

The surface pressure-intensity indicator F2 is defined as

$$F2 = \bar{L}_p - \bar{L}_{|In|} \qquad (3.10)$$

where $\bar{L}_p$ is the surface pressure level calculated as

$$\bar{L}_p = 10\text{Log}\ [(1/n)\sum_{1}^{n} 10^{0.1L_{pi}}] \qquad (3.11)$$

$\bar{L}_{|In|}$ is the surface unsigned intensity level calculated as

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[1] All the definitions of the ISO indicators are from Ref.3.

$$\bar{L}_{|In|} = 10\mathrm{Log}\ [(1/n)\sum_{1}^{n}|I_{ni}|/I_0] \qquad (3.12)$$

where

n is the total measuring points,
Lpi is the pressure level at point i,
$|I_{ni}|$ is the magnitude of normal intensity at point i,
I_0 is the reference intensity as $10^{-12}w/m^2$.

To qualify the test results, a criterion relating to the indicator F2 is proposed in the ISO draft standard.

$$L_d > F2 \qquad (3.13)$$

where L_d is the Dynamic Capability Index of the instrumentation used. The objective of this criterion is to keep the phase mismatch error within an acceptable limit.

The Dynamic Capability Index is defined as

$$L_d = PII - 10 \qquad (3.14)$$

where the PII is the residual pressure-intensity index calculated from Eq.(3.8).

From the derivation, we can see that if the criterion is satisfied the phase mismatch error will be smaller than 0.5dB.

The F2 indicator at different distance measurement surfaces and the dynamic capability index are calculated and shown in Fig.3.10 and Table A1-1.9. All F2 indicators are below the dynamic capability index especially at high frequencies. This qualifies the instrumentation and the

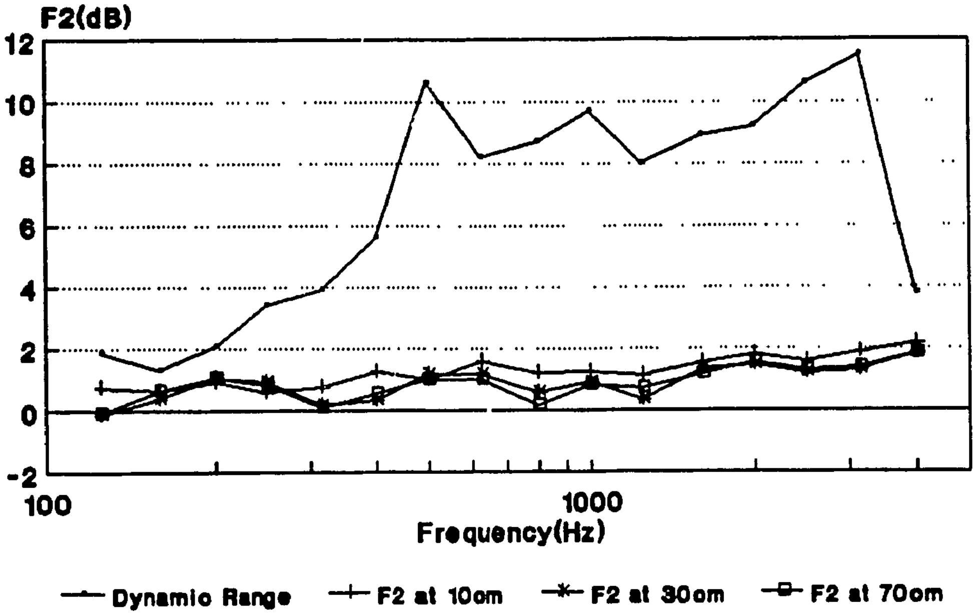

Fig.3.10:Adequacy of Instruments for SWL

measurement results. The difference between the F2 values at different distances is not significant although the F2 values at 10cm are slightly higher at most frequencies than that at other distances.

Two F2 values for d=30cm and d=70cm at 125 Hz were found to be negative. This seems, in the normal sense, impossible. However, by detailed theoretical analysis, one can find that the negative F2 values are just as natural as positive ones. Consider an extreme situation, namely the standing wave sound field such as the plane wave in a standing wave tube. If the termination material mounted at one end of the tube has an absorption coefficient α, then α can be derived from the incident pressure magnitude A and the reflective pressure magnitude B as[38]

$$\alpha = 1 - (B/A)^2 \tag{3.15}$$

The intensity I in a plane wave is related with the magnitude of the root mean square pressure as

$$I = P^2/\rho c \tag{3.16}$$

where

ρc is the characteristic impedance of the medium, for air typically is 415.

The maximum pressure magnitude in the standing wave tube is A+B, whilst the minimum is A-B. In the decibel notation one has

$$SPL_{max} = 10Log\{(A+B)^2/p_0^2\} \tag{3.17}$$

$$SPL_{min} = 10Log\{(A-B)^2/p_0^2\} \tag{3.18}$$

where p_0 is the reference sound pressure, $2\cdot 10^{-5}$ Pa.

The sound intensity in the tube will be the sum of the incident intensity and the reflected intensity which have opposite travelling directions as

$$SIL = 10Log\{(A^2 - B^2)/(\rho c I_0)\} \tag{3.19}$$

Thus, the difference between SPL_{max} and SIL equals the difference between SIL and SPL_{min} which is

$$SPL_{max} - SIL = SIL - SPL_{min} = 10\text{Log}\{(A + B)/(A - B)\} \qquad (3.20)$$

From Eq.(3.15) one has

$$B/A = (1 - \alpha)^{1/2} \qquad (3.21)$$

Thus,

$$\begin{aligned} SPL_{max} - SIL &= SIL - SPL_{min} \\ &= 10\text{Log}\{[1+(1-\alpha)^{1/2}]/[1-(1-\alpha)^{1/2}]\} \qquad (3.22) \end{aligned}$$

This relationship is illustrated in Fig.3.11.

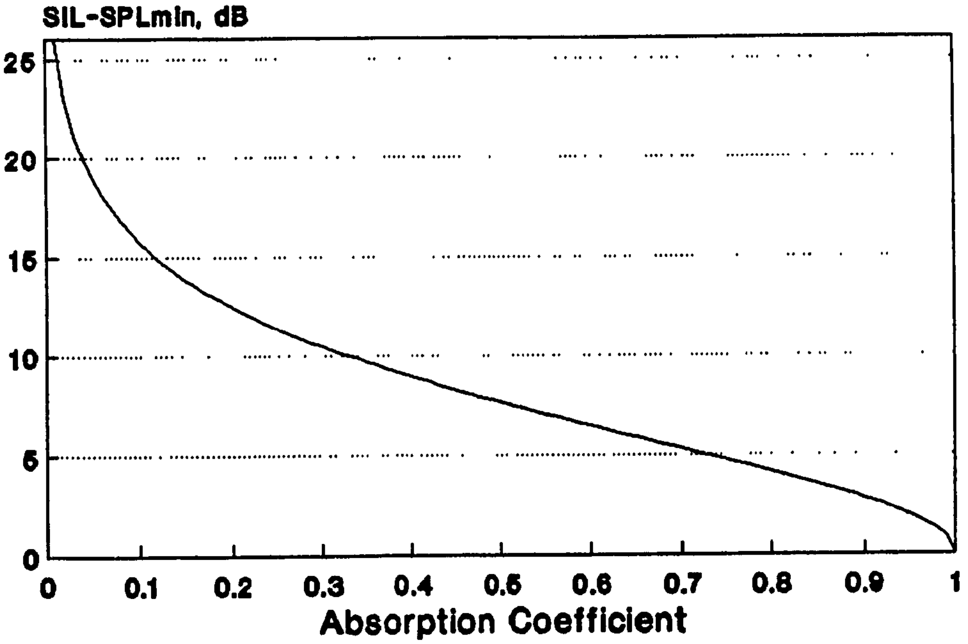

Fig.3.11 Intensity vs. Minimum Pressure
in a Standing Wave Field

From Fig.3.11 one can observe that if the absorption coefficient is unity, that is the perfect free field condition, the intensity will be equal to pressure. However, with the decrease of the absorption coefficient the intensity could be greater and greater than pressure up to infinity. From Fig.3.11, it is very clear that even when the absorption coefficient is 0.99 intensity could still be about 1dB greater than pressure.

This analysis concludes that: (1) Due to the possibility of standing waves in the sound field it is natural to have intensity greater than pressure at some points; (2) Because the standing wave in the standing wave tube is the extreme situation where minimum pressure can occur, the maximum difference between the intensity and the pressure will never exceed the curve in Fig.3.11. If it exceeds the limit in Fig.3.11, then instrumentation error is probably present; (3) If F2 indicator is negative, it indicates that some kind of standing wave exists.

If there is no extraneous noise during the intensity measurement, the true intensity level should be

$$SIL_t = 10\mathrm{Log}\{A^2/(\rho c I_0)\} \tag{3.23}$$

From Eq.(3.19) and (3.15) one can obtain the correction level for the measured intensity as

$$SIL_t - SIL = -10\mathrm{Log}\{\alpha\} \tag{3.24}$$

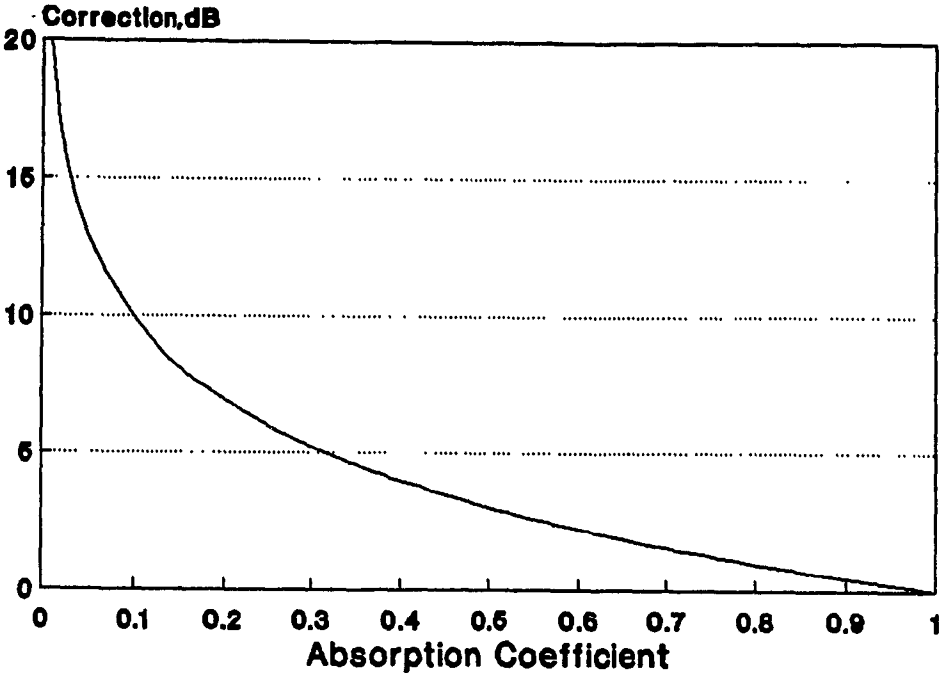

Fig.3.12 True Intensity Correction

This correction curve is presented in Fig.3.12 and it gives a maximum error bound due to the reflected noise. In practice, the sound field is much more complicated than the plane wave field and the correction by Fig.3.12 cannot be used directly.

3.3.2 Field Non-uniformity Indicator F4

Another important indicator proposed in the ISO draft standard is field non-uniformity indicator F4

$$F4 = (1/I)\{\Sigma(I_i - \bar{I})^2/(n - 1)\}^{1/2} \qquad (3.25)$$

where

n is the number of measuring points,
I_i is intensity at point i,
I is the mean of the surface intensity.

F4 is actually the coefficient of variation, or normalized standard deviation, of the normal intensity on the measuring surface.

The second criterion proposed by ISO draft standard is related to the F4 indicator and it is the qualification of the number of measuring points. The total number of measuring points N must satisfy the following requirement

$$N > C \cdot (F4)^2 \tag{3.26}$$

where C are constants defined in Table 3.3 for one third octave band.

Table 3.3 Values for Factor C

Freq. Hz	Precision	Engineering
50- 160	15	8
200- 630	28	15
800-5000	90	28

The criterion 2 actually sets the minimum number of measurement points N required to produce an estimate of the average normal intensity which has 95% confidence limits of certain dB. The formula for constant C can be written as[63]

$$C = [t/(1 - 10^{(-\sigma/10)})]^2 \tag{3.27}$$

where t is Student-t factor, t=1.96 for 95% confidence if N>20, σ is the confidence limit in dB. We find that if C=8 then the confidence limit will be 5dB; if C=15 then 3dB; if C=28 then 2dB; if C=90 then 1dB.

The normalized surface intensity standard deviation at different distance(F4 indicators) and the requirement of the number of points on the surface for precision and engineering class tests as well as the number of points used in tests are shown in Table A1-1.10 to Table A1-1.12. The comparisons of the F4 indicators at different distances are shown in Fig.3.13 and the qualifications of measuring point numbers on each measurement surface are displayed in Fig.3.14, Fig.3.15 and Fig.3.16. It should be noted that the minimum number of points required in the ISO draft standard is 20 because of the theory on which the formula 3.24 is based.

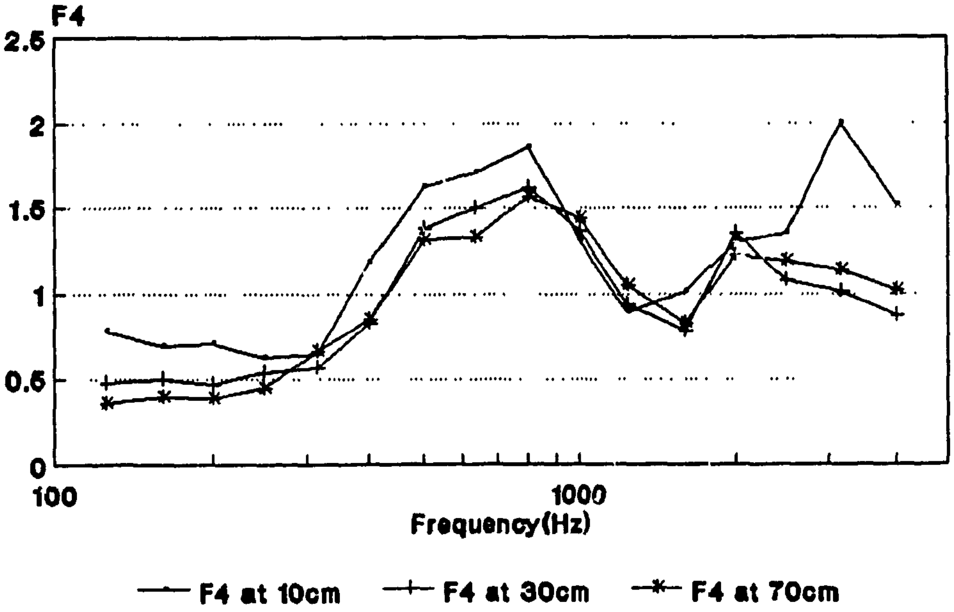

Fig.3.13: IL Coeff. of Variation for SWL

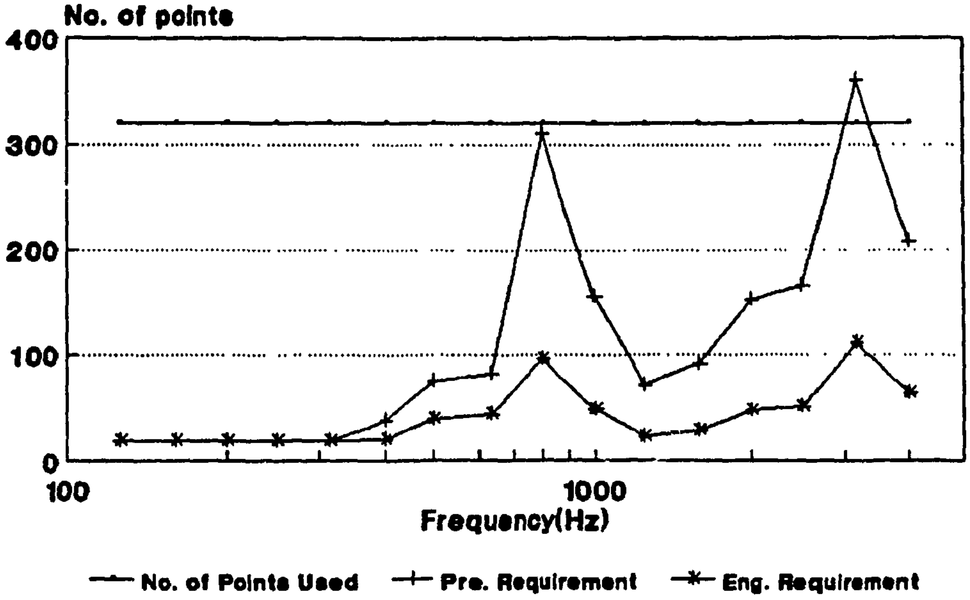

Fig.3.14: Adequacy of Test Array at 10cm

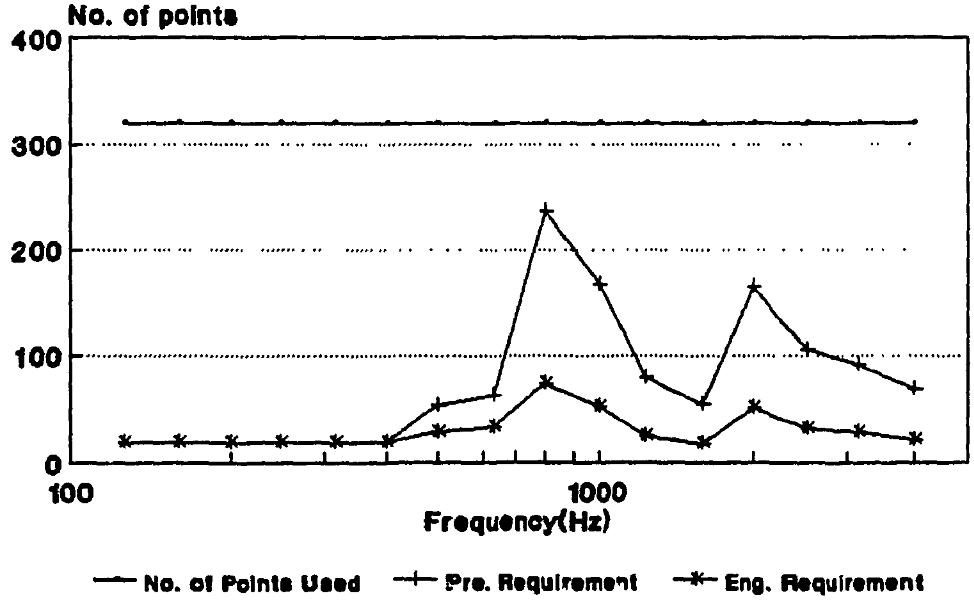

Fig.3.15: Adequacy of Test Array at 30cm

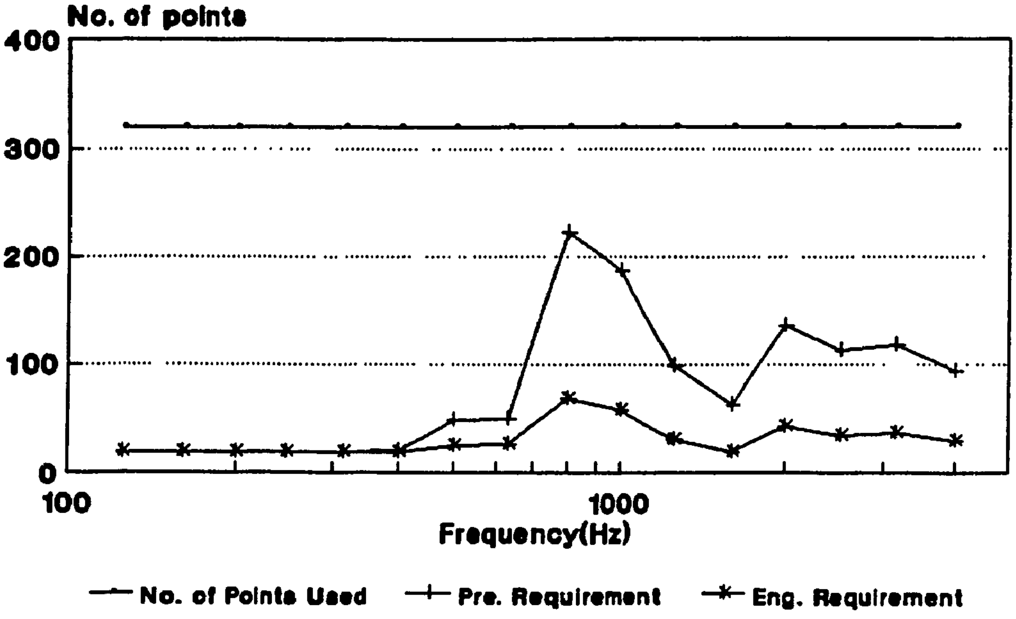

Fig.3.16: Adequacy of Test Array at 70cm

From Fig.3.13, we find that the normalized surface intensity variations at the 10cm surface are higher than that at other distance at most frequencies. This is because the near field is more complicated and the variation is higher. It means that if the surface is close to the source, the more measuring points are required to achieve a certain accuracy. Fig.3.14 to Fig.3.16 confirm this observation where at the 10cm surface, 320 measuring points are not sufficient for the precision requirement at 3150Hz. On the other hand, we can see that to satisfy this requirement, many points are needed which implies significant measuring time.

3.3.3 Other ISO Indicators

Two more indicators are required to be evaluated in the

ISO draft standard.

The Negative Partial Power Indicator F3 is calculated from the equation

$$F3 = \overline{L}_p - \overline{L}_{In} \qquad (3.28)$$

The only difference between F2 and F3 is that the unsigned average intensity level in F2 is replaced by the signed intensity level in F3.

If F2 and F3 are significantly different, the sound field is either under strongly directional extraneous noise source or too much sound is circulated back to the source. In this case the accuracy of the result will be reduced. ISO requires the difference between F2 and F3 less than 3 dB.

Because the tests discussed in this chapter were well controlled, the F2 and F3 indicators for all measurements are identical. Therefore, the negative partial power effect is excluded.

The Sound Field Temporal Variability Indicator F5 is measured at an appropriate position selected on the measurement surface and calculated from

$$F5 = (1/\overline{I})\{\Sigma(I_i - \overline{I})^2/(m - 1)\}^{1/2} \qquad (3.29)$$

where

$\overline{I}$ is the mean of m time samples,

I_i is the intensity reading for time sample i.

The ISO draft standard requires that F5 must be less than 0.6.

Since the source tested was kept unchanged, this effect is also excluded. However, if the steadiness of a noise source is unknown, an extra microphone can be employed to monitor the source during the course of measurement and the standard deviation can be treated as the error of source for sound power measurement.

Generally speaking, the ISO indicators are easily evaluated. They give an idea how much the error would be if their criteria are met. The purpose of these indicators is to control the phase mismatch error and the random error caused by choosing the measuring arrays. However, the demand for measuring point numbers are quite restrictive and may not be necessary as will be discussed in Section 3.5.

3.4 Assessment of ANSI Data Quality Indicators[1]

In the ANSI draft standard, there are seven groups of data quality indicators and one or more indicators in each group are recommended to be evaluated. Some of the ANSI indicators can be calculated from a single measurement of sound power data, they are indicators D21, D23, D24, D25, D26,

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[1] All the definitions of ANSI indicators are from Ref.4.

D52 and D53. These indicator values for the current measurements are listed in Table 3.4, 3.5 and 3.6 and the discussions will be presented as follows.

3.4.1 Source and Background Level Variability Indicators D1

The premise of the sound power measurement is that the source is in steady state during the course of measurement. To have a valid measurement result, the variability of the source and background sound level must be evaluated. Four indicators are designed in this group, each based on the normalized temporal standard deviation.

Table 3.4 ANSI Indicators for SWL Test at 10cm

Freq	D21	D23	D24	D25	D26	D52	D53
125	0.0	0.59	0.59	-2.11	3.85	11.09	0.59
160	0.0	0.49	0.49	-3.26	2.04	10.65	0.49
200	0.0	0.76	0.76	-2.95	2.85	11.19	0.76
250	0.0	0.43	0.43	-4.08	1.78	12.81	0.43
315	0.0	0.60	0.60	-3.73	0.28	13.17	0.60
400	0.0	1.12	1.12	1.40	0.29	14.38	1.12
500	0.0	0.87	0.87	4.25	0.40	19.58	0.87
630	0.0	1.45	1.45	4.64	0.02	16.58	1.45
800	0.0	1.04	1.04	5.37	0.42	17.49	1.04
1000	0.0	1.10	1.10	2.37	0.70	18.41	1.10
1250	0.0	0.96	0.96	-1.01	0.46	16.86	0.96
1600	0.0	1.37	1.37	0.06	1.56	17.36	1.37
2000	0.0	1.63	1.63	2.30	0.99	17.43	1.63
2500	0.0	1.45	1.45	2.62	1.26	18.98	1.45
3150	0.0	1.73	1.73	6.02	1.99	19.68	1.73
4000	0.0	2.01	2.01	3.63	1.50	11.67	2.01

Table 3.5 ANSI Indicators for SWL Test at 30cm

Freq	D21	D23	D24	D25	D26	D52	D53
125	0.0	-0.26	-0.26	-6.44	-0.64	11.87	-0.26
160	0.0	0.23	0.23	-6.10	2.99	10.89	0.23
200	0.0	0.88	0.88	-6.49	3.03	11.12	0.88
250	0.0	0.76	0.76	-5.33	3.51	12.53	0.76
315	0.0	0.03	0.03	-4.91	1.38	13.68	0.03
400	0.0	0.19	0.19	-1.66	0.51	15.21	0.19
500	0.0	1.00	1.00	2.82	0.51	19.47	1.00
630	0.0	1.01	1.01	3.54	0.76	17.04	1.01
800	0.0	0.43	0.43	4.20	1.54	18.09	0.43
1000	0.0	0.77	0.77	2.70	0.71	18.77	0.77
1250	0.0	0.20	0.20	-0.53	0.98	17.61	0.20
1600	0.0	1.19	1.19	-2.14	1.29	17.55	1.19
2000	0.0	1.30	1.30	2.63	1.16	17.79	1.30
2500	0.0	1.04	1.04	0.70	1.13	19.41	1.04
3150	0.0	1.15	1.15	0.07	1.22	20.21	1.15
4000	0.0	1.70	1.70	-1.20	1.26	11.96	1.70

Table 3.6 ANSI Indicators for SWL Test at 70cm

Freq	D21	D23	D24	D25	D26	D52	D53
125	0.0	-0.25	-0.25	-8.88	1.61	11.93	-0.25
160	0.0	0.46	0.46	-7.95	1.36	10.67	0.46
200	0.0	0.91	0.91	-8.29	2.92	11.06	0.91
250	0.0	0.67	0.67	-6.97	1.52	12.56	0.67
315	0.0	-0.06	-0.06	-3.58	0.62	13.71	-0.06
400	0.0	0.40	0.40	-1.44	0.61	15.02	0.40
500	0.0	0.87	0.87	2.38	0.56	19.60	0.87
630	0.0	0.87	0.87	2.50	1.55	17.15	0.87
800	0.0	0.02	0.02	3.90	1.75	18.45	0.02
1000	0.0	0.67	0.67	3.17	0.96	18.84	0.67
1250	0.0	0.56	0.56	0.38	0.88	17.27	0.56
1600	0.0	1.02	1.02	-1.58	1.31	17.69	1.02
2000	0.0	1.38	1.38	1.78	1.43	17.73	1.38
2500	0.0	1.15	1.15	0.97	0.66	19.28	1.15
3150	0.0	1.24	1.24	1.17	1.21	20.13	1.24
4000	0.0	1.68	1.68	0.18	1.93	11.98	1.68

$$D11 = 10\text{Log}\ \frac{N^2\sum_1^N[10^{0.1\bar{L}_{pn}} - (1/N)\sum_1^N 10^{0.1\bar{L}_{pm}}]^2}{(N-1)[\sum_1^N 10^{0.1\bar{L}_{pn}}]^2} \tag{3.30}$$

$$D12 = 10\text{Log}\ \frac{N^2\sum_1^N[10^{0.1L_{pin}} - (1/N)\sum_1^N 10^{0.1\bar{L}_{pim}}]^2}{(N-1)[\sum_1^N 10^{0.1L_{pin}}]^2} \tag{3.31}$$

$$D13 = 10\text{Log}\ \frac{N^2\sum_1^N[\bar{I}_n - (1/N)\sum_1^N \bar{I}_m]^2}{(N-1)[\sum_1^N I_n]^2} \tag{3.32}$$

$$D14 = 10\text{Log}\ \frac{N^2\sum_1^N[I_{in} - (1/N)\sum_1^N \bar{I}_{im}]^2}{(N-1)[\sum_1^N I_{in}]^2} \tag{3.33}$$

where

$\bar{L}_p$ is the surface sound pressure level,
L_{pi} is the sound pressure level at measurement location i,
$\bar{I}$ is the surface intensity,
I_i is sound intensity at measurement location i,
N is the number of times tests are repeated.

The surface intensity and pressure level are calculated from Eq.(3.2) or Eq.(3.4).

We can see that indicator D14 has the following relation with the ISO indicator F5

$$D14 = 20Log(F5) \tag{3.34}$$

If the subject sound source can be shut off without affecting the background noise, then D1 indicators gives "background only" variability. Otherwise, "source plus background" variability is obtained.

Because the normalized standard deviation can be the value between zero and infinity, the D1 indicators could be any positive or negative real values. The smaller the D1 indicators, the more stable the source level is. Indicator D13 for "source plus background" must not exceed the engineering class requirement on the standard deviation given in Table A1-1.6. If D1 indicators are too high, one may increase the measurement averaging time. If the variability is due to the background only, one may increase the signal to noise ratio by reducing the measurement distance or introducing a barrier to attenuate the noise.

To evaluate a sound field temporal variation using ANSI D1 indicators is rather cumbersome because it requires several times surface intensity and pressure level measurements each with m measuring points for D11 and D13. Actually, all four indicators are for the same purpose, to evaluate D12 or D14 only is effective enough.

3.4.2 Parasitic Noise Level Indicators D2

The parasitic noise is referred to the background noise and/or the noise reflected from the boundary of the room or the fittings in the room. That is, any noise which is not directly coming from the subject source.

There are seven indicators in this group.

$$D21 = \bar{L}_{|I|} - \bar{L}_I \tag{3.35}$$

where

$\bar{L}_{|I|}$ is the unsigned surface intensity level,
$\bar{L}_I$ is the signed surface intensity level.

It is easily seen that

$$D21 = F3 - F2 \tag{3.36}$$

With low or moderate parasitic noise, D21=0, while D21>0 implies the presence of significant parasitic noise. All D21 indicator values for 10, 30 and 70cm surface measurement results are found to be zero. Therefore, there are no significant parasitic noises in the measureed sound fields.

$$D22 = \bar{L}_I - \bar{L}_{I,BO} \tag{3.37}$$

where

$\bar{L}_{I,BO}$ is the surface intensity level determined with background noise only.
$\bar{L}_I$ is the usual surface intensity level.

D22 is the signal to noise ratio if room effect noise can be neglected. D22>10dB means background noise is negligible, while D22<10dB implies that action will be needed to reduce the background noise.

$$D23 = \bar{L}_p - \bar{L}_I + 10\mathrm{Log}[p_0^2/\rho c I_0] \qquad (3.38)$$

where
$\bar{L}_p$ is the average surface pressure level,
p_0 is the reference sound pressure, $2\cdot 10^{-5}$Pa,
I_0 is the reference sound intensity, 10^{-12}W/m
ρc is the characteristic impedance of the medium, for air, typically, ρc=415,
$\bar{L}_I$ is the average surface intensity level.

Compared with the ISO indicator, we have

$$D23 = F3 - 0.16 \qquad (3.39)$$

For D23, a value of zero implies no parasitic noise, while values greater than zero generally imply progressively increasing levels of parasitic noise. From Table 3.4-3.6 we can see that D23 are not zero. This means the sound fields are not free fields, instead some small, but not significant(from D21 indicators), parasitic noise existed. Negative D23 is also possible in theory as analyzed in Section 3.3.1. The negative D23s in the table are the indications that a standing wave is present.

$$D24 = \bar{L}_p - \bar{L}_{|I|} + 10\mathrm{Log}[p_0^2/\rho c I_0] \qquad (3.40)$$

The only difference between D23 and D24 is that the surface intensity level in D23 is replaced by the unsigned surface intensity level in D24.

D24 is similar to D23 but more related to phase error due to the sound field diffusibility since

$$D24 = F2 - 0.16 \qquad (3.41)$$

All D24 values in the sound power measurements are the same as D23 values which means no negative intensity has been encountered. Negative D24s are also the indications of the standing wave.

$$D25 = 10Log\{[\sum_{1}^{n}(I_m - \bar{I})^2]/[(n - 1)\bar{I}^2]\} \qquad (3.42)$$

where
$\bar{I}$ is average surface intensity,
n is the total number of measuring points,
I_m is the intensity at segment m.

D25 is the normalized spatial intensity standard deviation and has the relation with F4 as

$$D25 = 20Log[F4] \qquad (3.43)$$

The larger the D25 value, the higher the spatial variation of the sound field. This may be due to source directivity or parasitic noise. D25 may be positive or negative.

$$D26 = D25 - 10\text{Log}\{[\sum_{1}^{n}(10^{0.1L_{pi}} - 10^{0.1\overline{L}_p})]/[(n - 1)10^{0.1\overline{L}_p}] \qquad (3.44)$$

D26 is the difference between the intensity variation and pressure variation. D26 can be positive or negative. Because the influence of source directivity is almost the same for the intensity and pressure, D26 is more sensitive to parasitic noise. From Table 3.4-6, non-zero D26 values are found which indicate the existence of some parasitic noise influence.

$$D27 = L_W - L_W' \qquad (3.45)$$

where

L_W is the sound power level determined in real situation with parasitic noise,

L_W' is the sound power level determined using the same measurement surface and same procedure as that for L_W but with additional absorption in the measurement environment.

Values for D27 less than one-half the standard deviation of the engineering class given in Table A1-1.6 implies that the effects of the parasitic noise are negligible.

This indicator has research value only. In many engineering measurements of sound power, this indicator would not be practical.

3.4.3 Surface Averaging Accuracy Indicators D3

$$D31 = |\ \overline{L}_I - \overline{L}_I'\ | \qquad (3.46)$$

$$D32 = | \bar{L}_I - \bar{L}_I'' | \qquad (3.47)$$

where

$\bar{L}_I'$ is the surface intensity level using 4 times the number of measuring points as for L_I,

$\bar{L}_I''$ is the surface intensity using the same number of measuring points as for L_I but at different positions on the measurement surface,

$\bar{L}_I$ is the average surface intensity level.

These indicators can qualify the adequacy of measuring points number and the distribution of the points on the measurement surface.

The test data for 10cm and 70cm measurement surfaces have been dissected to have 20, 40, 80, 160 and 320 points evenly distributed on the surface. The surface intensity for each case is calculated and the D31 and D32 indicators are evaluated.

The D31 indicators and the allowable values are plotted in Fig.3.17 and 3.18 and listed in Table A1-1.13 to A1-1.18. The D32 indicators and its allowable values are displayed in Fig.3.19 and Fig.3.20 and listed in Table A1-1.19 to Table A1-1.26.

From Fig.3.17 and 3.18, we can see that to satisfy the ANSI requirement on D31 indicator, 80 points are enough for both 10cm and 70 cm surfaces. For the 70cm surface even 40 points are sufficient with only one exception at 2000Hz where D31 is slightly above the allowable value. While from Fig.3.19 and 3.20, we need 160 points to meet the requirement. Eighty

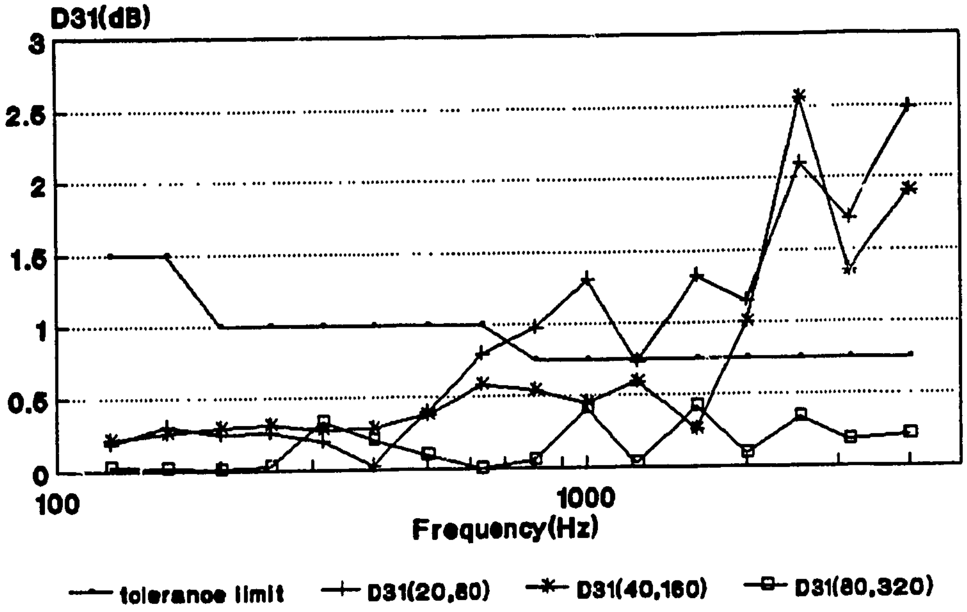


Fig.3.17: SWL D31 indicators,d=10cm

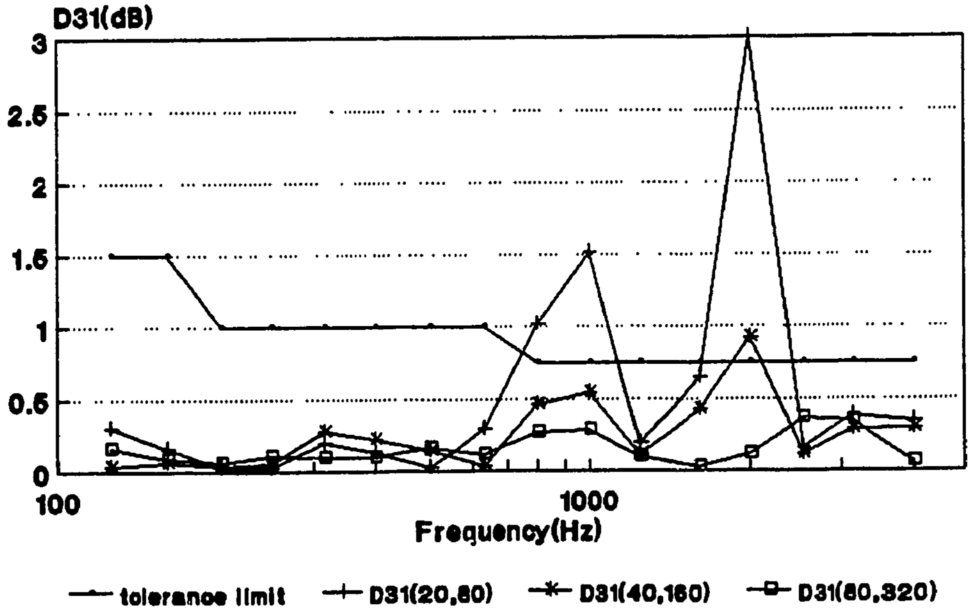


Fig.3.18: SWL D31 Indicators,d=70cm

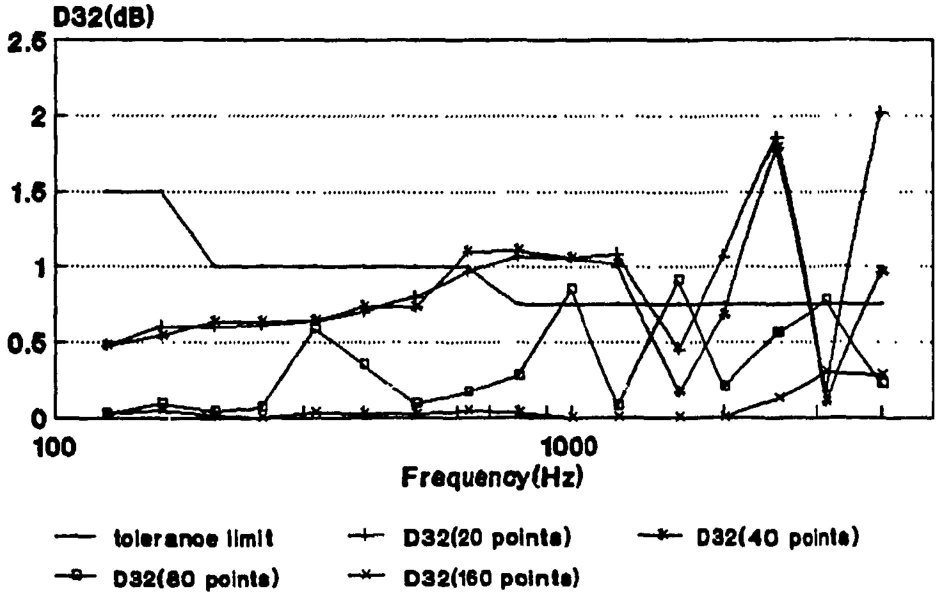


Fig.3.19: ANSI Indicator D32s at 10cm

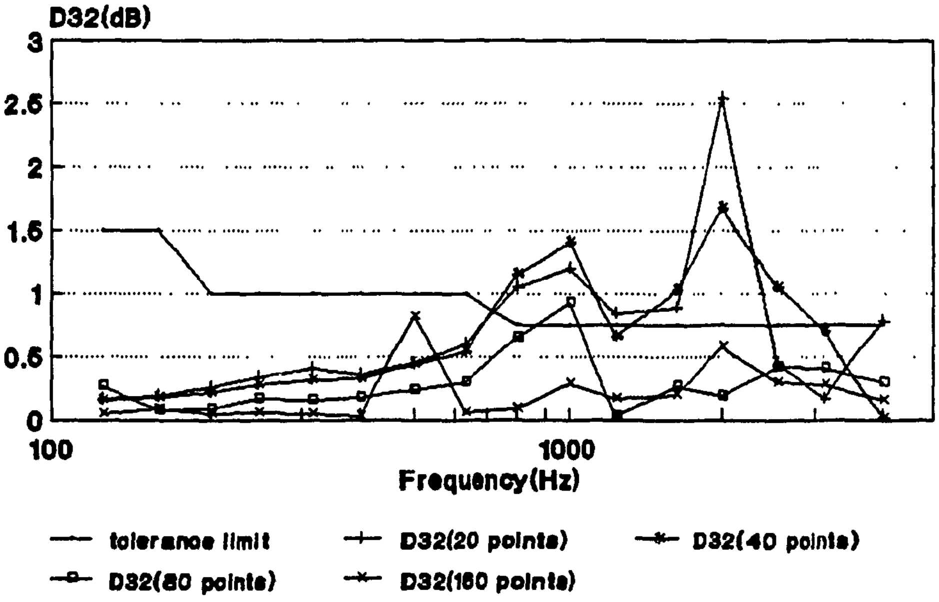


Fig.3.20: ANSI Indicator D32s at 70cm

points would not satisfy the requirement for 70cm surface at one frequency and 2 for the 10cm surface. This means 80 points are enough, provided they are appropriately distributed on the surface. Nevertheless, our results are well qualified in accordance with the ANSI D3 indicators.

3.4.4 Sound Power Accuracy Indicators D4

The D4 group of indicators are designed for evaluating the random error of the sound power measurement under the assumption that the measurement instrumentation functions correctly. They can not be evaluated from one measurement.

$$D41 = | L_w - L_w' | \qquad (3.48)$$

where

L_w and L_w' are sound power levels determined using two different measurement surfaces.

$$D42 = 10\mathrm{Log}\{[\sum_{1}^{n}(10^{0.1L_{wi}} - 10^{0.1\bar{L}_w})]/[(n - 1)10^{0.1\bar{L}_w}] \qquad (3.49)$$

where

$\bar{L}w$ is mean sound power level,
Lwi is individual sound power level.

D42 is an estimate of the normalized standard deviation of the sound power levels determined by a number of different measurement surfaces.

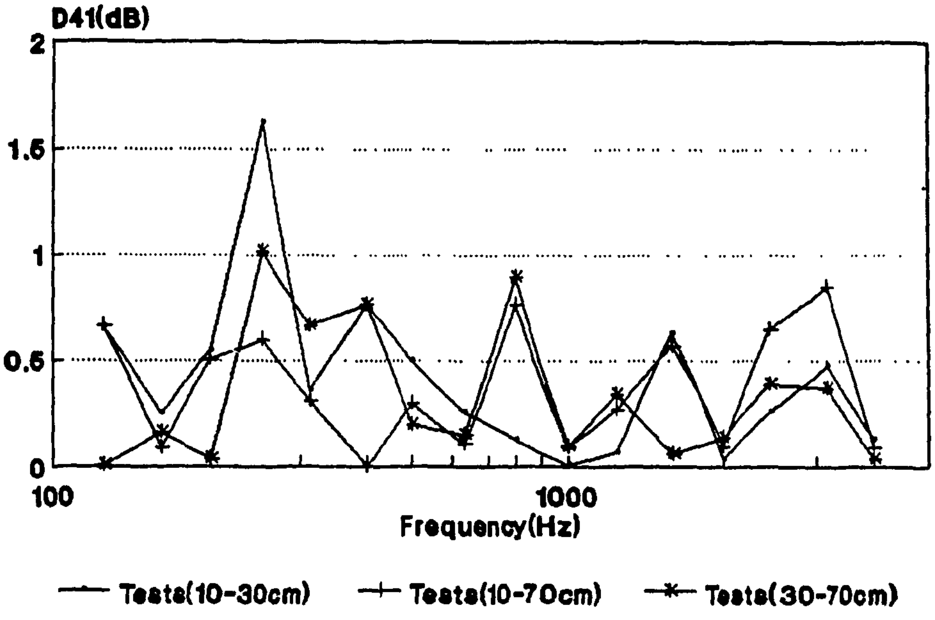


Fig.3.21: ANSI Indicator D41 for SWL

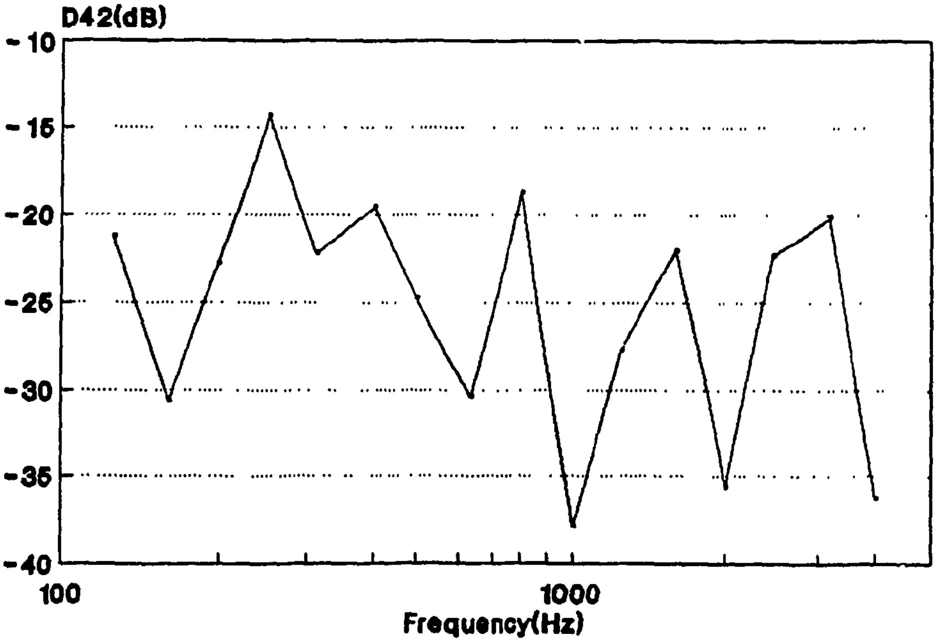


Fig.3.22: ANSI Indicator D42 for SWL

There are no criteria on D4 indicators. Instead, it gives the accuracy of the sound power measurement results.

The D41 indicators have been calculated and the results are displayed in Fig.3.21 and listed in Table A1-1.27.

Small D41 indicators can be observed on Fig.3.21. Except at 250Hz where two values exceed 1dB, other D41 values for the sound power measurements are below 1dB.

The D42 values is shown in Fig.3.22 and Table A1-1.28. Because D42 is a logarithmic value, it could be positive or negative. If D42 equals zero, the standard deviation of the sound power is identical to its mean. That is, the error is 3dB. If D42 is negative, the error is less than 3dB. The more negative, the less the error. From Fig.3.20, the random error of the sound power results are far less than 3dB as indicated in Fig.3.5.

3.4.5 Phase Indicators D5

This group of indicators is for evaluating the phase quality of the instrumentation used for the sound power measurements.

$$D51 = (L_W - L_W')/2 \tag{3.50}$$

where L_W' is the sound power level determined as for L_W but with the intensity probe oriented to measure in the opposite direction. This is known as probe reversal test. The difficulty of this, in practice, is that it is impossible to reverse the probe exactly when you repeat the sound power tests. However, with careful manipulation the probe reversal test for sound intensity can be performed at a certain position as discussed later.

$$D52 = (\bar{L}_p - \bar{L}_I)_r - (\bar{L}_p - \bar{L}_I) \qquad (3.51)$$

D52 is the difference of residual pressure-intensity index measured in a reactive field and the pressure-intensity index in the real measurement. For D52>7dB the phase mismatch error will be less than 1dB. This indicator is like the ISO criterion of Eq.3.13.

$$D53 = L_p - L_I - 10\mathrm{Log}(\rho c I_0/p_0^2) = D23 \qquad (3.52)$$

D53 is the pressure-intensity index of the sound field which is exactly the same as indicator D23. To be useful for evaluating the instrumentation, it must be used together with the residual pressure-intensity index as in D52.

D54 is for p-u method and it will not be discussed here.

3.4.6 Averaging Time Sufficiency Indicators D6

The four indicators in this group have an exact form as the four indicators in the D1 group, D61 corresponding to D13, D62 corresponding to D14, D63 corresponding to D11 and D64 corresponding to D12. This group of indicators could be eliminated because they have exactly the same function as the D1 indicators.

3.4.7 Measurement Interference Indicators D7

To evaluate the influence of the interference by the presence of the operator or the equipment during the test, D7 indicators can be used.

$$D71 = |\bar{L}_I - \bar{L}_I'| \tag{3.53}$$

$$D72 = |L_{Ii} - L_{Ii}'| \tag{3.54}$$

where

$\bar{L}_I', L_{Ii}$ are the surface intensity level and the individual intensity level at location i measured with care to avoid interference by the presence and movement of measurement equipment and/or operator during the course of testing.

$\bar{L}_I$ and $\bar{L}_{Ii}$ are surface intensity level and local intensity level at location i measured as usual.

$$D73 = 10\mathrm{Log}[|\mathrm{Max}(I_i'') - \mathrm{Min}(I_i'')|] \tag{3.55}$$

where

I_i'' is the intensity at location i while various possible interfering objects are moved in the vicinity of the measurement location and throughout the measurement environment as usual.

Although D7 indicators are easily understood, they are not practical in many measurement circumstances.

From the discussion on the ANSI indicators, we can see that most ANSI indicators require too many extra measurements and in consequence are unlikely to be used. By trading off the necessity of those indicators and their inconvenience, one can conclude that only a few indicators have practical usefulness. The functions of these useful indicators are the same as the ISO indicators. However, the intentions of the ANSI indicators are useful as a check list for research purpose.

3.5 Remarks on ISO and ANSI Draft Standards

From the analysis of the measurement results some remarks can be made upon the existing draft standards.

Besides the requirement on the test environment such as physical site, atmospheric conditions and background noise level, the following requirements in the draft standards will be discussed in this section, namely, instrumentation, measurement surface, shape of measurement surface, averaging time and the number of measuring points.

3.5.1 Instrumentation

In the ISO draft standard, the residual pressure-intensity index, the pressure calibration and the probe reversal test must be fulfilled. The difference between the two intensity levels, before and after reversal, must be less than 1.5 dB for all frequencies.

In the ANSI draft standard, the pressure calibration, the residual pressure-intensity index and the probe reversal test are also required to be undertaken before each test. The tolerance difference of intensity levels between the before and after reversal test is 1.5dB for 125-160Hz and 1dB for 200-5000Hz. Furthermore, the sound power determination on a reference source with known sound power output is added as an additional requirement where the difference between the measured sound power and the known power is capped as follows: for 125-160Hz, 3dB; for 200-630Hz, 2dB; for 800-5000Hz, 1.5dB.

The probe reversal test is performed in a well defined field and the results for present instrumentation are presented in Fig.3.23 and listed in Table A1-1.29. The ISO and ANSI allowable level for probe reversal tests are also shown. The probe reversal test can be used to investigate the phase property between two channels, but in this instance an accurate knowledge of the field is imperative. The qualification of probe reversal test should be consistent with the qualification of reactivity calibration as we have confirmed from Fig.3.6 and Fig.2.23.

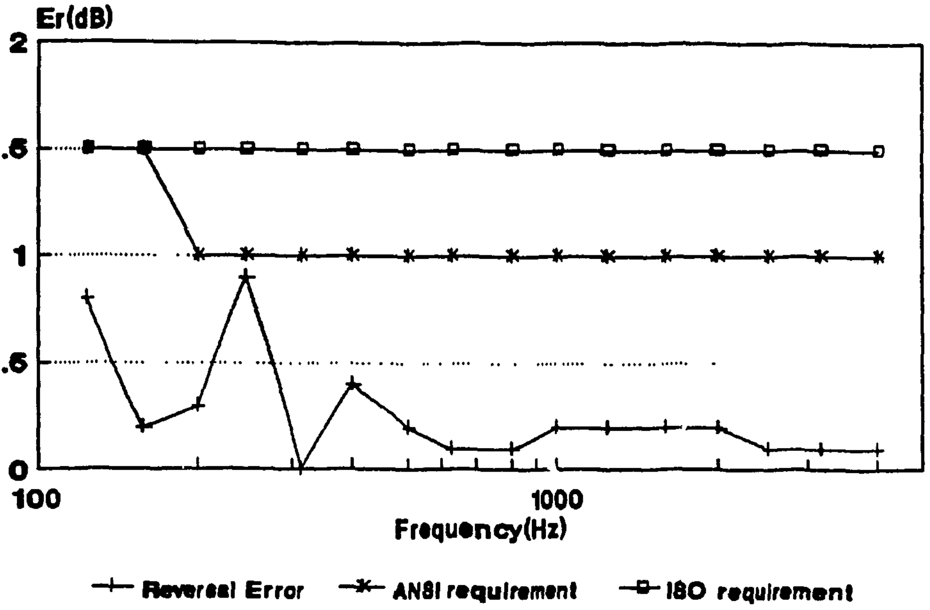


Fig.3.23: Probe Reversal Test Result

In our tests, the pressure calibration and the residual pressure-intensity index were also done. These two instrumentation requirements are imperative to control the measurement errors. They can ensure the instrumentation working well to start tests. The probe reversal test also gives confidence in the instrumentation. The reference power is an additional calibration, but this calibration will be time consuming.

3.5.2 Measurement Surface

ISO requires the measurement surface to be at least 0.5m from the source tested while ANSI does not have this restriction. Although it was found that on the 10cm surface the variation of the surface intensity is higher than the 30cm and 70cm surfaces(this means that more measuring points are needed), the sound power results(see Fig.3.1 as well as Fig.3.5) from different distance surfaces are essentially same. Therefore, the ISO minimum 0.5m distance restriction is not necessary, especially when one considers that sometimes it is impossible to have the measuring surface 0.5m from the source due to physical constraints and, in addition, the diagnostic value of the measurement will be lost. The close surface is acceptable and, as will later be shown, can lead to useful observation of surface emissions.

3.5.3 Shape of Measurement Surface

The rectangular surface was the most convenient surface in the current tests and this is one of the preferred measurement surface suggested in ISO draft standard. ANSI suggests a spherical or hemisphere-over-reflective-plane as the first choice but a near field conformal surface may also be used. A measurement surface must be convenient to define, otherwise extra error may occur, thus the rectangular surface is recommended, although in the case of circular or spherical sources, advantage can be seen in fixed distance conformal profiles.

3.5.4 Averaging Time

ISO sets a BT=400 criterion for averaging time requirement where B is the band width and T equals averaging time. This is based on a 95% confidence level of an error of 5% of the averaging time for white noise with Gaussian distribution.

ANSI requires a minimum 30 seconds for centre frequencies on or below 160Hz and 10 seconds for centre frequencies on or above 200Hz. There is no explanation for this requirement in the standard.

The BT=400 criterion was employed in the sound power tests. For the lowest frequency 125Hz, T=400/(141-112)=13.8, the instruments 16 seconds option satisfied the requirements.

3.5.5 Number of Measuring Points

ISO requires a minimum of 10 points and that Eq.(3.23) be satisfied; for the present measurements this precision class requirement appears too demanding, since for the relatively uncomplicated source used here a measurement mesh of less than 4cm was found inadequate.

ANSI requires a minimum 8 points and adequacy is determined by successively doubling the number of points until the convergence index δ for each frequency band of interest is less than the tolerance value given in Table 3.7.

The convergence index δ is defined as

$$\delta = L_{WN} - L_{W2N} \tag{3.56}$$

where

L_{WN} and L_{W2N} are the sound power levels determined by N and 2N measuring points.

Table 3.7 Tolerances in Sound Power Level

centre freq.Hz	tolerance limits dB
100-160	±1.5
200-630	±1.0
800-5000	±0.75

To test the ANSI required number of measuring points for the present sound power measurements, the test data for d=10cm and d=70cm surfaces have been carefully selected to have the measuring points as 10(2 on each individual surface of the rectangular box), 20, 40, 80, 160 and 320 evenly distributed on the surface. The corresponding convergence indices for 70cm measurement surface are calculated and listed in Table A1-1.30 to Tab.A1-1.34. The absolute value of the convergence indices for 70cm surface are plotted in Fig.3.24. The convergence indices for 10cm surface are displayed in Table A1-1.35 to Table A1-1.39 and Fig.3.25.

From Fig.3.24 and 3.25, we can notice that to achieve the accuracy in Table 3.7, about 80 points are needed for both the 10cm and 70cm surfaces. Recalling from Table A1-1.10 and A1-1.12, the engineering class requirement by ISO, that 69 points are required for the 70cm surface and 112 points are requested for 10cm surface, we still can see that the ISO requirement is more demanding than the ANSI requirement. If the measuring surface is divided evenly, then the mean of the surface intensity will determine the sound power level. Therefore, to compare half of the confidence interval of the ISO requirement and the ANSI convergence tolerance limits of the sound power level is reasonable. The ISO requirement is based on the variation of surface intensity and half of its confidence interval(see Section 3.3.2) is wider than the ANSI convergence tolerance limit.

The inconvenience of the ANSI method lies in the requirement of at least two sets of data in order to determine the convergence index; thus the ISO method is easier to follow.

It is recommended that one should start from a relatively small number of measurement points for a test depending on the source directivity and acoustic environment, then, employ the ISO criterion to evaluate the adequacy of number. If it is not adequate according to ISO requirement, then double the number of measurement points and repeat the test again. Then, reevaluate the new result by the ISO criterion and ANSI requirement and so on.

3.6 Conclusions to chapter 3

The following conclusions can be drawn:

The sound power level can be measured accurately by the

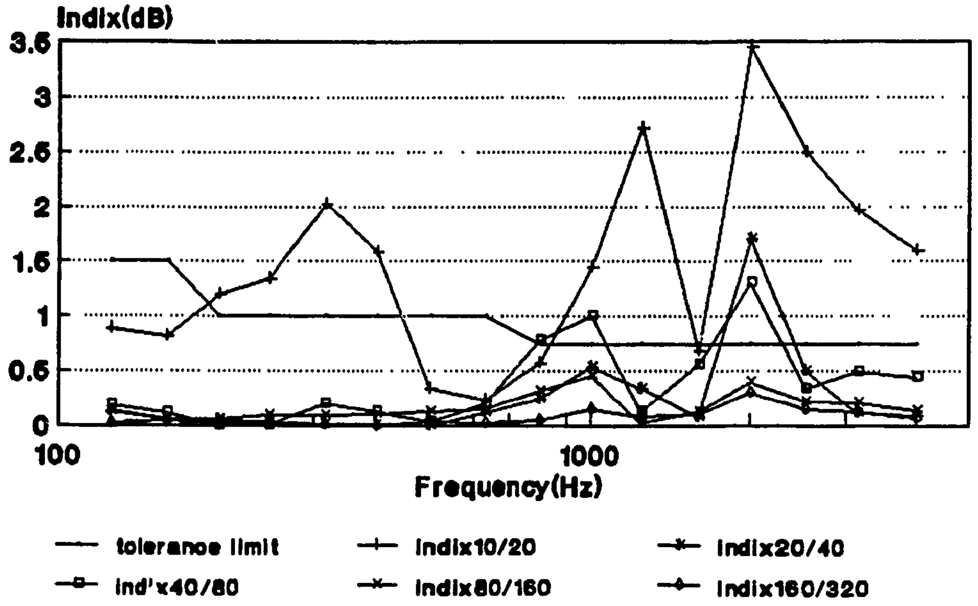


Fig.3.24: Convergence Indices at 70cm

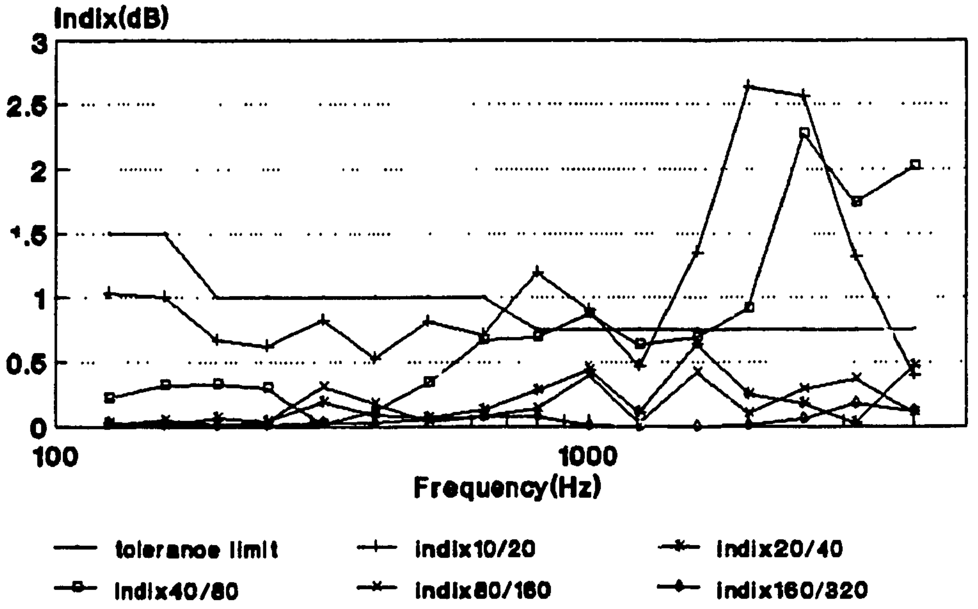


Fig.3.25: Convergence Indices at 10cm

sound intensity technique.

The phase mismatch error is more severe at low frequencies than at high frequencies due to the instrumentation performance.

No significant difference between the phase mismatch error at different distances was found for the laboratory measurement. The phase mismatch error is mainly due to the instrumentation provided that the test environment is reasonably controlled.

Among various error sources, the test random error is the most dominant. Total error is severe at the high and low frequency ranges. By carefully controlling the tests, the total error bounds can be limited to less than 1.5 dB.

The surface intensity variation at surfaces close to the source is higher than that at far surfaces. Thus, more measuring points are needed at close surfaces than for far surfaces.

The ISO indicators on sound power measurements are easier to follow than the ANSI indicators. But criterion 2 in the ISO draft standard is too demanding. The negative F2 indicators can be indications of a standing wave.

The minimum 0.5m distance between source and measurement surface in the ISO draft standard may be relaxed. The 10cm distance has been found adequate in the present work; any closer distance will invoke progressively greater finite difference technique errors.

The pressure calibration and residual pressure-intensity index are basic necessities for successfully completing a test, the probe reversal test and the reference source test are also good verifications of the instrumentation.

CHAPTER 4

ANALYSIS ON TRANSMISSION LOSS TESTS

Introduction

Compared with sound power measurements, Transmission Loss measurements by the intensity technique has few references; in consequence a standard has not yet been proposed.

To test the measurement facility and evaluate the isolation ability of a partition, three TL tests were undertaken on the same panel. The test set-up is presented in Section 2.4.3, and the theory of TL tests by the intensity technique has been discussed in Section 2.2. The first test employed a measuring surface 10cm from the panel; the second test had the measuring surface 30cm from the panel with the measuring surface still covering the whole aperture; whilst the third test had a main surface 40cm from the panel and a secondary surface covering the gap between the main surface and aperture. Schematics of the measuring surface schemes are shown in Figure 2.4.

4.1 Results

The TL results for each test are displayed in Fig.4.1 and tabulated in Table A1-2.1.

The transmission loss of this low-performance panel measured at different distances and over different measuring surfaces agree well with each other. For later detailed analysis, the surface intensity and pressure levels are also presented in Figures 4.2 and 4.3 and Table A1-2.2 and A1-2.3. From Fig.4.2 and 4.3 it can be seen that the surface intensities and pressures are similar for each test condition except at 125 Hz. This finding is due to the fact that the energy within the aperture is conserved to a great extent as

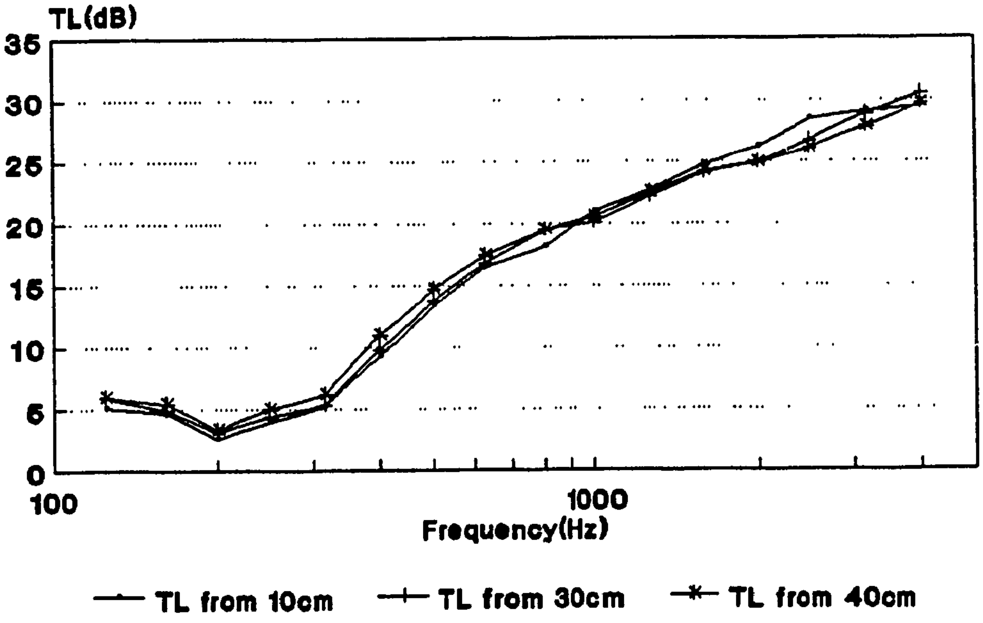


Fig.4.1: TL from Different Distance

a result of the rigid test aperture frame; naturally, had the aperture frame been absorbent, then moving progressively away from the source surface would result in progressively lower overall energy levels.

One of the advantages of using the sound intensity measurement technique is the ability to diagnose sound paths from the source panel. Fig.4.4 and Fig.4.5 present the transmitted intensities at 1000Hz across the 10cm and 30cm surface respectively. The transmitted intensities are distributed more uniformly on the 30cm surface compared to the 10cm surface; that is, the further away one measures, the more diffuse is the measurement field. On the 10cm surface, the transmitted intensities are ranged from 44dB to 68dB, while on the 30cm surface the intensities are ranged from 59dB to 68dB. The 10cm measurement surface clearly shows a poor transmission path(that is higher transmission loss) region located at the lower right hand whilst on the 30cm surface the feature is not as obvious. Similarly on the 10cm surface stronger intensities are sensed on the edges of the panel especially at the four corners; thus, it is better to sense the sound leakage paths as close to the panel surface as possible whilst the overall transmitted sound field may be measured in the more uniform field far from the panel surfaces with fewer measuring points.

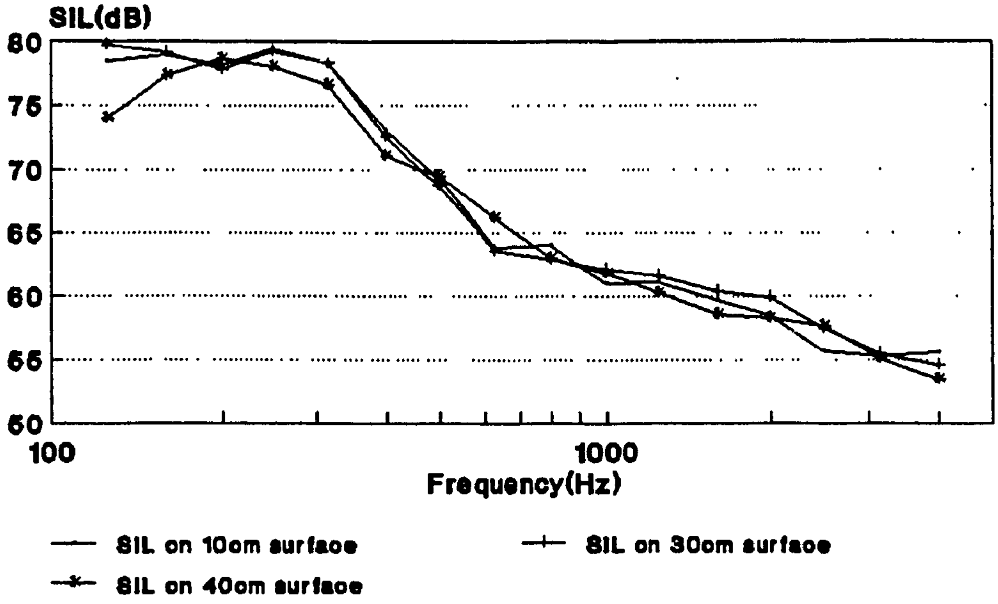


Fig.4.2: Surface Intensity Level for TL

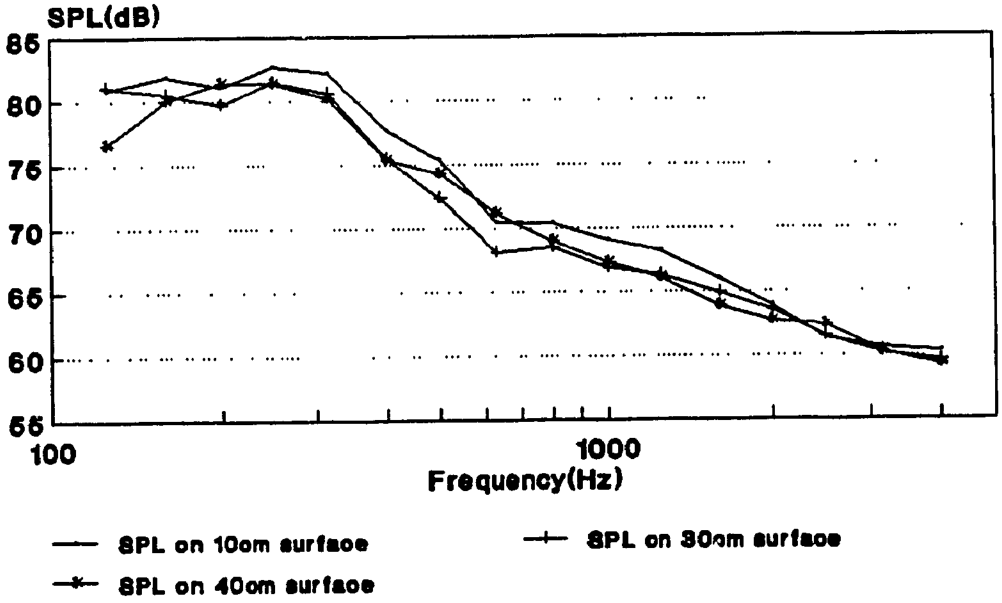


Fig.4.3: Surface Pressure Level for TL

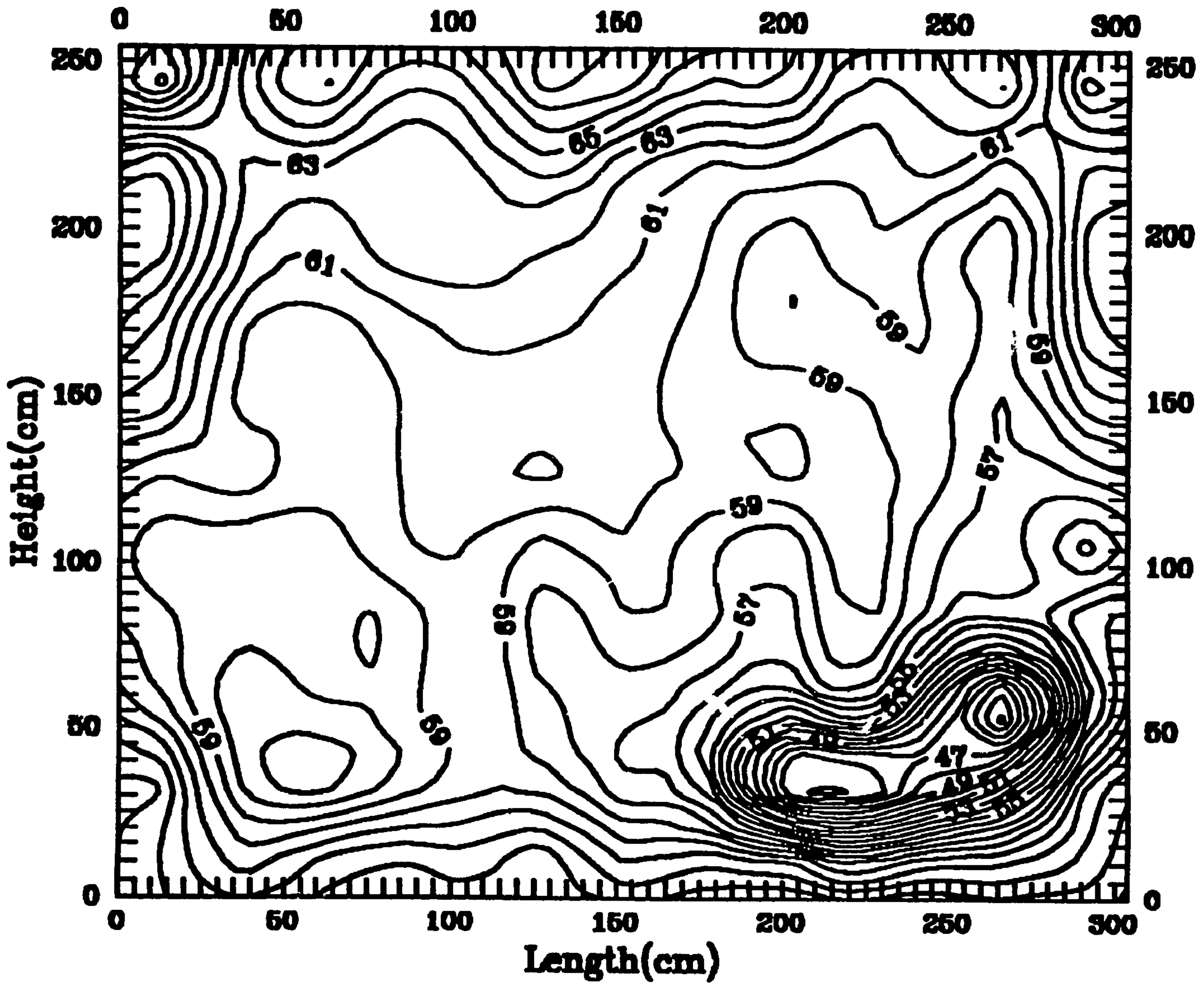


Fig.4.4 Transmitted Intensity(dB),1kHz,10cm surface

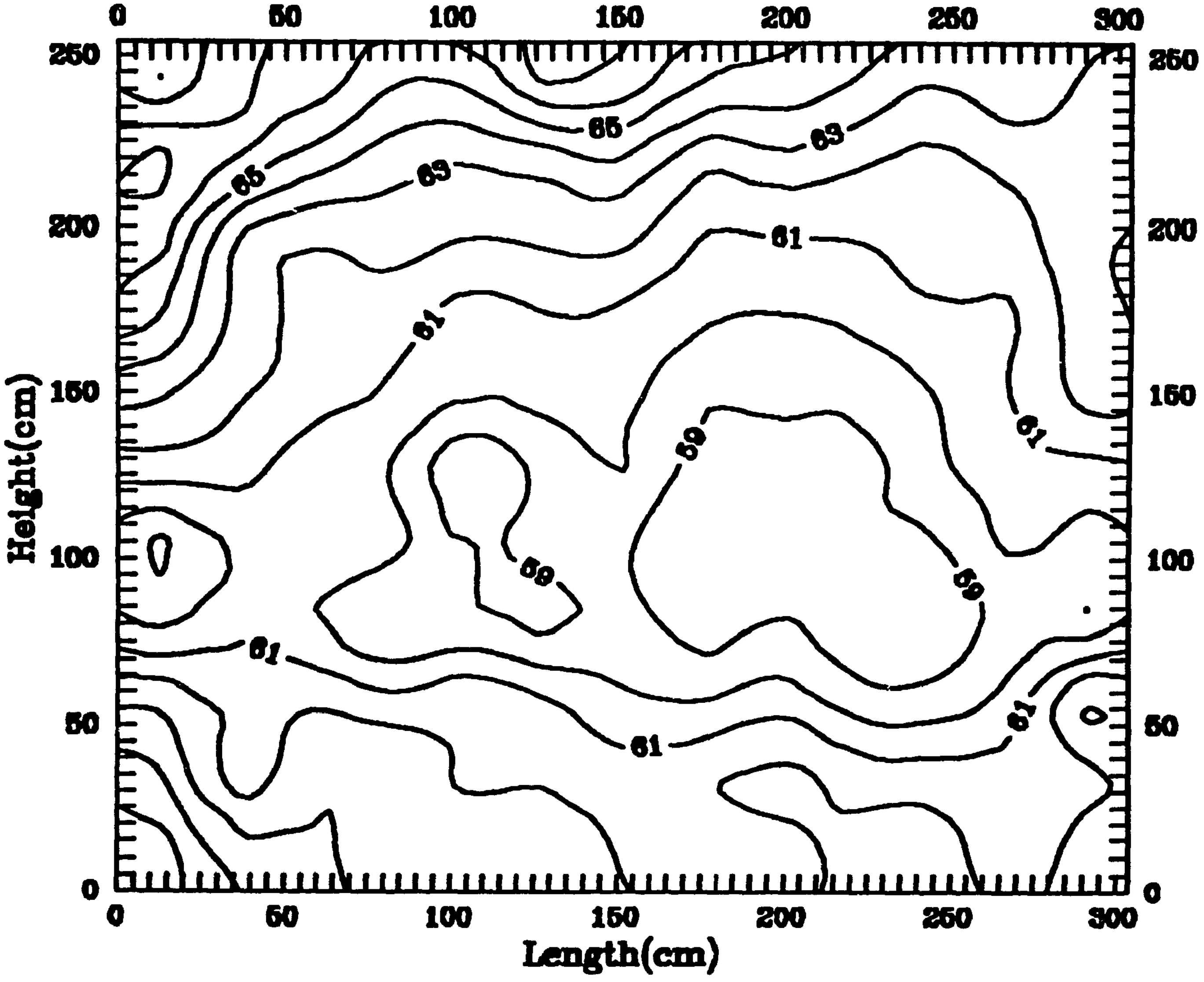


Fig.4.5 Transmitted Intensity(dB),1kHz,30cm surface

4.2 Error Analysis

With respect to error analysis the TL test has similar error potentials as the sound power measurement except that one new error source is introduced, namely, the source room non-uniform field error. Theoretically, the sound pressure level in the source room should be identical at different positions and different times; however, due to the non-perfect nature of the reverberant room, pressure is not constant and the consequent error cannot be avoided. In the sound power measurement the source level is assumed steady and the error due to this assumption will go to the test random error, whilst in the TL test the source room non-uniformity itself will form a new error source. The standard deviation of the measured sound pressure level at different times and locations is defined as the error. The sound pressures in the source room are measured by a microphone traversing the core of the room during the test. For every measuring point on the reception side, the sound pressure level is measured once; thus the total number of the measuring samples for source room pressures equals the numbers of the measuring points on the reception side. Source side errors are calculated and shown in Table 4.1. Naturally, the source room error is independent of the reception side measurement surface. Above 200Hz the source room error is found to be less than 1dB.

Table 4.1 Source Nonuniform Error for TL Test

Freq.,Hz	Er1,dB	Er2,dB	Er3,dB	Er_{max},dB
125	1.58	1.82	1.62	1.82
160	1.18	1.13	1.03	1.18
200	0.57	0.61	0.63	0.63
250	0.43	0.47	0.45	0.47
315	0.59	0.59	0.59	0.59
400	0.52	0.48	0.35	0.52
500	0.45	0.48	0.49	0.49
630	0.41	0.49	0.63	0.63
800	0.51	0.58	0.60	0.60
1000	0.38	0.36	0.38	0.38
1250	0.50	0.46	0.45	0.50
1600	0.66	0.64	0.63	0.66
2000	0.40	0.41	0.37	0.41
2500	0.23	0.24	0.19	0.24
3150	0.16	0.17	0.19	0.19
4000	0.12	0.12	0.13	0.13

The test random error, which is the repeatability standard deviation of transmission loss results from different measurement surfaces calculated by Eq.(3.6), is illustrated in Fig.4.6 and Table A1-2.4. The random error is compared with the allowable level prescribed by the traditional two-chamber method of TL test in ASTM standard E90-87[1] because currently there is no standard on the intensity technique based TL tests. Except at 2500 Hz where the error is slightly above the allowable limit, errors at all other frequencies are below the limits.

The residual pressure-intensity index of the intensity probe for TL tests is tested in the same standing wave tube as for sound power instrumentation and is displayed in Fig.4.7 and Table A1-2.5. All indices are greater than 10dB which

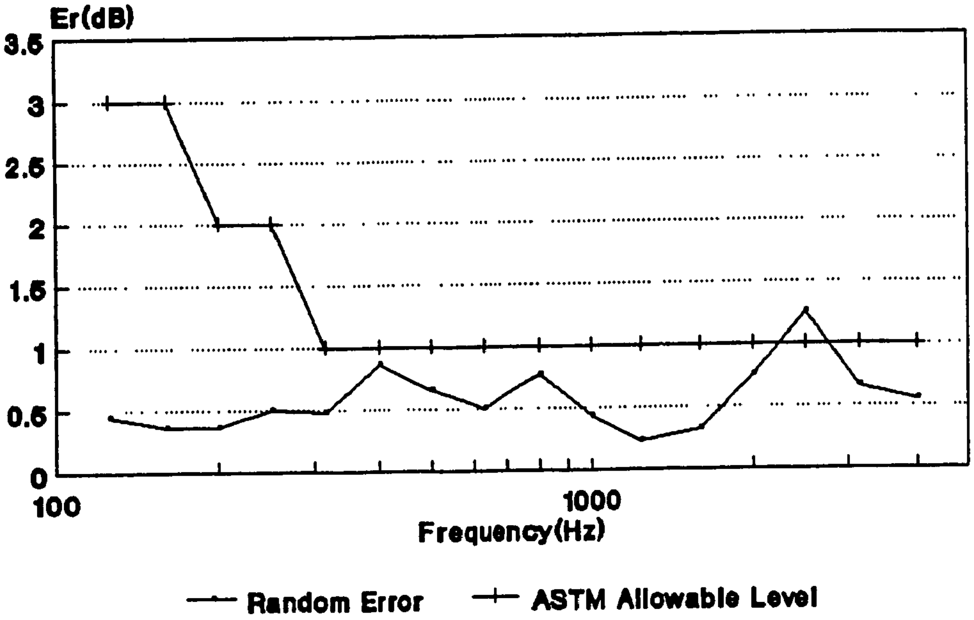


Fig.4.6: Random Error for TL Tests

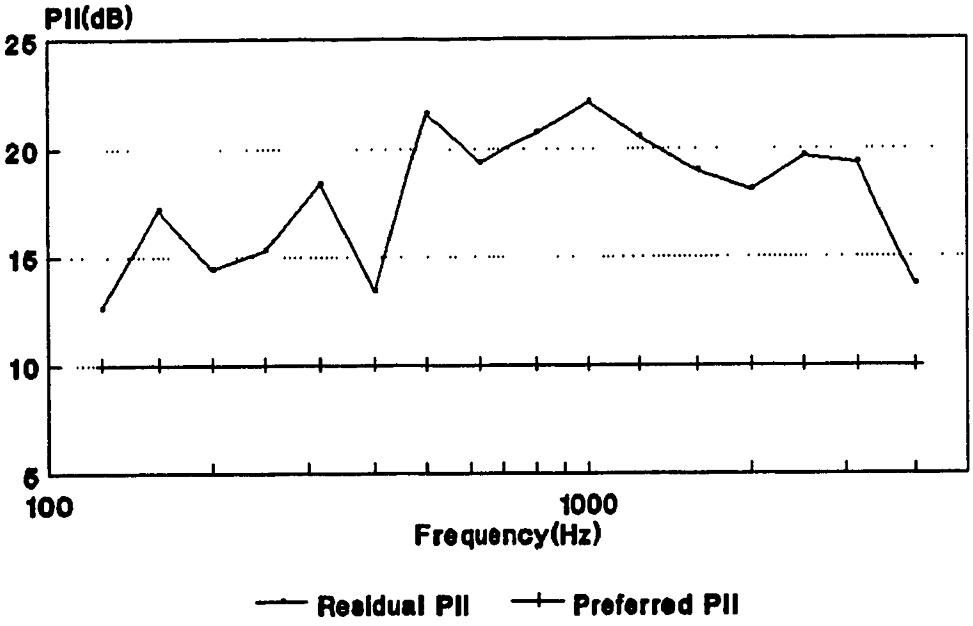


Fig.4.7: Residual PII for TL Tests

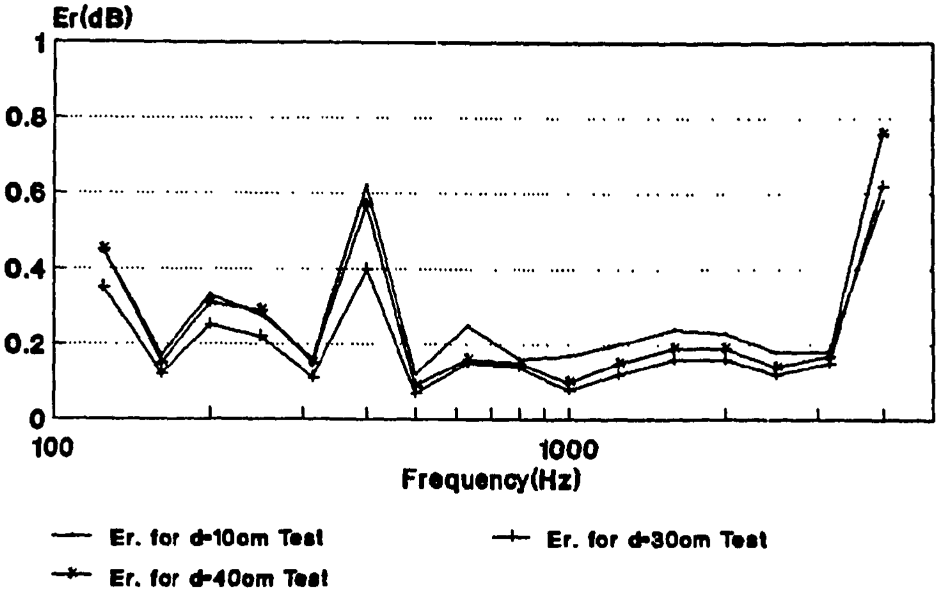


Fig.4.8: Phase Mismatch Error on TL

confirms their adequacy.

The phase mismatch error for different distance TL tests are calculated using Eq.(2.11) and shown in Fig.4.8 and Table A1-2.6. From Fig.4.8, one can observe that although the phase mismatch error on the 10cm surface is slightly higher than the 30cm surface, there is no significant different phase mismatch error for all three tests. This shows that the sound field phase property does not change much on the three surfaces, which in turn is probably the result of the anechoic reception side; had the reception side been reverberant, then further away from the test surface would yield increasingly reactive conditions.

The finite difference errors at 10cm from the panel are the same as in Table 3.2 because this error only depends on

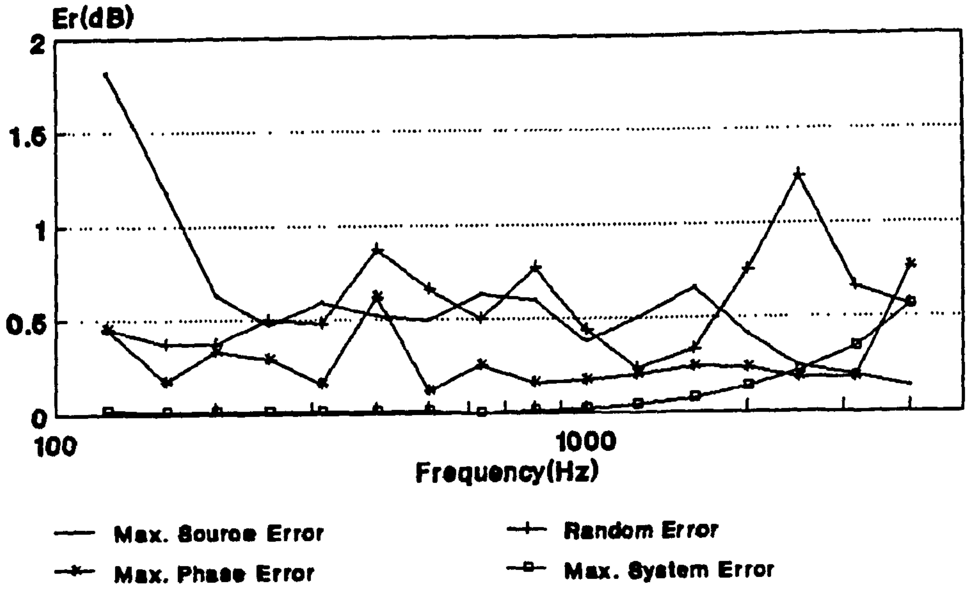


Fig.4.9: Various Errors on TL Tests

the microphone spacing and the distance from the source.

The various errors are plotted in Fig.4.9. Here, the source non-uniform error is the most dominant, especially at low frequencies. This may be explained by the relatively low modal density at low frequencies for the source reverberant chamber employed. The random error and phase mismatch errors must still however be considered.

The mean TL is calculated from Eq.(3.7) and its total error bounds are calculated from

$$Er_{tot} = |Er_{source,max}| + |Er_{phase,max}| + |Er_{random}| + |Er_{system,max}| \qquad (4.1)$$

The mean TL and the total error bounds are shown in Fig.4.10 and Table A1-2.7. Because of the introduction of the

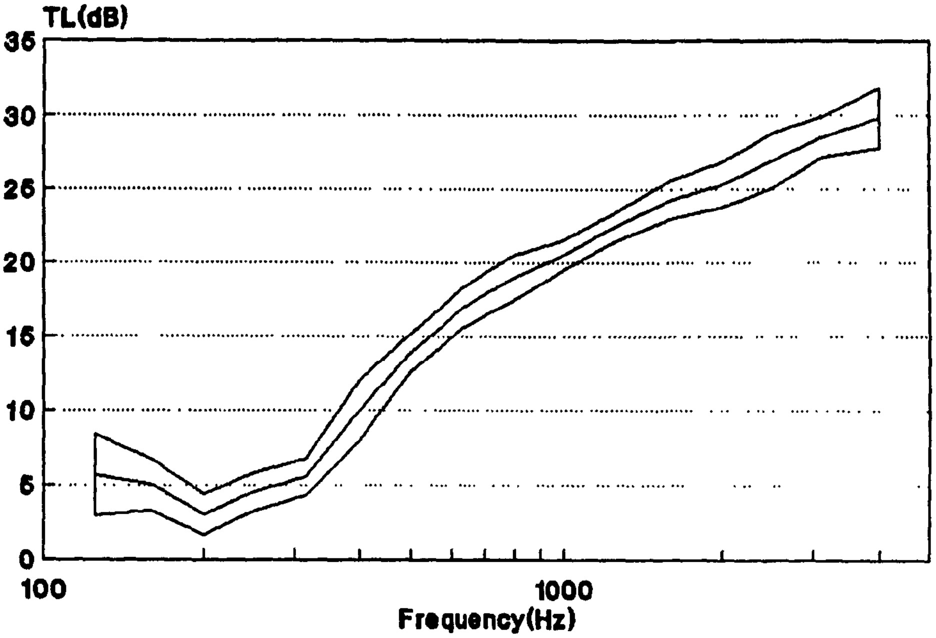


Fig.4.10: Total Error Bounds on TL Tests

source room non-uniform error, the total error bounds are increased significantly compared with power measurements. However, the total error bounds are no more than 3 dB at all frequencies.

4.3 Recommended Indicators for TL Test

The purpose of designing indicators for the measurements is to qualify the tests so that the errors incurred are within acceptable limits.

In TL test by the intensity technique there are four kinds of error, namely, source error, random error, phase mismatch error and system error.

Because the system error is inherent in the technique and cannot be avoided, there is nothing one can do to eliminate it. However, as we have seen, this error is fairly small compared with the other three kinds provided that the distance from the source is much greater than the microphone spacing, say, distance at least twice microphone spacing.

Thus, the indicators recommended here are for minimizing the source error, random error and phase mismatch error.

4.3.1 Source Room Non-uniformity Indicator T1

This indicator is for monitoring the uniformity of the sound pressure level in the reverberant room.

The traditional two-reverberant-chamber method for TL tests has no requirement on the standard deviation of the sound pressure level in the reverberation rooms. However, the ISO 3741[64] standard on sound power determination in reverberation rooms sets a criterion to the room in terms of standard deviation of band pressure level. It is reasonable to use a similar criterion to qualify the source room to be used in TL tests by the intensity technique.

The indicator T1 can be defined as the standard deviation of the pressure level in the source room written as

$$T1 = \{ \Sigma(Lpi - \overline{Lp}) \;/\; (N - 1) \}^{1/2} \qquad (4.2)$$

where

$\overline{Lp}$ is the arithmetic mean of pressure level;
Lpi is the individual pressure level;

N is the total sample number.

Naturally, additional constraints must be imposed to ensure adequate distribution of measuring points.

Since the reverberation room for TL tests has the test panel located on one wall and usually the panel has an absorption coefficient greater than the fixed surface(an absorption coefficient 0.06 is the requirement for the reverberant chamber surfaces by ISO 3741), it is most likely that the reverberation room for TL tests is less diffuse than the room required for sound power measurements. Therefore, the criterion can be modified to be less restrictive. For example, a one half decibel more on the ISO 3741 maximum allowable standard deviation of sound pressure level would qualify the present source room.

The proposed criterion, S, is listed in Table 4.2.

The criterion can be written as

$$T1 < S \tag{4.3}$$

Table 4.2 Maximum Allowable Standard Deviation of SPL in Reverberation Room for TL Tests

Freq.,Hz	S,dB
125 - 160	2.0
200 - 630	1.5
800 - 2500	1.0
3150 - 4000	1.5

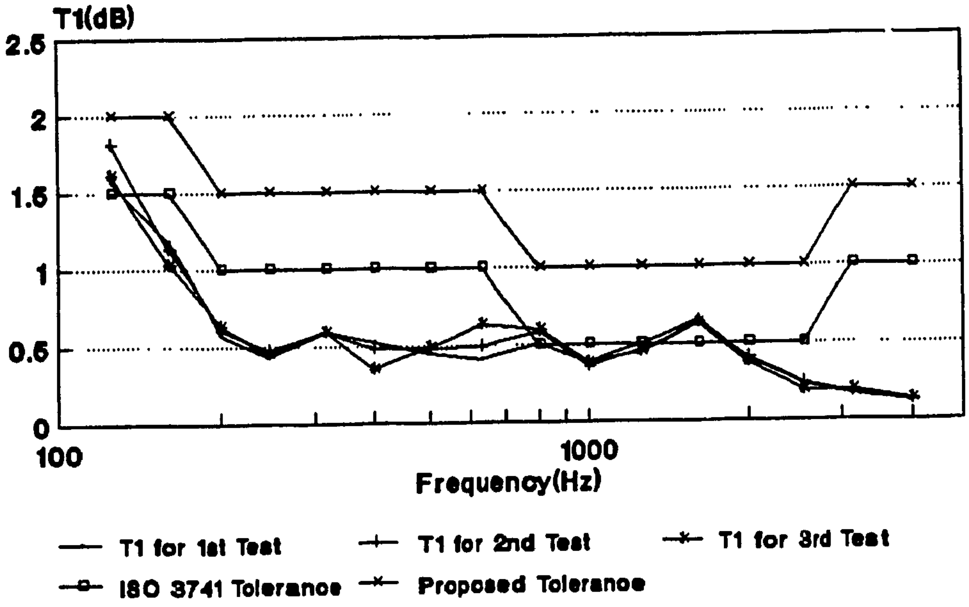


Fig.4.11: Indicator T1 for TL Tests

The source room non-uniformity error, the standard deviation of pressure level T1 which is listed in Table 4.1, for each test along with the ISO 3741 requirement and the proposed criterion are displayed in Fig.4.11.

4.3.2 Phase Indicator T2

To control the phase mismatch error, the measurement surface intensity and pressure level must be considered together with the residual pressure intensity index.

An indicator T2 which has an exact form to the F2 indicator in the ISO sound power measurement draft standard, can serve this purpose.

$$T2 = \bar{L}_p - \bar{L}_{|in|} \qquad (4.4)$$

where

$\bar{L}_p$ is surface pressure level;
$\bar{L}_{|in|}$ is unsigned surface intensity level.

The Dynamic Capability Index, Ld, in the ISO draft standard for sound power measurement is the value that is 10dB less than the residual pressure-intensity index. Employing the ISO criterion F2<Ld to test the current TL results. Table A1-2.8 lists the Ld=PII-10 values and T2 values for each TL test. They are also shown in Fig.4.12.

From Fig.4.12, we can see that none of the test is qualified by the criterion for sound power measurement. However, even though the results are not qualified according to the ISO criterion, their phase mismatch error are still

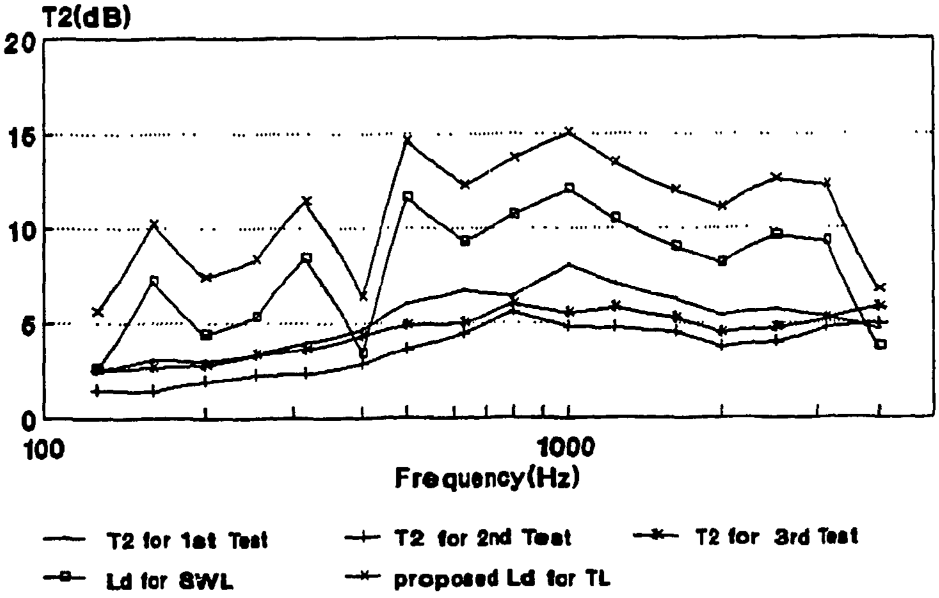


Fig.4.12: Indicator T2 for TL Tests

less than 1 dB. This suggests that we might redefine the dynamic capability index for TL test.

The Dynamic Capability Index, Ld_{TL}, for TL test could be defined as:

$$Ld_{TL} = PII - 7 \tag{4.5}$$

where

PII is the residual pressure-intensity index.

From Eq.(2.11) we can derive that if $T2<Ld_{TL}$ the phase mismatch error is still less than 1dB. This is also confirmed in Fig.4.12 and 4.7.

Therefore, a criterion can be established as

$$T2 < Ld_{TL} \tag{4.6}$$

4.3.3 Random Error Control Indicator T3

To reduce the random error one can increase the sample averaging time and/or sample numbers. As the sound transmitted through the panel is usually steady, increasing the sample numbers will normally increase the accuracy of the average transmitted intensity on the measurement surface and consequently increase the accuracy of the transmission loss evaluation.

The normalized surface intensity standard deviation is a good indicator for the evaluation of the uniformity of the intensity on the surface as the indicator F4 used in ISO sound power measurement draft standard.

The same criterion $N>C\cdot(F4)^2$ as used in sound power measurement can be employed to evaluate the TL results. Consider the sound power measurement criterion to test the adequacy of the TL results. Table A1-2.9 and Fig.4.13 displays the F4 values on each measurement surface. From Fig.4.13, it seen that the 30cm surface is the most uniform for the transmitted intensity, while on the 40cm surface the deviation is consistently higher than on the 30cm surface and at high frequencies the deviation on the 10cm surface is much higher than that on the 30cm surface.

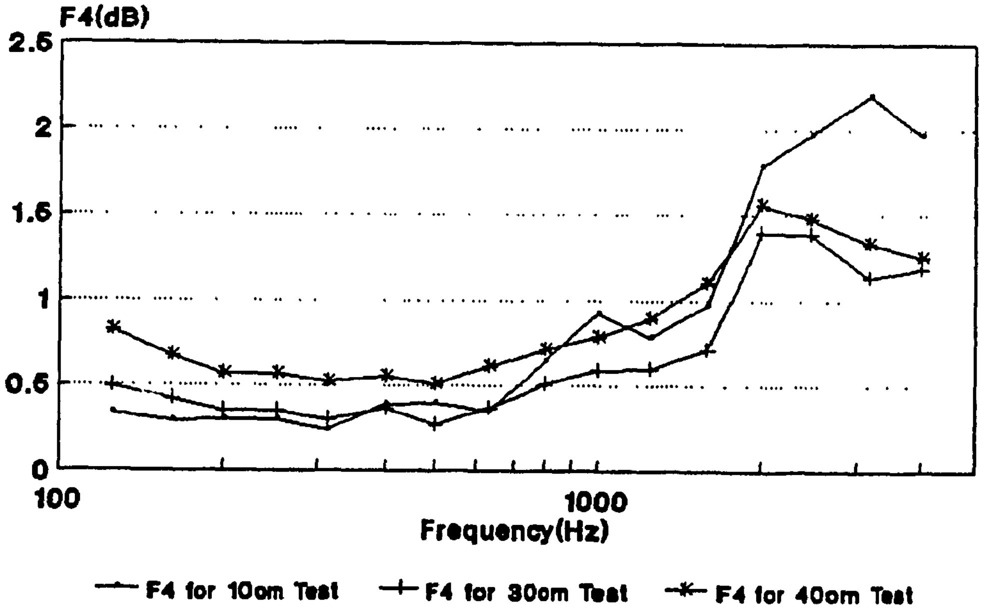


Fig.4.13: Normalized SSD for TL Tests

The number of points used and the number of points required by the ISO sound power measurement criterion, both precision and engineering level, on each measurement surface are shown in Table A1-2.10 to Table A1-2.12 and Fig.4.14 to Fig.4.16. From the figures one can see that no test qualifies to the precision level requirement for sound power measurement. This is because the transmitted sound fields found in the TL tests are more complicated than the source used for sound power measurements. However, all three tests are qualified by the engineering level requirement, although on the 10cm surface 143 points just satisfies. 143 points on a 3.04 by 2.54 surface implies a relative small surface area per point and the accuracy (total error less than 3dB) is acceptable, it seems not to be worth increasing the number of points tremendously to meet the requirement of the precision level. Actually, if we satisfy the engineering level requirement, the maximum random error, with 95% confidence limits, will be less than 2.5dB for 125 and 160 Hz bands, 1.5dB for 200 to 630 Hz bands and 1dB for 800 to 4000Hz bands. Thus, considering that the requirements by the traditional two-chamber method is 3dB at 125Hz to 160Hz bands, 2dB for 200 to 250Hz bands and 1dB for 315 to 4000Hz, the engineering class allowable levels for sound power measurement are one half dB less than the traditional TL requirement for 125 to 250Hz bands and one half dB more for 315 to 630Hz bands. Therefore, the engineering level requirement for sound power measurement could be used as the criterion for TL tests.

The criterion is stated here as

$$N > C\cdot(T3)^2 \qquad (4.7)$$

where

C is 8 for 125-160Hz, 15 for 200-630Hz and 28 for 800-4000Hz;
N is total number of measurement points;
T3 is normalized standard deviation of intensity.

$$T3 = (1/\bar{I})\{\Sigma(I_i - \bar{I})^2/(N - 1)\}^{1/2} \qquad (4.8)$$

where

$\bar{I}$ is the surface average intensity;
I_i is the individual intensity.

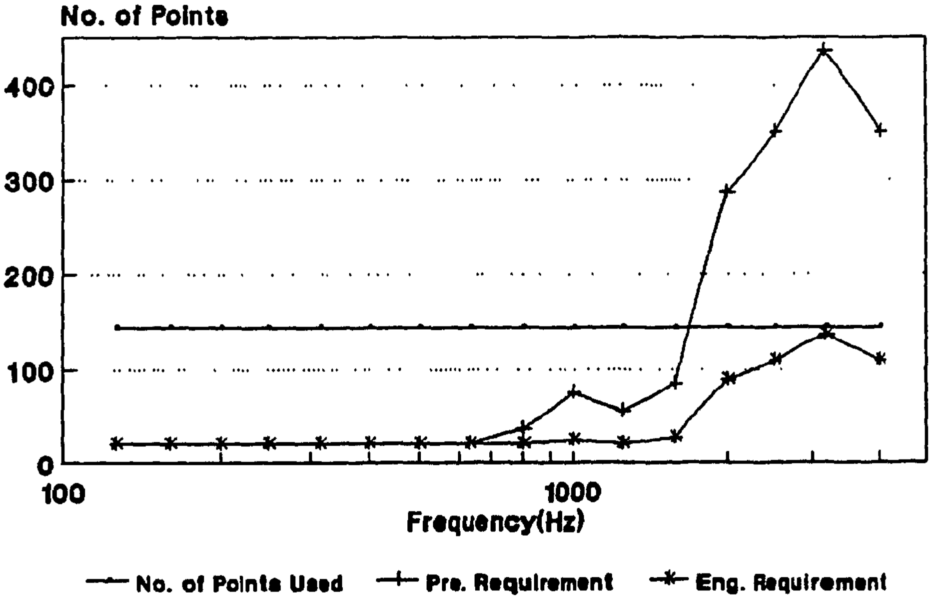


Fig.4.14: Adequacy of 10cm Array for TL

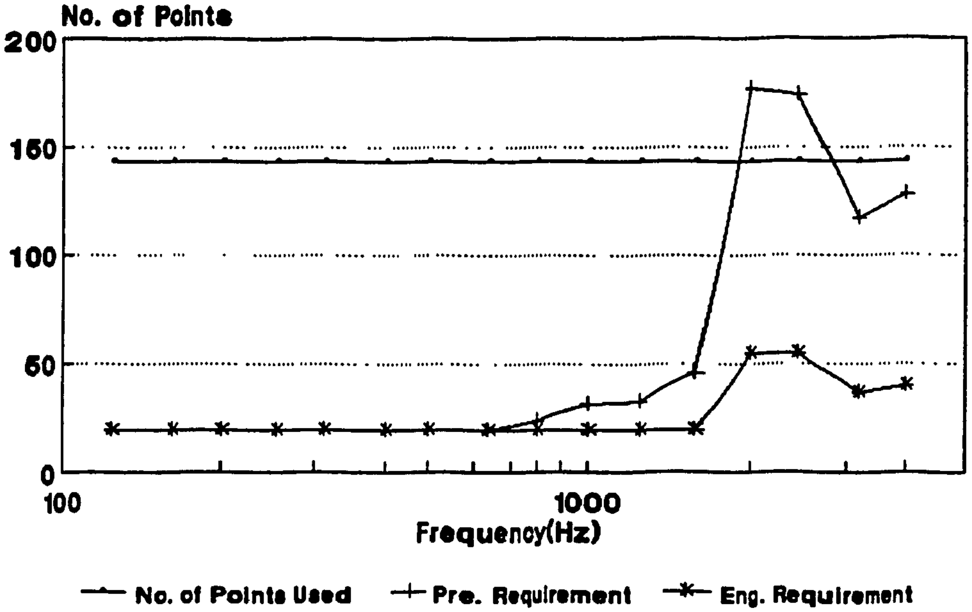


Fig.4.15: Adequacy of 30cm Array for TL

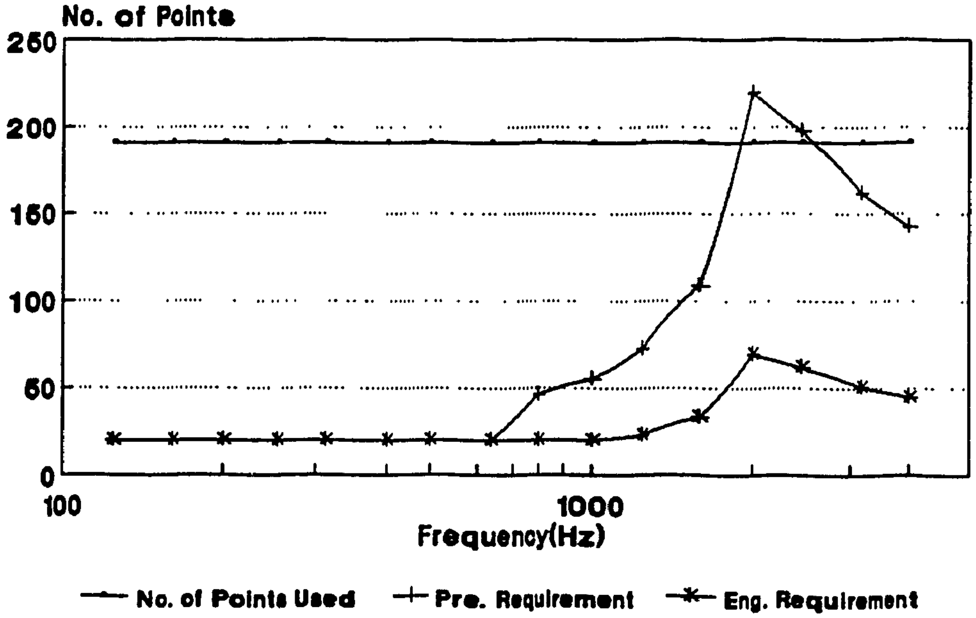


Fig.4.16: Adequacy of 40cm Array for TL

4.4 Guidelines for Laboratory Based TL Tests

To have acceptable laboratory based TL measurement results, some guidelines based on the experience acquired during this work can be made.

4.4.1 Test Rooms

The reverberation room with the test panel located on one wall ideally should meet the needs of the ASTM E90-87 standard[1], namely, "Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions". While for the evaluation of the measurements, indicator T1(Eq.4.2) can be used to ensure the adequacy of the room.

The reception room may be any room adjacent to the source room. However, it is preferable to line the reception room with absorbent material.

The aperture between the two rooms which functions as a holder of the test panel must be very rigid and the gaps between the aperture and the panel must be sealed well to exclude flanking.

Background noise in the reception room must be at least 10dB below the transmitted sound levels.

4.4.2 Instrumentation

Because the instrumentation for TL tests are the same as for sound power measurements, the requirements discussed in 3.5.1 are also valid for TL test purpose.

4.4.3 Measurement Surface

Because most panels have a flat rectangular shape, a parallel rectangular plane is the best measurement surface to measure the normal transmitted intensity.

Under the assumption that the aperture is very rigid and thus does not absorb acoustic energy, the measurement surface should be chosen within the aperture frame and cover the whole aperture. This forms a rectangular plane. If the surface only covers the panel and the probe is not very close to the panel some sound energy may be lost through the side path between the surface and the panel; thus a peripheral side surface measurement is also necessary. If the surface is chosen to be outside the aperture frame, then again a secondary side surface must be added to the main surface. This will make the measurement inconvenient and some error may be caused.

4.4.4 Measurement Distance

A close-to-panel surface gives more detailed information of sound transmission whilst further away from the panel surface yields a more uniform distribution of the transmitted intensity; this means more points are needed on the close surface. However, provided one can satisfy the required number, a close surface measurement can generate a more useful result for diagnostic purpose. A surface about 10cm from the panel has been found to be appropriate for TL tests.

4.4.5 Measuring Time

By controlling the number of measuring points to minimize the random error, the measuring time can be fixed using the BT=400 principle as for sound power measurements. That is, for 125Hz as the lowest band frequency, 16 seconds on the analyzer option is appropriate. However, since the tests here are fully automated, higher averaging time can be tolerated.

4.4.6 Number of Measuring Points

According to the experience acquired during the previous analysis and regarding the needs for evaluating the detailed sound transmission paths, many points are needed for TL tests. Actually, the number of measuring points depends on the property of the panel. If the panel responds uniformly across its surface then fewer points are needed; the T3 indicator must be evaluated after the test. For measurement convenience, the number of measuring points should be evenly distributed, one point for each segment. The segment preferably has a square shape.

4.5 Conclusions to chapter 4

The following conclusions can be made based on the foregoing discussions:

TL can be measured well by sound intensity technique.

TL test incorporates an additional source room non-uniform error, which is likely to be significant at low frequencies.

Among the different error sources, the source room non-uniform error and test random error are most important, however, provided that the source room requirements of ASTM E90-87 are met, the source room error should be acceptable.

The phase mismatch error at different distance surface has no significant difference due to the configuration of the aperture.

The complicated sound field conditions on the reception side of the panel suggests the need to relax the dynamic capability index for TL tests. The dynamic capability index can be defined as the residual pressure-intensity index minus 7 dB rather than minus 10 dB the resulting phase mismatch error would still be less than 1 dB.

The most uniform intensity was found on the surface within the test aperture but farthest from the test panel and under this condition fewer measuring points are needed to achieve a given accuracy. However, detailed transmission path information will be lost the further one moves from the panel surface.

The close-to-panel surface(about 10cm from the panel) has been found appropriate for TL tests.

CHAPTER 5

ANALYSIS OF 3-D MEASUREMENTS

Introduction

To complete the facility software development, a three dimensional sound intensity assessment is now developed.

The previous tests were done using a one dimensional intensity probe which senses sound intensity along one axis, e.g., the intensity normal to the measurement surface. If one wants to determine the intensity vectors or source directivity pattern then a three dimensional intensity probe must be employed. The commissioning of a three dimensional(3-D) intensity measurement system for sound power and transmission loss measurements will be discussed in this chapter. Typical measurement results will also be presented and discussed.

5.1 Sound Power Measurements with the 3-D Probe

For measuring sound power, one pair of intensity microphones directing to the normal of the enclosing measurement surface is sufficient. However, the sound source property can be investigated in more detail by a 3-D probe. The small rectangular source with dimension 345x235x200 mm used for 1-D measurements was taken as the test source. Three tests with the distance 10, 30, and 70cm from the source to the measurement surface were repeated. The sound source and the measurement surface arrangement described in Section 2.4.4 and shown in Fig.2.4 are employed for the current 3-D sound power measurements. The instrumentation used is described in Section 2.4.1 and 2.4.2. Each enclosing measurement surface is formed by five rectangular measurement planes connected to each other as illustrated in Figure 2.4. There are 36(6 by 6) measuring points on each rectangular plane and thus 180 measuring points on each measurement surface.

5.1.1 Measurement Results

At each measuring point, the pressure and three components of the intensity were measured. The sound power was calculated from the normal components of the intensity to the measurement surfaces from Eq.(3.1). The sound power level measured at different surfaces are shown in Fig.5.1 and listed in Table A1-3.1. One can see that the results agree well with each other.

For later analysis, the average normal surface intensity levels and pressure levels are also calculated from equations 3.2 to 3.5 and measured by the pair of intensity microphones located normal to the measurement surfaces. The intensity and pressure levels are illustrated in Fig.5.2, 5.3 and Tables

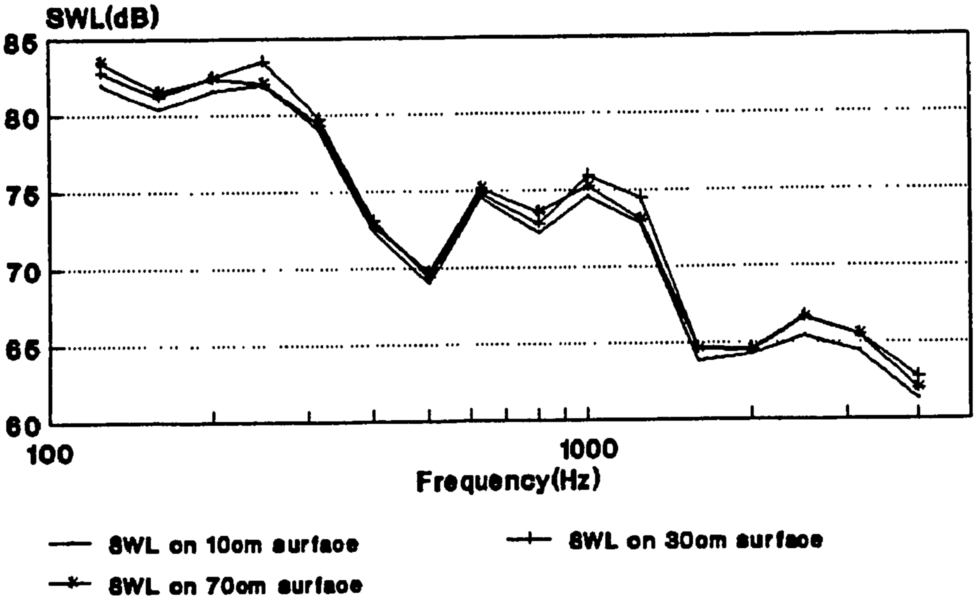


Fig.5.1: SWL from 3-D Measurements

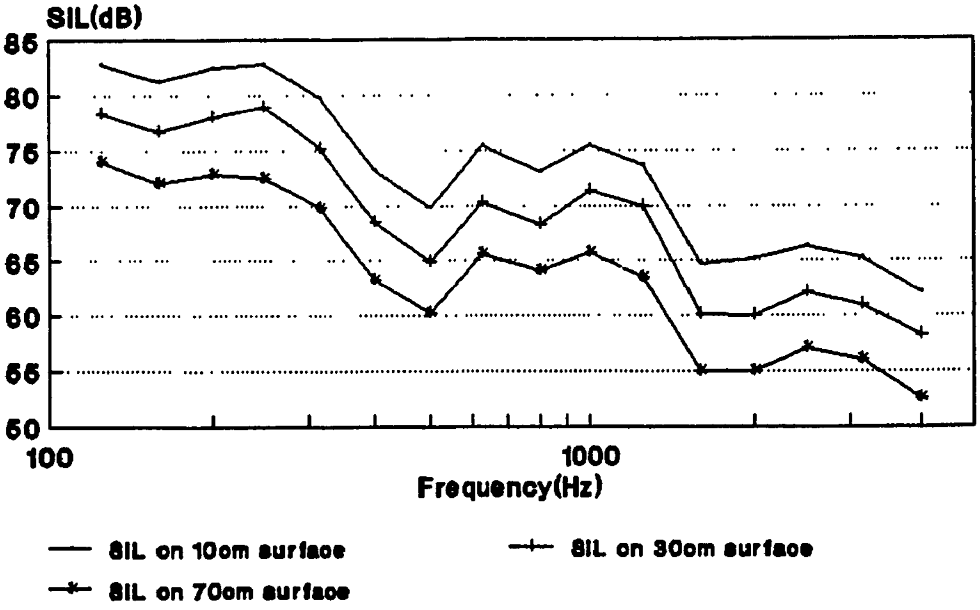


Fig.5.2: Average SIL from 3-D Tests

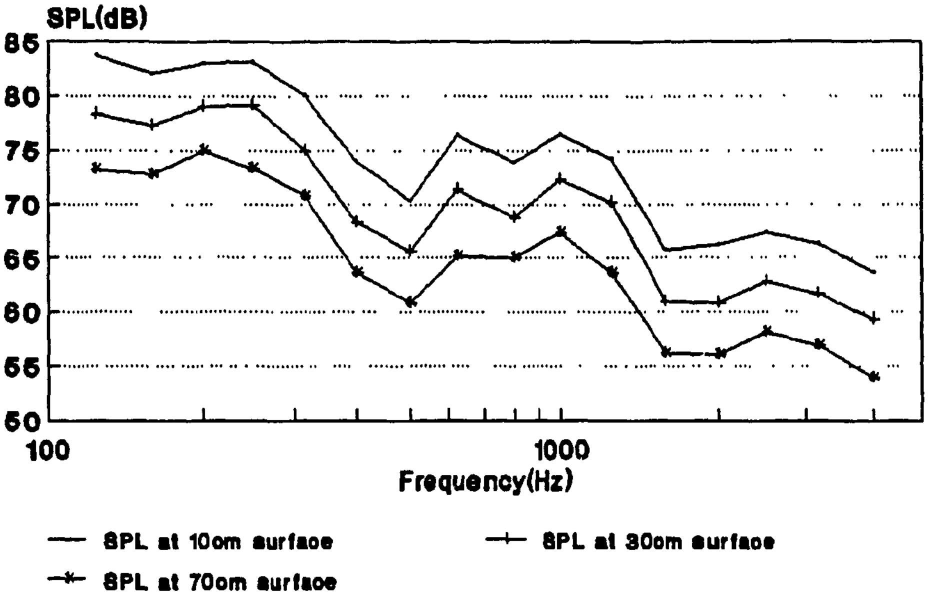


Fig.5.3: SPL for 3-D Sound Power Tests

A1-3.2 and A1-3.3.

The results for surface average intensity and pressure levels are normal, that is, they decrease as the surface moves further away from the source. The intensity levels are quite close to the pressure levels which means the sound fields approach free field conditions.

For monitoring the sound source to ensure the source levels are steady for all three measurements, pressures at a fixed reference point were measured before each tests using 16 seconds linear averaging time from microphone Z1. The pressure levels measured are listed in Table 5.1. The standard deviations of these monitored levels are calculated from Eq.(3.6) and listed in Table A1-3.4 and displayed in Fig.5.4.

From Fig.5.4 one can find that the variation of the source is small(all are less than 0.8dB). Thus, the sound source for 3-D sound power measurements were quite steady and the three measurements were made for the same source.

Table 5.1 Monitored SPL for 3-D SWL Tests

Freq.Hz	Test1,dB	Test2,dB	Test3,dB
125	80.1	80.7	79.4
160	79.0	79.5	80.1
200	80.9	81.1	81.6
250	80.0	80.1	80.0
315	75.4	75.4	75.9
400	65.0	65.3	65.6
500	64.9	65.1	66.2
630	76.8	77.4	77.5
800	74.3	74.0	73.9
1000	71.5	71.5	72.0
1250	69.1	69.2	69.5
1600	65.4	65.7	65.6
2000	60.3	60.2	59.9
2500	64.5	64.6	64.1
3150	66.0	66.1	66.0
4000	63.6	63.5	63.9

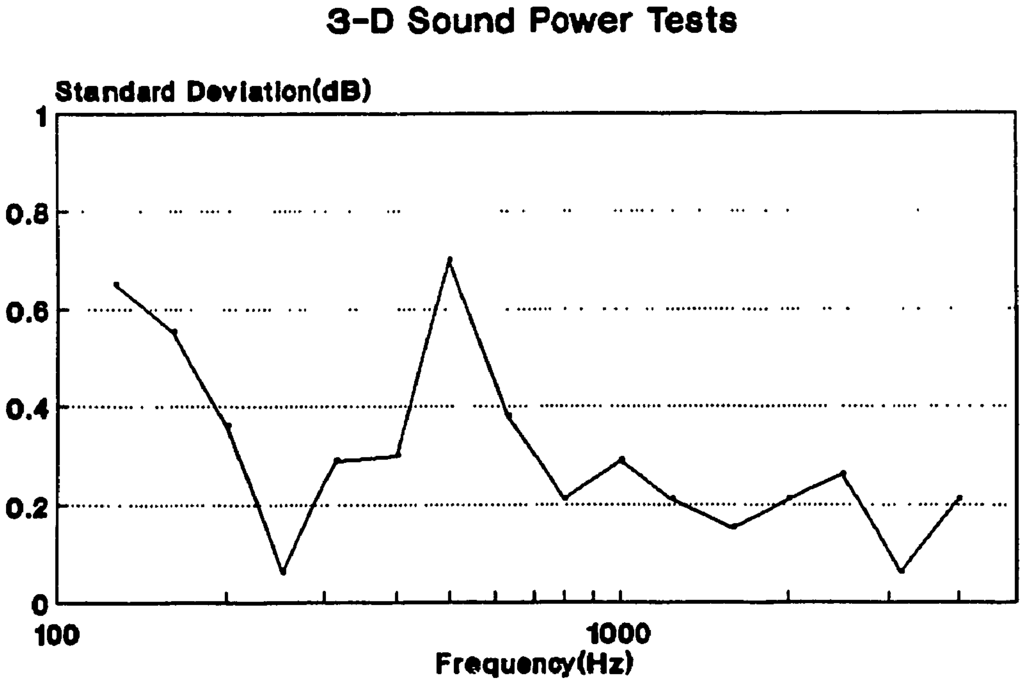


Fig.5.4: Monitored Source Variation

5.1.2 Error Analysis

The three kinds of errors in the sound power measurements will be briefly discussed here.

The finite difference error has the largest values on the 10cm surface and the errors are the same as that presented in Table 3.2 because the spacing for the 3-D probe is also 12mm.

The random errors are calculated from Eq.(3.6) and are presented in Table A1-3.5 and Fig.5.5. The precision and engineering class allowable uncertainties set by ISO and ANSI draft standards are also presented. The measurements are qualified by the ISO and ANSI draft standards.

The residual pressure-intensity indices for the 3-D intensity probe are displayed in Fig.5.6 and Table A1-3.6.

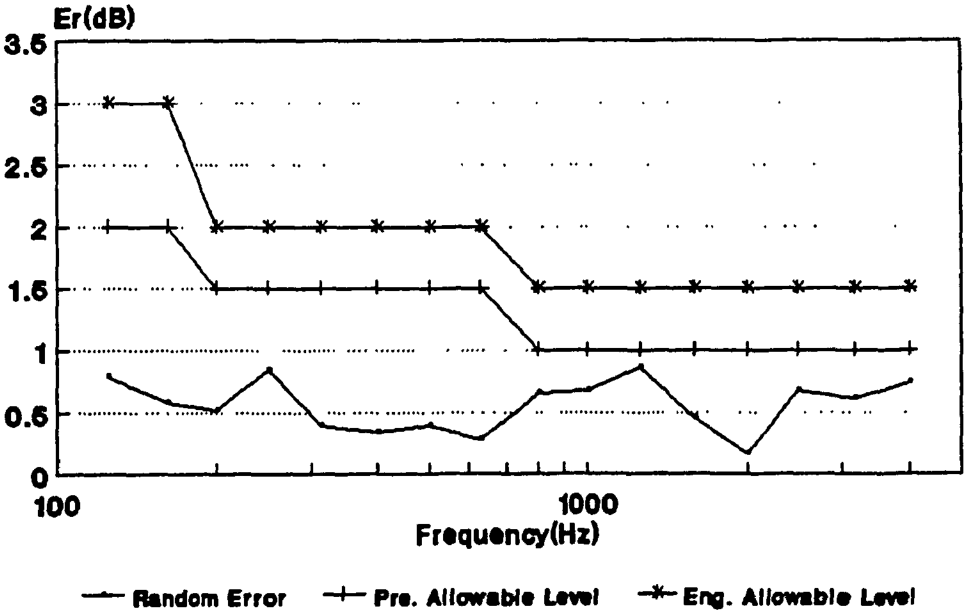


Fig.5.5 Random Error on 3-D SWL Tests

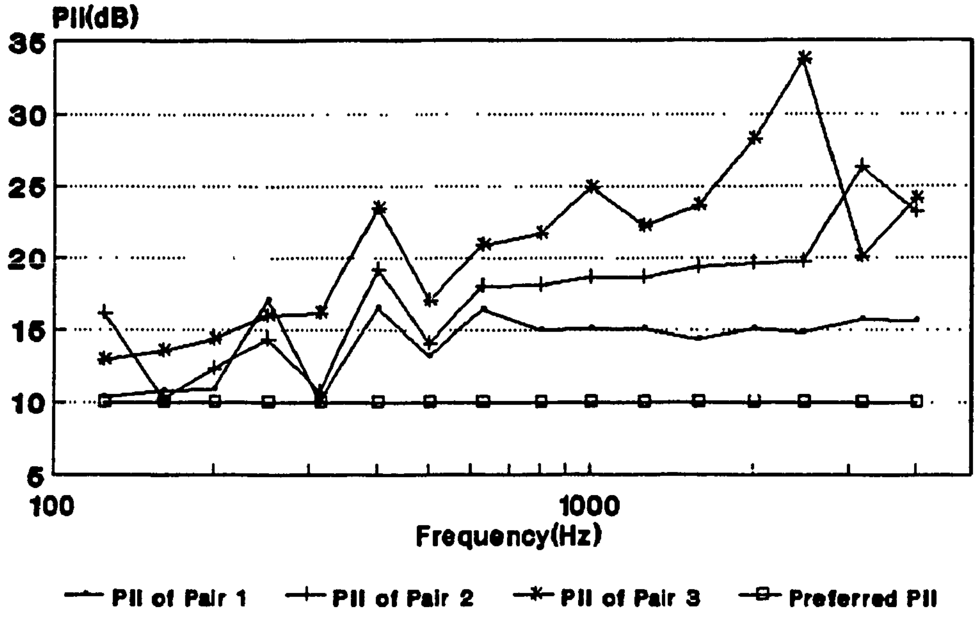


Fig.5.6 Instrument PII for 3-D SWL Tests

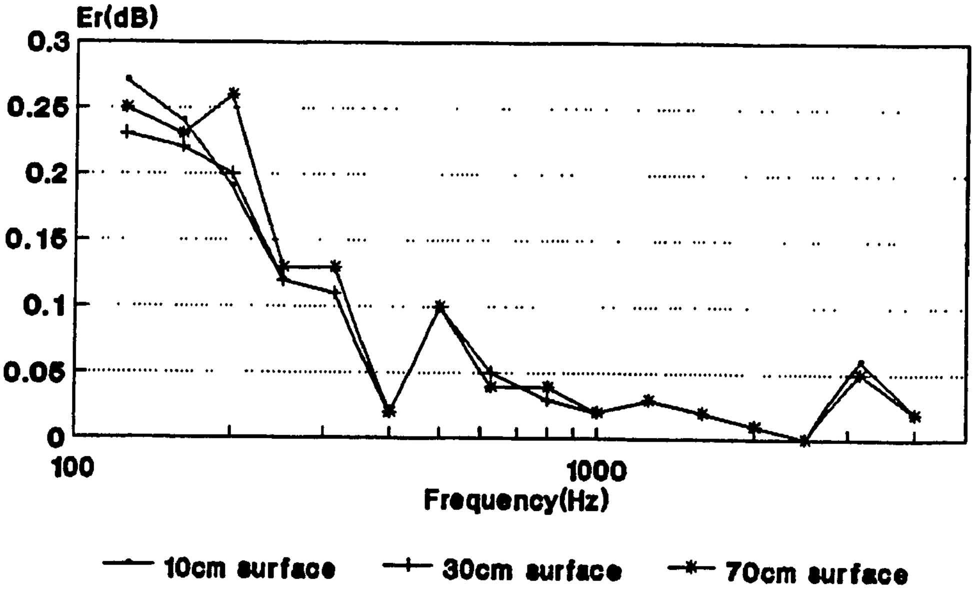

3-D Sound Power Measurements

Fig.5.7: Phase Mismatch Errors

From Fig.5.6 it is seen that the three microphone pairs have PII greater than 10 dB which qualifies the 3-D probe in this aspect.

The phase mismatch errors have been calculated according to Eq.(2.11) for each measurement surface, and they are plotted in Fig.5.7 and listed in Table A1-3.7. It can be seen from Fig.5.7 that phase mismatch errors at different measuring surfaces are almost same which means the phase properties of the sound fields are the same. Also, the phase mismatch errors are less than 0.3dB at all frequencies.

The various errors for the 3-D sound power measurements are presented in Fig.5.8. The phase errors are taken as the maximum value among the three groups of phase errors and the

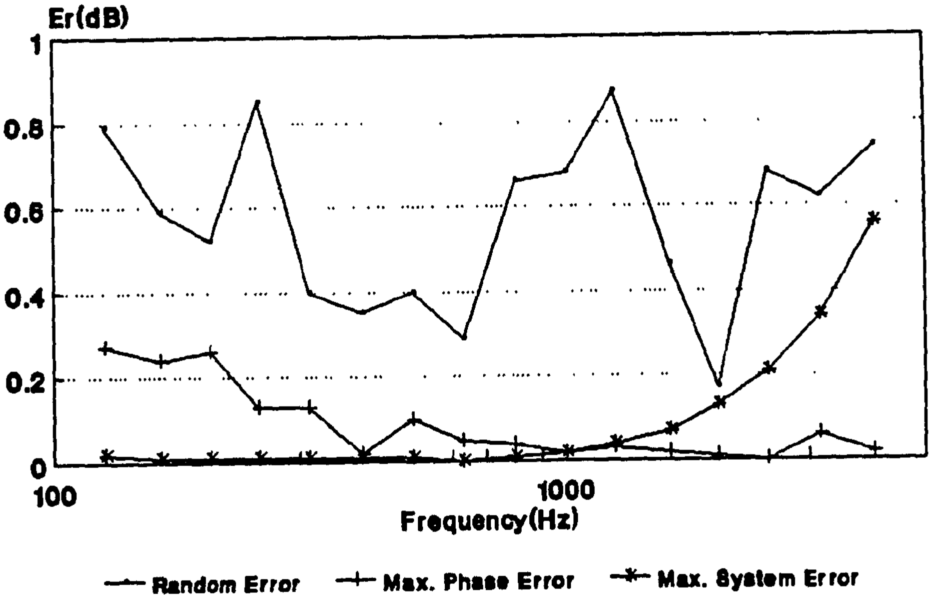


Fig.5.8:Various Errors for 3-D SWL Tests

finite difference errors are maximum at the 10cm measuring surface. It is seen that only the random error is significant among the three errors for the current 3-D sound power measurements and any error is less than 1 dB.

The mean sound power level computed from Eq.(3.7) and the total error bounds coming from Eq.(3.9) are illustrated in Table A1-3.8 and Fig.5.9. It is found that the total error bounds at any frequency is below 1.5 dB.

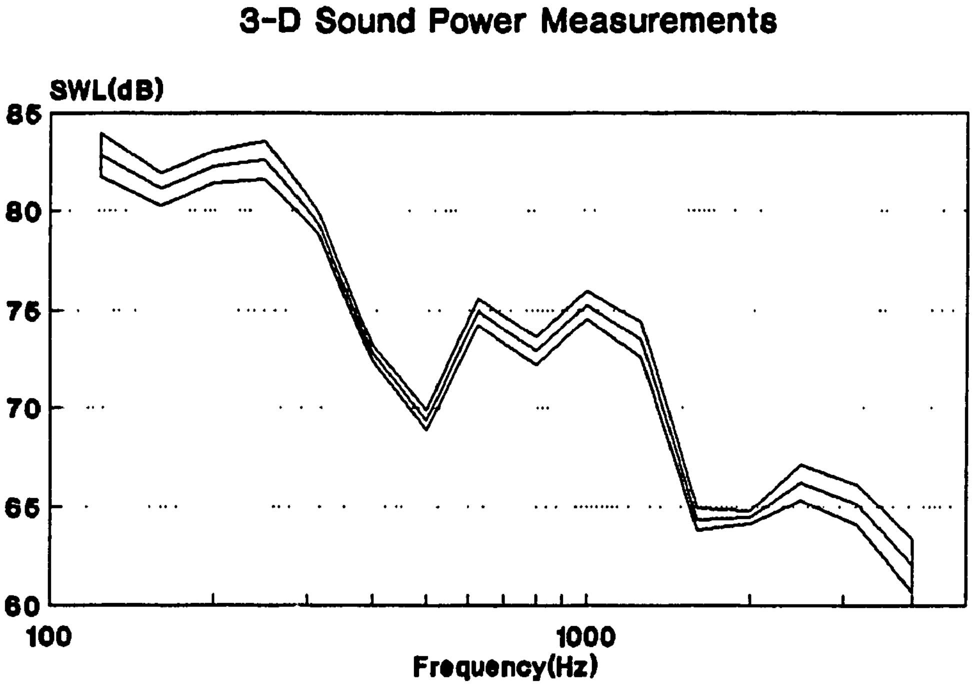


Fig.5.9: Mean SWL and Total Error Bounds

5.1.3 Adequacy of Measurements

As discussed in chapter 3, to qualify the test results, the ISO indicators are sufficient. The indicators are the indications of the random error and phase mismatch error limits.

The dynamic capability index of the 3-D sound power measurement instrumentation and the F2 indicators are calculated from Eq.(3.14) and Eq.(3.10) and they are illustrated in Fig.5.10 and Table A1-3.9.

One can see from Fig.5.10 that the F2 indicators at different measuring surfaces are below the dynamic capability index. Thus the resulting phase mismatch errors are less than 0.5 dB as confirmed in Fig.5.7. Hence, the adequacy of the 3-D instrumentation is demonstrated.

Some small negative F2 values are found on the 30cm and 70cm surfaces. This indicates the existence of a standing wave as discussed in Section 3.3.1.

The field non-uniformity indicator F4 values at different measuring surfaces are calculated from Eq.(3.23) and thereby the number of measuring points required by precision and engineering class are calculated from Eq.(3.24). The required measuring numbers along with the number of points used at each measuring surface are displayed in Fig.5.11, 5.12 and 5.13 and listed in Table A1-3.10, A1-3.11 and A1-3.12. Again, one can observe that the precision class requirement of the ISO draft standard is quite restrictive and about 100 measuring points can satisfy the engineering class requirement.

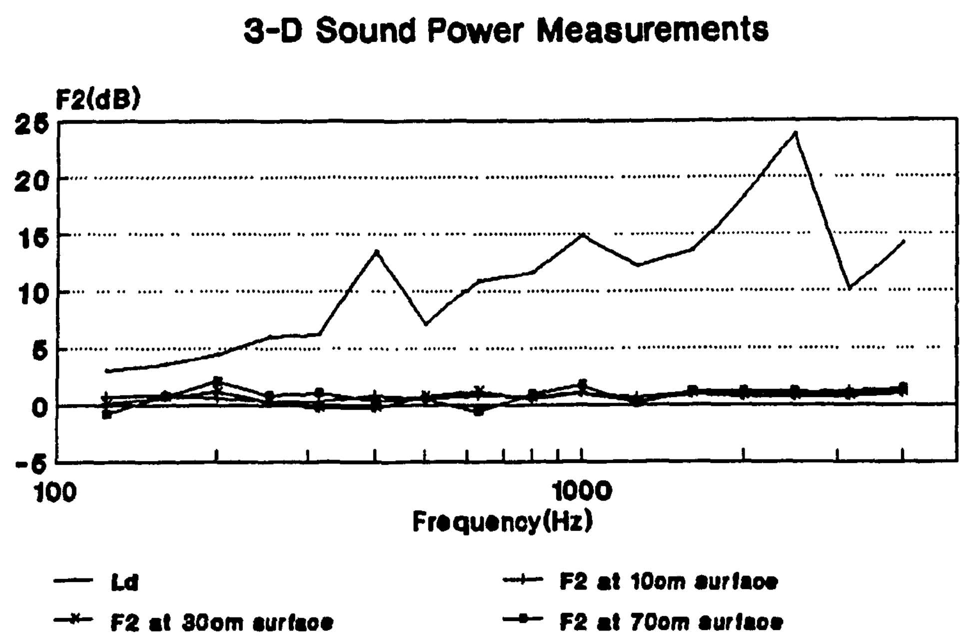

3-D Sound Power Measurements

Fig.5.10: Ld and F2 indicators

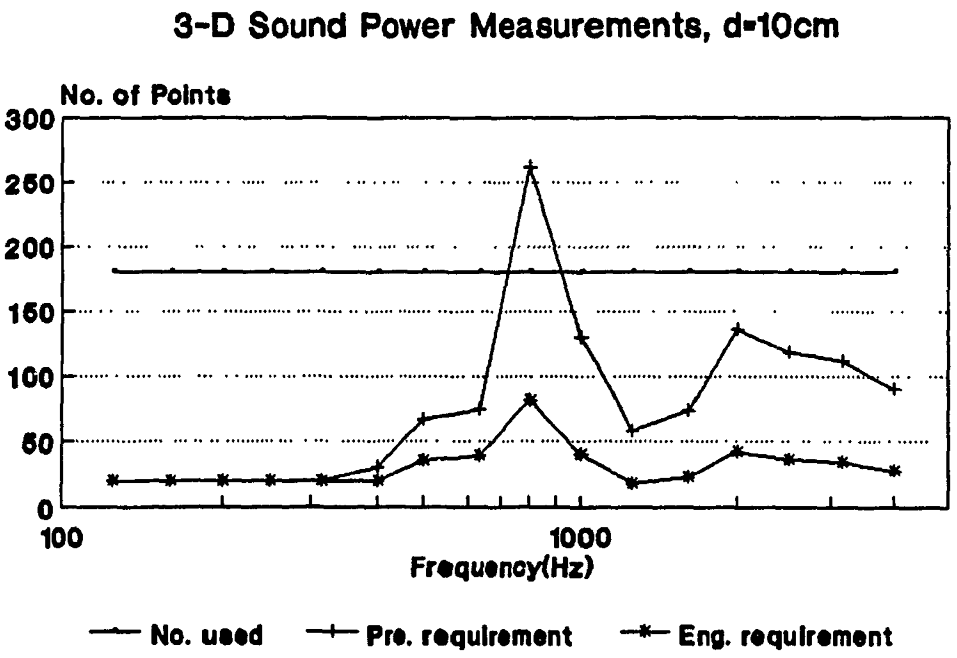

3-D Sound Power Measurements, d=10cm

Fig.5.11: Adequacy of Measurement Array

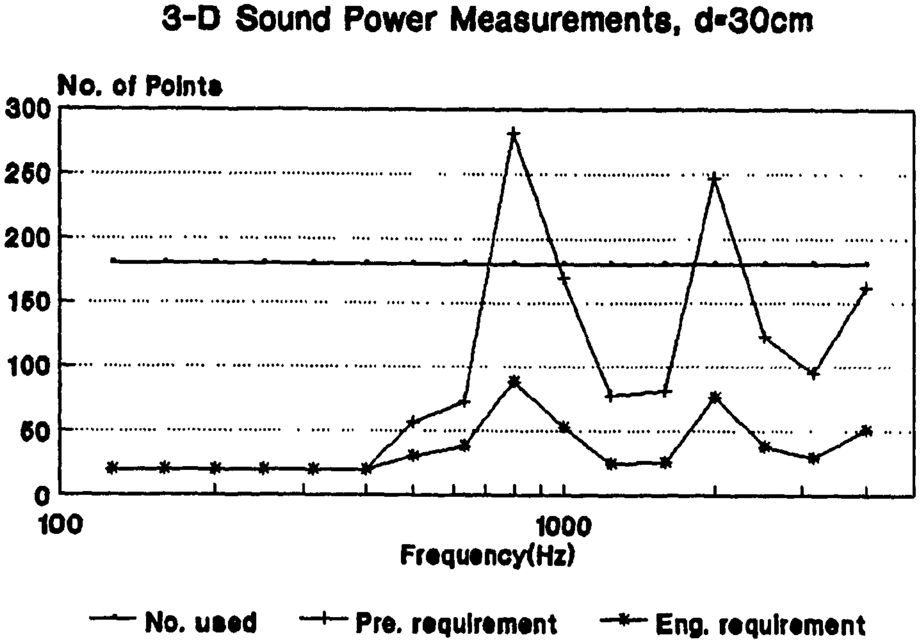

3-D Sound Power Measurements, d=30cm

Fig.5.12: Adequacy of Measurement Array

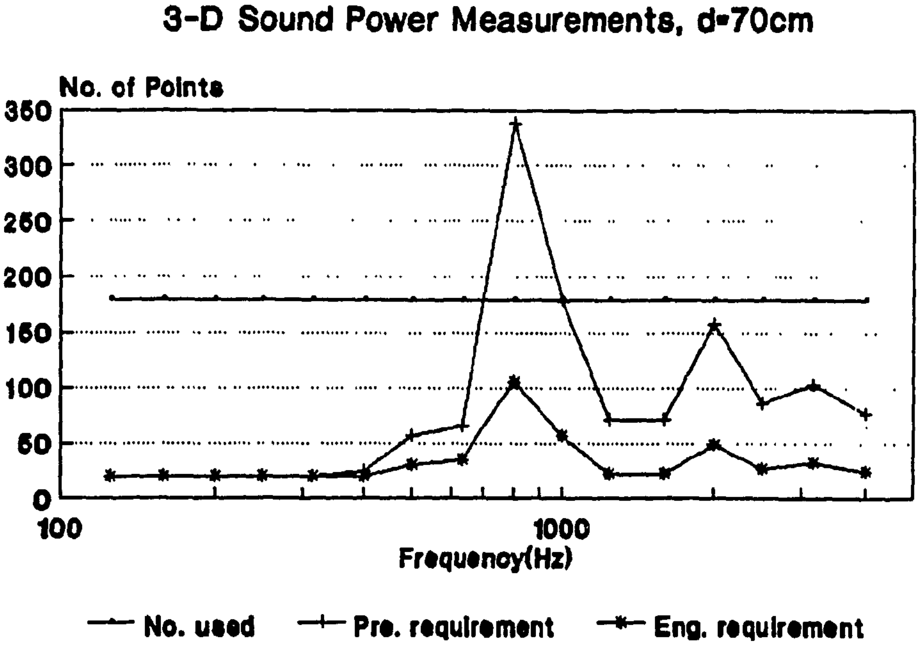

3-D Sound Power Measurements, d=70cm

Fig.5.13: Adequacy of Measurement Array

5.2 Assessment of the Sound Source for SWL Measurements

Three dimensional intensity measurement allows one to have a "real" assessment of sound source location. Because one dimensional intensity measurement provides the component along one direction, e.g., normal intensity to the measurement surface, the actual magnitudes of the intensity vectors will not be known except in the unique case that it has the one axis of propagation. Thus assessment of the source can be enhanced by three dimensional intensity measurements.

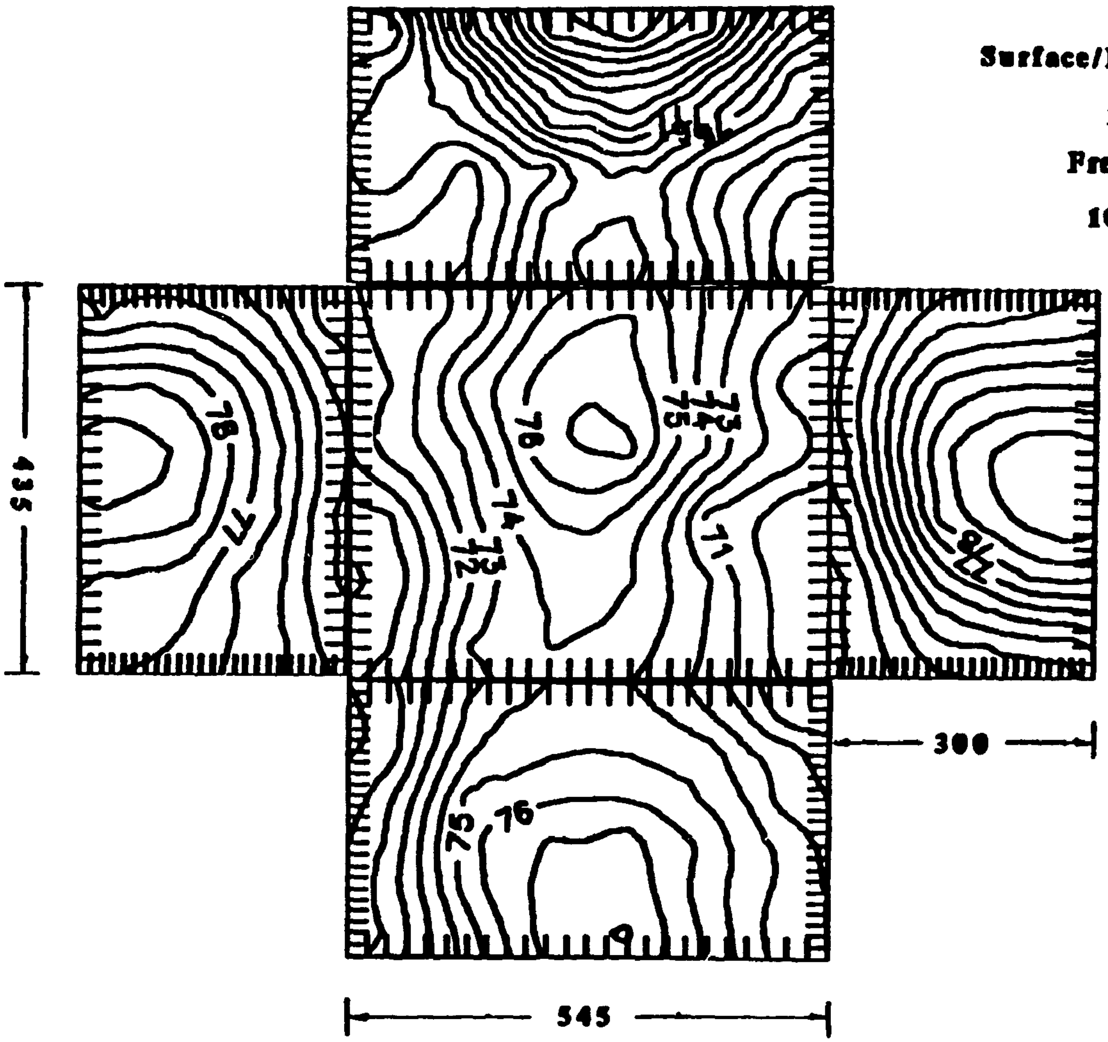
Fig.5.14 shows the distribution of the magnitudes of the intensity vectors at 1000Hz on the 10cm measuring surfaces for SWL measurements. The magnitudes of the intensity vectors are calculated from

$$|SIL| = 5\mathrm{Log}\{(10^{SILX/10})^2 + (10^{SILY/10})^2 + (10^{SILZ/10})^2\} \qquad (5.1)$$

where

|SIL| is the magnitudes of intensity vectors;
SILX, SILY, SILZ are components of an intensity vector along X, Y and Z direction.

One can find from Fig.5.14 that on each of the four lateral surface, the intensity level increases towards the lower centre. The intensity level range for front surface is from 69 to 78dB; for left surface is 72 to 80dB; for back surface is 71 to 84dB; for right surface is 70 to 80dB. The range of the intensity on the top surface is from 68 to 77dB and the peak point is located at the centre but relatively



Surface/Panel Distance:

10cm

Frequency:

1000Hz

Fig.5.14 Distribution of Magnitudes of Intensity Vectors on a 545x435x300 Measurement Surface for SWL of a Sound Source close to the back surface. This distribution clearly indicates that the strongest emission is towards the back and close to the floor. The source emission is quite symmetric along the left-right axis. Thus, attention should be concentrated at the lower part of the back surface.

5.3 Measurements of TL with 3-D Probe

To qualify the 3-D instrumentation on TL tests, three tests were repeated for a panel with the dimension of 2.8m by 2.35m. The arrangement of test panel and the measurement surfaces for the current 3-D TL are shown in Fig.2.4. The measurement surfaces are 10cm, 30cm and 40cm from the test panel. 143 points(11 rows and 13 columns) are used on the 10cm and 30cm surface and 191 points are used on the 40cm surface. On each point at the reception side, the sound pressure levels, the sound intensity levels from each of the three microphone pairs are measured. The source room sound pressure levels are recorded during the course of the measurement as many times as the measuring points on the measurement surface.

5.3.1 Results

The TL levels from different measuring surfaces are calculated from the transmitted intensities measured by the microphone pair 3 which is located normal to the measuring surface. The TL levels are illustrated in Fig.5.15 and Table A1-3.13. With the exception of TL levels at 500Hz, 630Hz and 800Hz where the TL levels from 10cm surface are about 2dB lower than that from the other two measuring surfaces, the TL values at other frequencies agree well with each other.

The average surface intensity levels and the pressure levels on each measuring surface are presented in Fig.5.16 and 5.17 and listed in Table A1-3.14 and A1-3.15. They will be used later for the error analysis and the qualification of the measurements. It is seen from the figures that the intensities on different measuring surfaces are not significantly different whilst the pressures on the 10cm surface are

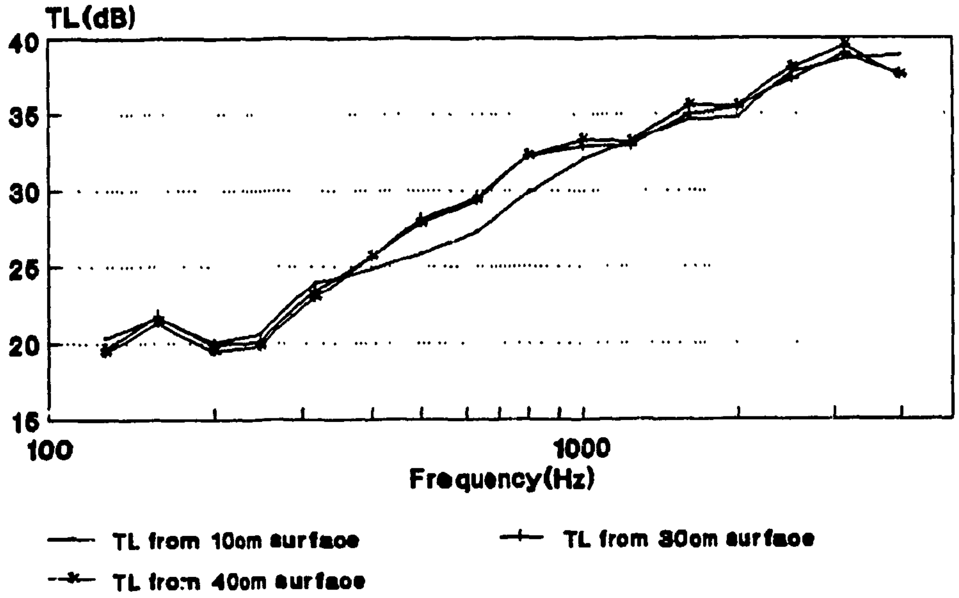


Fig.5.15 TL from 3-D Measurements

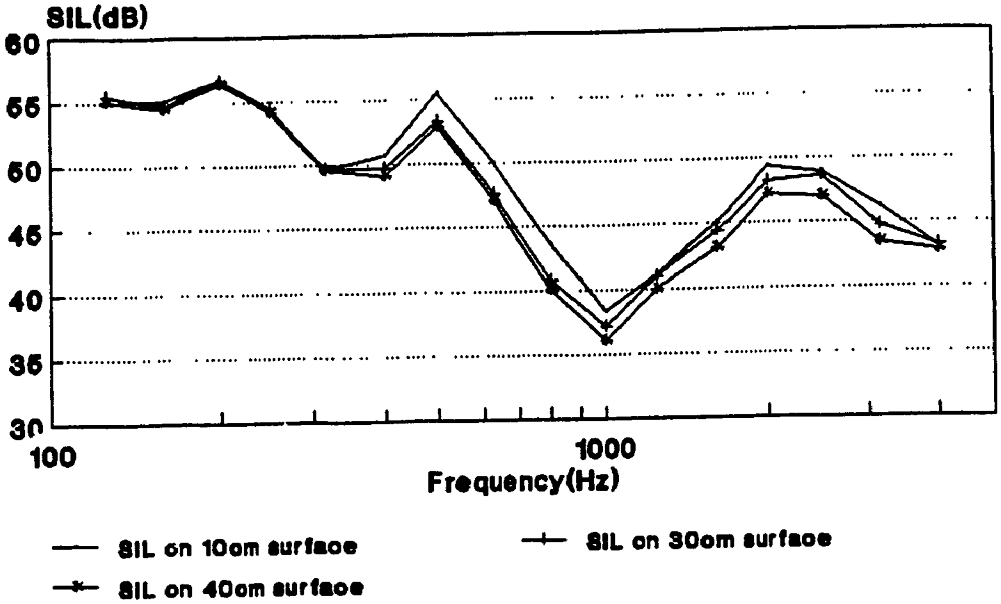


Fig.5.16 Average SIL from 3-D TL Tests

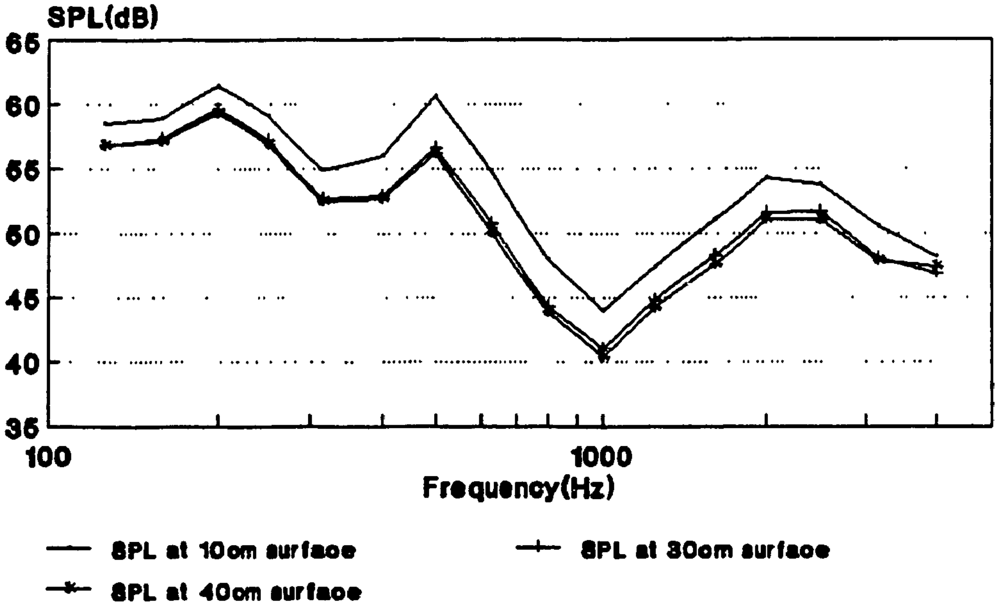


Fig.5.17 SPL from 3-D TL Tests

consistently higher than that on the other two measuring surfaces.

5.3.2 Error Analysis

Various errors must be investigated to establish the total error bounds.

The source room non-uniform error, the standard deviation of the sound pressure levels measured in the source room, for the current TL tests with 3-D probe are shown in Table 5.2. Except at 125Hz, the errors at other frequencies are less 1dB Compared with the source room error for 1-D TL tests in Table 4.1 one can find that the source errors for the current 3-D TL tests are smaller. This is because the panel for the 3-D tests is more rigid compared with the previous panel for the 1-D TL tests. Thus more sound is reflected from the panel and the sound field in the reverberation room is more diffuse.

The random error which is the repeatability standard deviation of the TL levels measured from different measuring surfaces are presented in Fig.5.18 and Table A1-3.16. The results are compared with the requirement by the traditional two-chamber TL measuring method[1]. One can see that at 500Hz, 630Hz and 800Hz the random error are slightly above the allowable level whilst at other frequencies the random error are within the tolerance limits. At 500 to 800Hz, the relative large random errors are due to the lower TL levels from the

Table 5.2
Source Nonuniform Error for 3-D TL Tests

Freq.Hz	Er.1,dB	Er.2,dB	Er.3,dB
125	1.40	1.42	1.43
160	0.43	0.47	0.43
200	0.75	0.75	0.77
250	0.27	0.22	0.24
315	0.40	0.31	0.30
400	0.24	0.22	0.17
500	0.32	0.30	0.26
630	0.36	0.33	0.36
800	0.36	0.30	0.31
1000	0.14	0.16	0.17
1250	0.23	0.20	0.22
1600	0.51	0.50	0.54
2000	0.20	0.26	0.28
2500	0.16	0.18	0.19
3150	0.35	0.32	0.32
4000	0.21	0.27	0.26

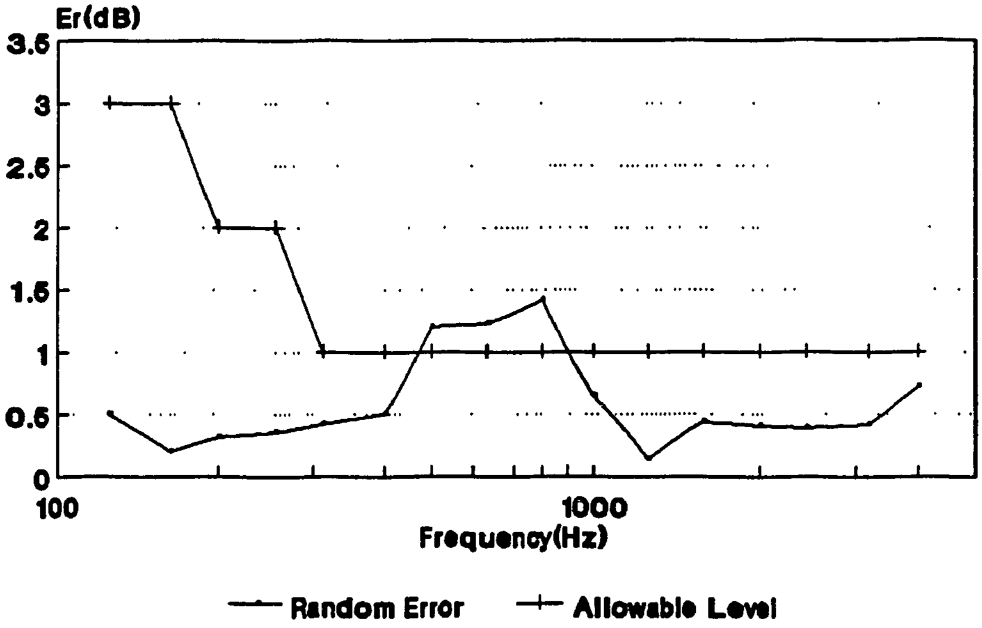


Fig.5.18 Random Error on 3-D TL Tests

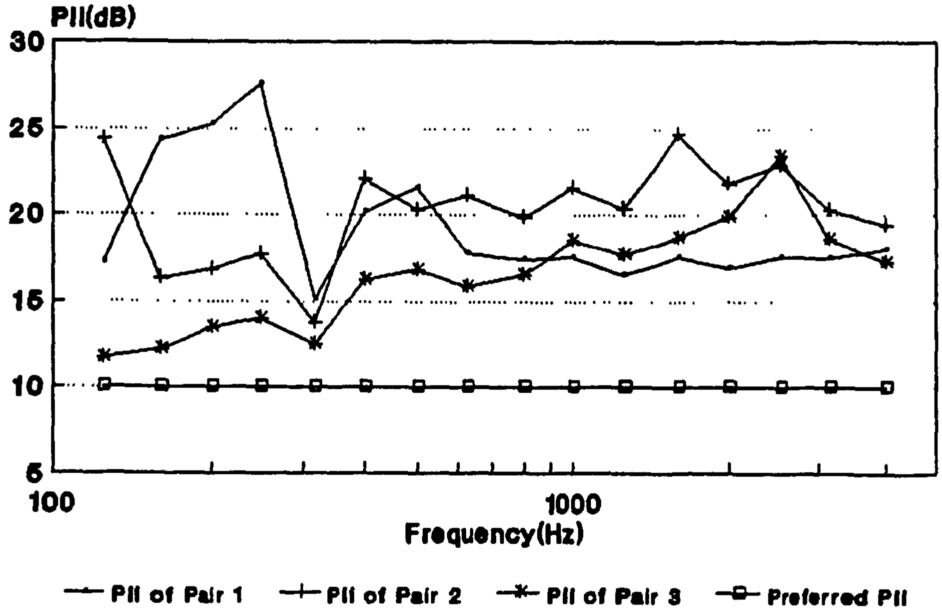


Fig.5.19 Instrument PII for 3-D TL Tests

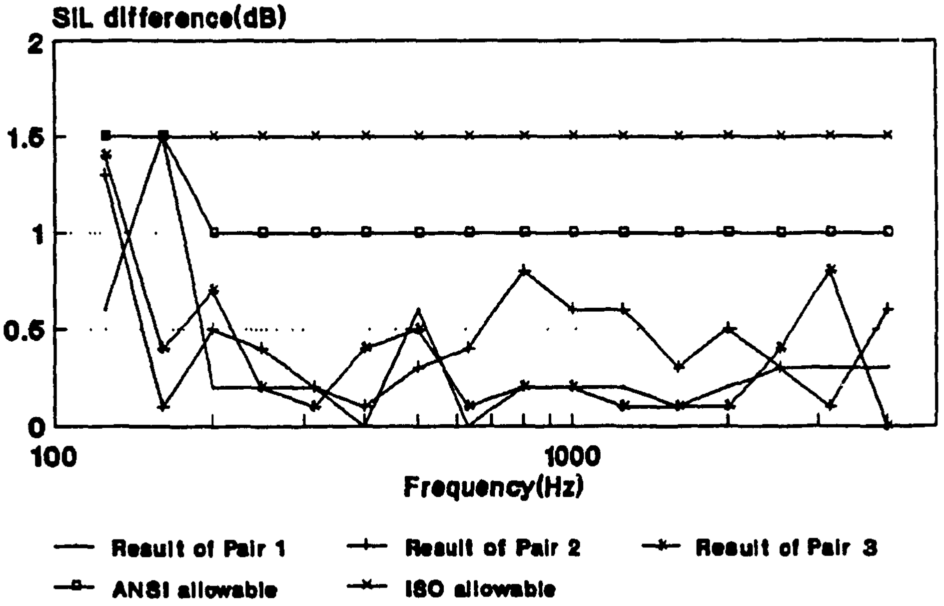


Fig.5.20 Probe Reversal Tests---3D probe

10cm surface.

To qualify the phase property of the 3-D probe, the residual pressure-intensity indices(PII) for each microphone pair of the 3-D probe were measured in a standing wave tube used previously. The residual PII values are presented in Fig.5.19 and Table A1-3.17. It is seen that all PII values for three pairs of microphones are above the preferred 10dB; thus good phase performance of the 3-D probe is confirmed.

The probe reversal tests for each pair of microphones were also performed to test their phase property. The intensity levels before and after the probe reversals were measured and they are summed to get the residuals. The residuals along with the allowable levels set by the ANSI and the ISO are displayed in Fig.5.20 and Table A1-3.18. All indices are found within the allowable levels which qualifies the probe in this respect.

The phase mismatch errors are calculated from Eq.(2.11) and they are displayed in Fig.5.21 and Table A1-3.19. From Fig.5.21 it is obvious that the errors on the 10cm measuring surface are higher than that on the other two measuring surfaces especially at low frequencies. This is due to the worse phase property on the 10cm surface.

The various errors incurred in the current TL tests by the 3-D probe are shown in Fig.5.22. It is seen from Fig.5.22 that the source room error, the phase mismatch error and the random error are all important. Thus the measures should be

3-D TL Tests

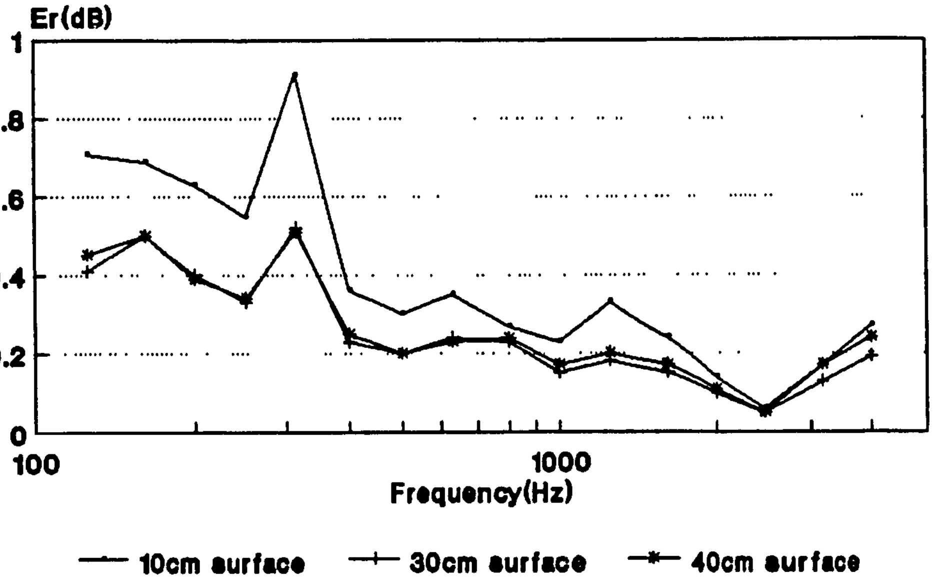


Fig.5.21 Phase Mismatch Errors

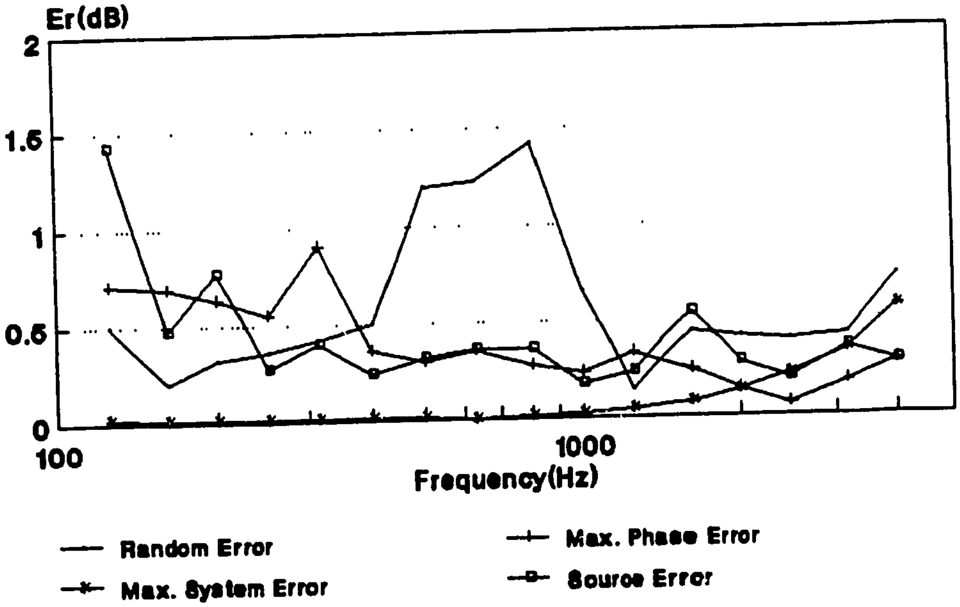


Fig.5.22 Various Errors for 3-D TL Tests

given to control these three errors.

The mean TL and the total error bounds for the current TL tests are shown in Fig.5.23 and Table A1-3.20. Although the total error bounds for the TL tests by the 3-D probe is greater than that for the measurements of sound power by a 3-D probe, the total error bound at any frequency is still less than 3dB.

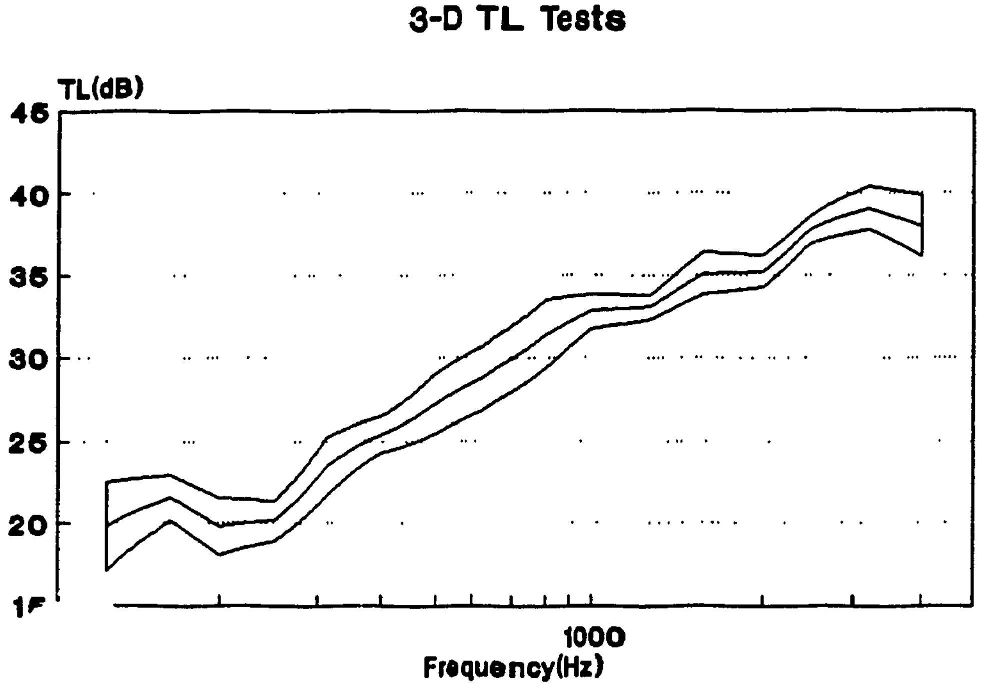


Fig.5.23 Mean TL and Total Error Bounds

5.3.3 Adequacy of TL Tests

The criteria for the qualifications of TL tests have been discussed in chapter 4 and they will be used to evaluate the current TL test results by the 3-D probe.

The T1 indicators, which are the standard deviation of the source room sound pressure levels, have been displayed in Table 5.2. They are presented in Fig.5.24 along with the ISO 3741 allowable levels and the tolerance limits proposed in chapter 4. From Fig.5.24 it is seen that both criteria are satisfied. This is because the panel used is more rigid than the panel used for the 1-D TL tests. Thus more sound is reflected from the panel and sound field in the reverberation room is more diffuse.

The T2 values are calculated by the equation 4.4 and the dynamic capability indices Ld_{TL} for TL tests are computed from Eq.(4.5). They are shown in Fig.5.25 and Table A1-3.21. From Fig.5.25, one can find that all the T2 values on the three different measuring surfaces are below the Ld_{TL} curve. This assures that the phase mismatch errors are less than 1dB; thus it qualifies the phase aspect of the TL test results.

The T3 indicators on each measuring surface are calculated from Eq.(4.8) and the required number of measuring points are calculated from Eq.(4.7). The number of measuring points used and required on each measuring surface are shown in Fig.5.26, 5.27 and 5.28 and displayed in Tables A1-3.22, A1-3.23 and A1-3.24. The intensities on the 10cm surface are not as uniform as on the other two surfaces. This leads to insufficient measuring numbers at 800Hz. However, except at 800Hz on the 10cm measuring surface, the measuring numbers are qualified.

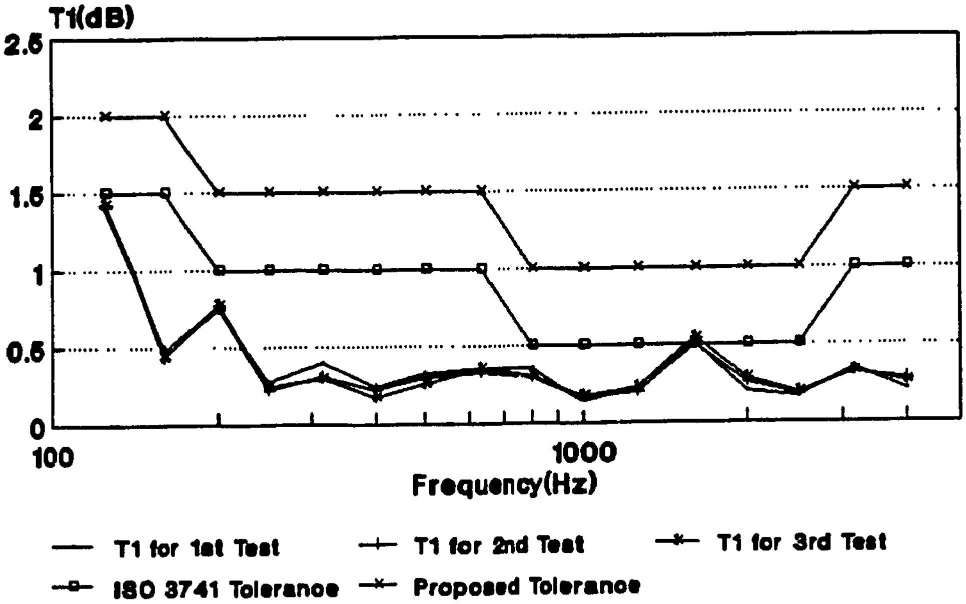


Fig.5.24: T1 for 3-D TL Tests

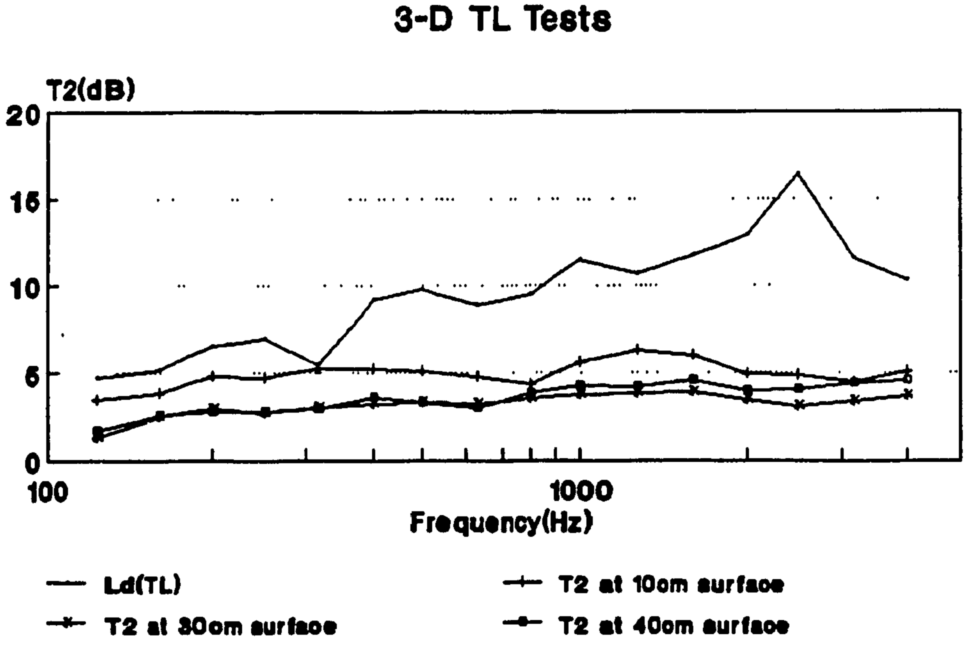

3-D TL Tests

Fig.5.25: Ld(TL) and T2 indicators

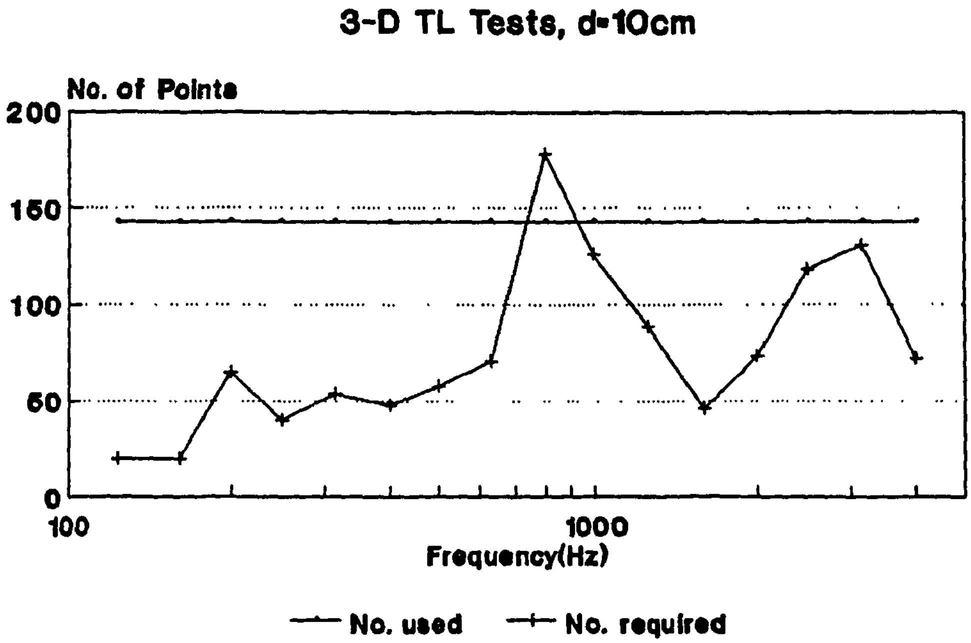

3-D TL Tests, d=10cm

Fig.5.26: Adequacy of Measurement Array

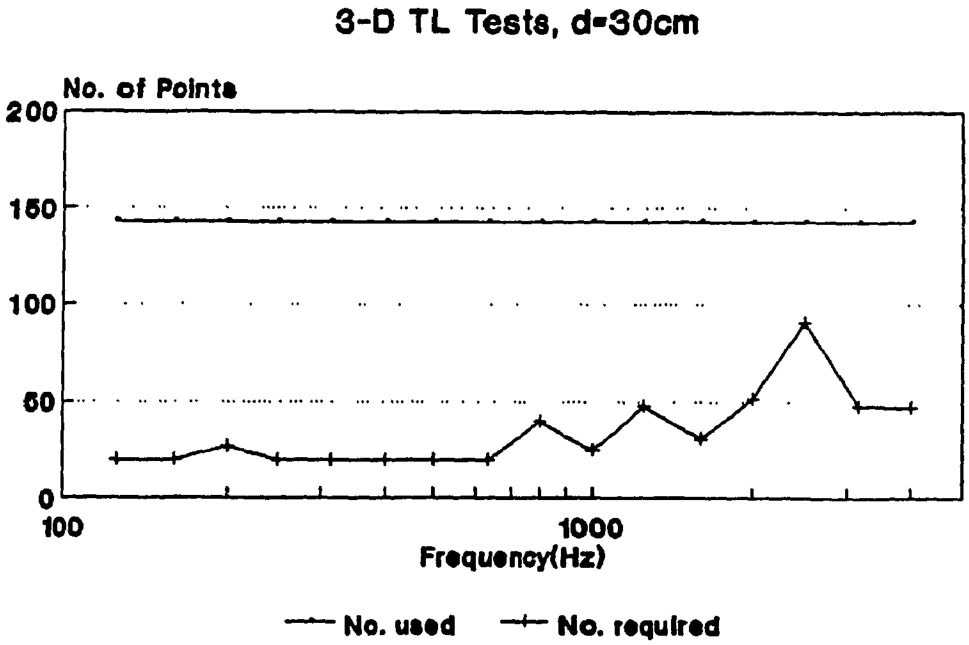

3-D TL Tests, d=30cm

Fig.5.27: Adequacy of Measurement Array

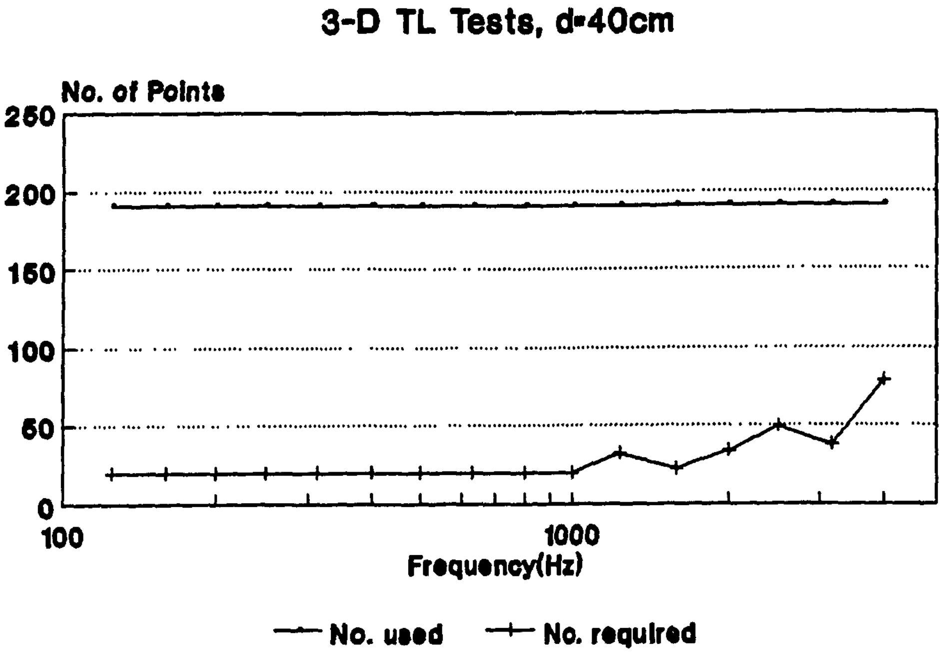


Fig.5.28: Adequacy of Measurement Array

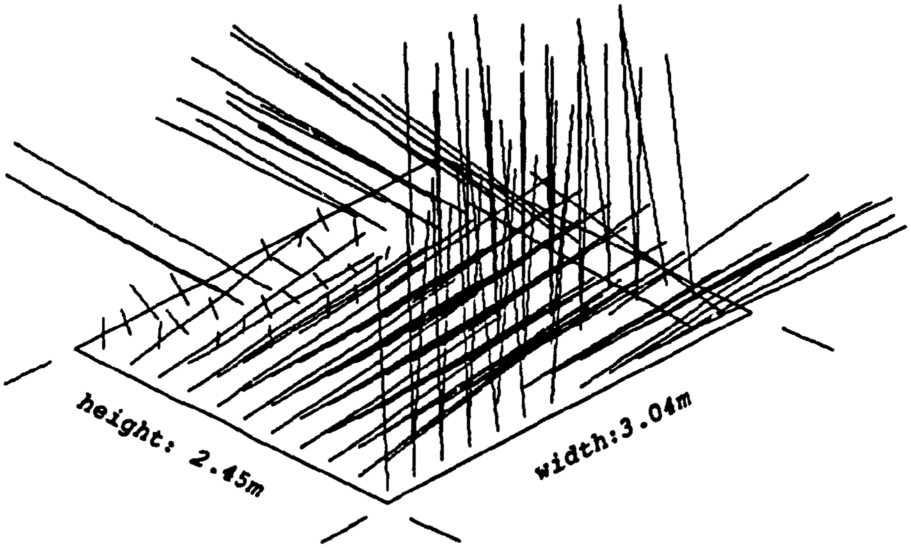
From the foregoing analysis, one may deduce that the 3-D probe, formed by the quarter inch microphones, is less accurate than the 1-D probe which consists of half inch microphones. However, if one used larger microphones to the 3-D probe, the large dimensions of the probe would cause more interference to the sound field and reduce the measurement accuracy.

5.4 Diagnosis of Sound Leakage through the Panel

By three dimensional measurements of the transmitted intensities on a measuring surface close to the panel, one can determine the sound sources of the panel. Both direction and the magnitude of the intensity vectors can be found; this makes the fault diagnosis of panel possible. Undoubtedly, this feature of the 3-D intensity measurements can be of use.

Three dimensional presentation of vectors is awkward although some rough representation can be drawn by the software AutoCAD. Fig.5.29 illustrates the overview of the magnitudes of the transmitted intensity vectors at 1000Hz on a measurement surface which is 10cm from the test panel. The distribution and direction of the vectors can be seen. The mean magnitude of the intensity vectors on the measuring surface is found to be 59.93dB.

Furthermore, the ten most intense vectors are located and shown in Fig.5.30 along with their magnitude. From Fig.5.30 it can easily be seen that the panel fault is at the bottom boundary especially close to the lower right corner where the highest transmitted intensity is found. Another fault area is located at the top right hand corner but to a less degree than the bottom edge, also the area of this fault is much smaller than at the bottom edge. Comparing the magnitudes of the top ten intensity vectors with the mean magnitude of all intensity vectors on the surface, one can find that these ten contribute



Mean of Magnitudes: 59.93dB

Fig.5.29 Overview of Transmitted Intensity Vectors
on a Measurement Surface 10cm from Test Panel at 1000Hz

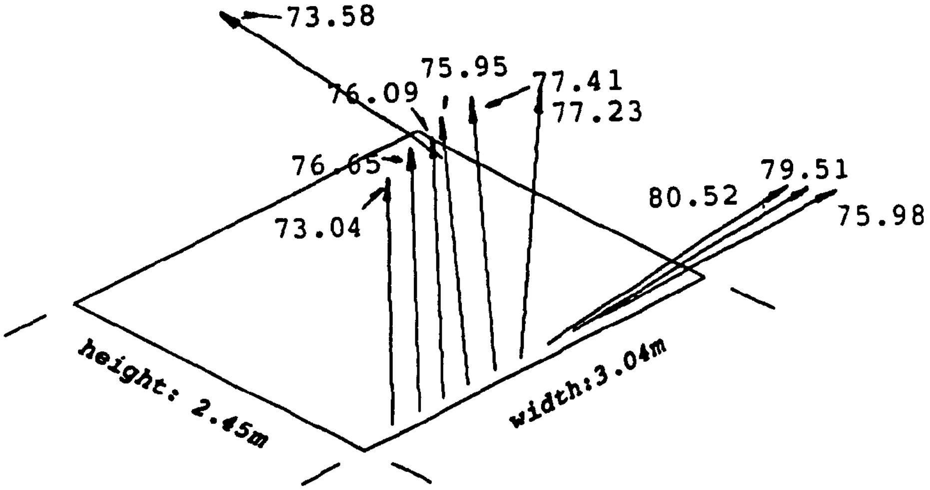


Fig.5.30 Top Ten Intensity Vectors on a Measurement Surface 10cm from Test Panel at 1000Hz

most of the sound energy transmitted through the panel. Thus, it is clear that one should improve these regions to enhance transmission insulation.

5.5 Conclusions to chapter 5

The 3-D intensity measurement facility can be used accurately to measure the sound power or sound transmission loss.

Fault diagnosis of sound sources or panels is enhanced by use of the 3-D intensity measurements.

The sound power or TL measurements by the 3-D probe confirm the conclusions drawn from the previous 1-D tests in chapter 3 and 4.

The performance of the half inch microphone 1-D probe is found slightly better than the quarter inch microphone 3-D probe used at the Acoustic Laboratory in the Centre for Building Studies.

CHAPTER 6

RECOMMENDATIONS for FUTURE RESEARCH

6.1 Sound Power Measurements

The scanning method for sound power measurements by the intensity technique is time saving compared to the point to point method, and is likely to be used frequently in engineering practice. No standard has been established for this technique, however, a need exists. Thus work should be undertaken in this area.

The influence of equal or higher extraneous noise compared to the source in the case of the sound power determination for large subject sources should be investigated, since under these conditions net extraneous sound energy through the enclosing measuring surface may not be ignored.

The three dimensional intensity measurement technique may be further developed to better evaluate the performance of different noise control measures such as the noise insulation enclosures or vibration damping.

The current one plane automated probe traverse could be improved to three dimensional traverse system. This would greatly enhance its convenience in sound power measurements.

The automatic graphic representation of three dimensional intensity vectors needs development to yield simple, unambiguous representation.

6.2 Sound Transmission Loss Tests

The scanning method should be investigated with a view to establishing a standard for transmission loss tests, probably with respect to field measurements.

The transmission loss suite aperture could be designed to allow easy installation and change of smaller test panels whilst pertaining a high transmission loss value for the containing wall.

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APPENDIX 1

TABLES OF MEASUREMENT RESULTS

TABLES FOR CHAPTER 3

1-D: SOUND POWER MEASUREMENTS

Table A1-1.1 Sound Power at Different Distance

Frequency Hz	d=10cm dB	d=30cm dB	d=70cm dB
125	81.12	81.78	81.79
160	78.84	79.09	78.93
200	80.29	79.74	79.78
250	79.66	81.28	80.26
315	77.43	77.79	77.12
400	70.28	71.05	70.28
500	66.98	67.48	67.28
630	72.38	72.64	72.49
800	71.41	71.28	72.18
1000	73.00	72.99	73.09
1250	71.70	71.77	71.43
1600	60.86	61.49	61.43
2000	61.16	61.20	61.06
2500	63.13	63.39	63.78
3150	62.31	61.83	61.46
4000	58.96	58.83	58.87

Table A1-1.2 Average Surface Intensity & Pressure Levels and Phase Mismatch Errors at d=10cm

Frequency,Hz	SIL,dB	SPL,dB	Er,dB
125	81.95	82.75	0.35
160	79.67	80.33	0.39
200	81.12	82.03	0.34
250	80.50	81.09	0.23
315	78.26	78.99	0.21
400	71.11	72.34	0.16
500	67.81	68.83	0.05
630	73.21	74.83	0.10
800	72.24	73.45	0.08
1000	73.83	75.12	0.06
1250	72.53	73.67	0.09
1600	61.70	63.23	0.08
2000	61.99	63.76	0.08
2500	63.96	65.59	0.06
3150	63.15	64.97	0.05
4000	59.80	61.93	0.31

Table A1-1.3 Average Surface Intensity & Pressure Levels and Phase Mismatch Errors at d=30cm

Frequency,Hz	SIL,dB	SPL,dB	Er,dB
125	77.69	77.71	0.29
160	75.00	75.41	0.37
200	75.65	76.63	0.35
250	76.99	77.86	0.25
315	73.70	73.93	0.19
400	66.96	67.35	0.13
500	63.39	64.51	0.05
630	68.55	69.70	0.09
800	67.18	67.80	0.07
1000	68.89	69.83	0.06
1250	67.68	68.07	0.08
1600	57.40	58.75	0.08
2000	57.10	58.51	0.07
2500	59.30	60.49	0.05
3150	57.74	59.03	0.04
4000	54.73	56.57	0.29

Table A1-1.4 Average Surface Intensity & Pressure Levels and Phase Mismatch Errors at d=70cm

Frequency,Hz	SIL,dB	SPL,dB	Er,dB
125	72.28	72.26	0.29
160	69.42	70.05	0.39
200	70.27	71.31	0.35
250	70.75	71.59	0.25
315	67.61	67.80	0.19
400	60.77	61.35	0.14
500	57.77	58.77	0.05
630	62.98	64.03	0.08
800	62.67	62.93	0.06
1000	63.58	64.44	0.06
1250	61.92	62.65	0.08
1600	51.92	53.13	0.07
2000	51.55	53.02	0.07
2500	54.27	55.59	0.05
3150	51.95	53.33	0.04
4000	49.36	51.18	0.28

Table A1-1.5 Monitored Source Variation

Freq.,Hz	σ,dB	Freq.,Hz	σ,dB
125	0.17	800	0.64
160	0.29	1000	0.60
200	0.12	1250	0.26
250	0.12	1600	0.00
315	0.31	2000	0.81
400	0.15	2500	0.30
500	0.40	3150	0.53
630	0.75	4000	0.58

Table A1-1.6 Repeatability Errors and Allowable Uncertainty of Sound Power Determinations

Freq.,Hz	σ,dB	Prec.,dB	Eng.,dB
125	0.38	2	3
160	0.13	2	3
200	0.31	1.5	2
250	0.82	1.5	2
315	0.34	1.5	2
400	0.44	1.5	2
500	0.25	1.5	2
630	0.13	1.5	2
800	0.49	1	1.5
1000	0.06	1	1.5
1250	0.18	1	1.5
1600	0.35	1	1.5
2000	0.07	1	1.5
2500	0.33	1	1.5
3150	0.43	1	1.5
4000	0.07	1	1.5

Table A1-1.7 Residual Pressure-Intensity Index of Instrumentation for Sound Power Measurements

Freq.,Hz	PII,dB	Freq.,Hz	PII,dB
125	11.9	800	18.7
160	11.3	1000	19.7
200	12.1	1250	18.0
250	13.4	1600	18.9
315	13.9	2000	19.2
400	15.6	2500	20.6
500	20.6	3150	21.5
630	18.2	4000	13.8

Table A1-1.8 Total Error Bounds of Sound Power Measurements

Freq.,Hz	SWL,dB	Er_{tot},dB	Freq.,Hz	SWL,dB	Er_{tot},dB
125	81.56	0.75	800	71.62	0.58
160	78.95	0.53	1000	73.03	0.14
200	79.94	0.67	1250	71.63	0.31
250	80.40	1.08	1600	61.26	0.50
315	77.45	0.56	2000	61.14	0.28
400	70.54	0.61	2500	63.43	0.60
500	67.25	0.31	3150	61.87	0.82
630	72.50	0.23	4000	58.89	0.94

Table A1-1.9 Adequacy of Instrumentation for Sound Power Measurements

Freq. Hz	Ld,dB	F2,dB		
		d=10cm	d=30cm	d=70cm
125	1.9	0.75	-0.10	-0.09
160	1.3	0.65	0.39	0.62
200	2.1	0.92	1.04	1.07
250	3.4	0.59	0.92	0.83
315	3.9	0.76	0.19	0.10
400	5.6	1.28	0.35	0.56
500	10.6	1.03	1.16	1.03
630	8.2	1.61	1.17	1.03
800	8.7	1.20	0.59	0.18
1000	9.7	1.26	0.93	0.83
1250	8.0	1.12	0.36	0.72
1600	8.9	1.53	1.35	1.18
2000	9.2	1.79	1.46	1.54
2500	10.6	1.61	1.20	1.31
3150	11.5	1.89	1.31	1.40
4000	3.8	2.17	1.86	1.84

Table A1-1.10 Adequacy of Measuring Array,d=10cm

Freq.,Hz	N	F4,dB	$N_{precision}$	$N_{engineering}$
125	320	0.78	20	20
160	320	0.69	20	20
200	320	0.71	20	20
250	320	0.63	20	20
315	320	0.65	20	20
400	320	1.18	39	21
500	320	1.63	75	40
630	320	1.71	82	44
800	320	1.86	310	97
1000	320	1.31	156	49
1250	320	0.89	72	23
1600	320	1.01	92	29
2000	320	1.30	153	48
2500	320	1.35	165	52
3150	320	2.00	360	112
4000	320	1.52	208	65

Table A1-1.11 Adequacy of Measuring Array,d=30cm

Freq.,Hz	N	F4,dB	$N_{precision}$	$N_{engineering}$
125	320	0.48	20	20
160	320	0.50	20	20
200	320	0.47	20	20
250	320	0.54	20	20
315	320	0.57	20	20
400	320	0.83	20	20
500	320	1.38	54	29
630	320	1.50	64	34
800	320	1.62	237	74
1000	320	1.37	168	53
1250	320	0.94	80	25
1600	320	0.78	55	18
2000	320	1.35	165	52
2500	320	1.08	106	33
3150	320	1.01	92	29
4000	320	0.87	69	22

Table A1-1.12 Adequacy of Measuring Array,d=70cm

Freq.,Hz	N	F4,dB	$N_{precision}$	$N_{engineering}$
125	320	0.36	20	20
160	320	0.40	20	20
200	320	0.39	20	20
250	320	0.45	20	20
315	320	0.66	20	20
400	320	0.85	21	20
500	320	1.32	49	26
630	320	1.33	50	27
800	320	1.57	222	69
1000	320	1.44	187	59
1250	320	1.05	99	31
1600	320	0.83	63	20
2000	320	1.23	136	43
2500	320	1.19	113	35
3150	320	1.14	118	37
4000	320	1.02	94	30

Table A1-1.13 $D31_{20\text{-}80}$ Indicators and its Allowable Values, d=10cm

Freq.,Hz	SIL_{20},dB	SIL_{80},dB	D31,dB	L_{allow},dB
125	81.73	81.92	0.19	1.5
160	79.38	79.69	0.31	1.5
200	80.88	81.13	0.25	1.0
250	80.21	80.47	0.26	1.0
315	78.13	77.93	0.20	1.0
400	70.87	70.90	0.03	1.0
500	67.31	67.71	0.40	1.0
630	72.41	73.21	0.80	1.0
800	71.33	72.30	0.97	0.75
1000	72.93	74.24	1.31	0.75
1250	71.83	72.56	0.73	0.75
1600	60.79	62.12	1.33	0.75
2000	60.75	61.90	1.15	0.75
2500	61.52	63.62	2.10	0.75
3150	61.62	63.33	1.71	0.75
4000	57.53	60.02	2.49	0.75

Table A1-1.14 D31$_{40-160}$ Indicators and
its Allowable Values, d=10cm

Freq.,Hz	SIL$_{40}$,dB	SIL$_{160}$,dB	D31,dB	L$_{allow}$,dB
125	81.71	81.93	0.22	1.5
160	79.38	79.64	0.26	1.5
200	80.81	81.11	0.30	1.0
250	80.18	80.50	0.32	1.0
315	77.95	78.23	0.28	1.0
400	70.79	71.08	0.29	1.0
500	67.38	67.76	0.38	1.0
630	72.55	73.13	0.58	1.0
800	71.62	72.16	0.54	0.75
1000	73.39	73.84	0.45	0.75
1250	71.94	72.53	0.59	0.75
1600	61.43	61.69	0.26	0.75
2000	61.00	62.00	1.00	0.75
2500	61.35	63.91	2.56	0.75
3150	61.60	62.96	1.36	0.75
4000	58.01	59.91	1.90	0.75

Table A1-1.15 D31$_{80-320}$ Indicators and
its Allowable Values, d=10cm

Freq.,Hz	SIL$_{80}$,dB	SIL$_{320}$,dB	D31,dB	L$_{allow}$,dB
125	81.92	81.95	0.03	1.5
160	79.69	79.67	0.02	1.5
200	81.13	81.12	0.01	1.0
250	80.47	80.50	0.03	1.0
315	77.93	78.26	0.33	1.0
400	70.90	71.11	0.21	1.0
500	67.71	67.81	0.10	1.0
630	73.21	73.21	0.00	1.0
800	72.30	72.24	0.06	0.75
1000	74.24	73.83	0.41	0.75
1250	72.56	72.53	0.03	0.75
1600	62.12	61.70	0.42	0.75
2000	61.90	61.99	0.09	0.75
2500	63.62	63.96	0.34	0.75
3150	63.33	63.15	0.18	0.75
4000	60.02	59.80	0.22	0.75

Table A1-1.16 $D31_{20-80}$ Indicators and its Allowable Values, d=70cm

Freq.,Hz	SIL_{20},dB	SIL_{80},dB	D31,dB	L_{allow},dB
125	72.43	72.12	0.31	1.5
160	69.49	69.33	0.16	1.5
200	70.23	70.20	0.03	1.0
250	70.67	70.64	0.03	1.0
315	67.31	67.51	0.20	1.0
400	60.53	60.67	0.14	1.0
500	57.58	57.61	0.03	1.0
630	62.80	63.10	0.30	1.0
800	61.92	62.94	1.02	0.75
1000	62.35	63.87	1.52	0.75
1250	61.62	61.82	0.20	0.75
1600	51.30	51.95	0.65	0.75
2000	48.63	51.63	3.00	0.75
2500	53.74	53.90	0.16	0.75
3150	51.99	51.60	0.39	0.75
4000	49.08	49.43	0.35	0.75

Table A1-1.17 $D31_{40-160}$ Indicators and its Allowable Values, d=70cm

Freq.,Hz	SIL_{40},dB	SIL_{160},dB	D31,dB	L_{allow},dB
125	72.30	72.26	0.04	1.5
160	69.44	69.37	0.07	1.5
200	70.20	70.24	0.04	1.0
250	70.64	70.72	0.06	1.0
315	67.31	67.59	0.28	1.0
400	60.53	60.76	0.23	1.0
500	57.58	57.73	0.15	1.0
630	62.91	62.95	0.04	1.0
800	62.16	62.63	0.47	0.75
1000	62.88	63.43	0.55	0.75
1250	61.95	61.83	0.12	0.75
1600	51.39	51.82	0.43	0.75
2000	50.33	51.25	0.92	0.75
2500	54.24	54.12	0.12	0.75
3150	52.10	51.81	0.29	0.75
4000	48.98	49.28	0.30	0.75

Table A1-1.18 $D31_{80\text{-}320}$ Indicators and its Allowable Values, d=70cm

Freq.,Hz	SIL_{80},dB	SIL_{320},dB	D31,dB	L_{allow},dB
125	72.12	72.28	0.16	1.5
160	69.33	69.42	0.09	1.5
200	70.20	70.27	0.07	1.0
250	70.64	70.75	0.11	1.0
315	67.51	67.61	0.10	1.0
400	60.67	60.77	0.10	1.0
500	57.61	57.77	0.16	1.0
630	63.10	62.98	0.12	1.0
800	62.94	62.67	0.27	0.75
1000	63.87	63.58	0.29	0.75
1250	61.82	61.92	0.10	0.75
1600	51.95	51.92	0.03	0.75
2000	51.63	51.55	0.12	0.75
2500	53.90	54.27	0.37	0.75
3150	51.60	51.95	0.35	0.75
4000	49.43	49.36	0.07	0.75

Table A1-1.19 $D32_{20}$ Indicators and its Allowable Values, d=10cm

Freq.,Hz	SIL_{20}',dB	SIL_{20}'',dB	D32,dB	L_{allow},dB
125	81.73	82.20	0.47	1.5
160	79.38	79.98	0.60	1.5
200	80.88	81.48	0.60	1.0
250	80.21	80.82	0.61	1.0
315	78.13	78.77	0.64	1.0
400	70.87	71.57	0.70	1.0
500	67.31	68.11	0.80	1.0
630	72.41	73.38	0.97	1.0
800	71.33	72.40	1.07	0.75
1000	72.93	73.99	1.06	0.75
1250	71.83	72.91	1.08	0.75
1600	60.79	61.24	0.45	0.75
2000	60.75	61.82	1.07	0.75
2500	61.52	63.38	1.86	0.75
3150	61.62	61.79	0.17	0.75
4000	57.53	59.55	2.02	0.75

Table A1-1.20 D32$_{40}$ Indicators and
its Allowable Values, d=10cm

Freq.,Hz	SIL$_{40}$',dB	SIL$_{40}$",dB	D32,dB	L$_{allow}$,dB
125	81.71	82.18	0.47	1.5
160	79.38	79.92	0.54	1.5
200	80.81	81.44	0.63	1.0
250	80.18	80.81	0.63	1.0
315	77.95	78.59	0.64	1.0
400	70.79	71.52	0.73	1.0
500	67.38	68.11	0.73	1.0
630	72.55	73.65	1.10	1.0
800	71.62	72.73	1.11	0.75
1000	73.39	74.45	1.06	0.75
1250	71.94	72.96	1.02	0.75
1600	61.43	61.59	0.16	0.75
2000	61.00	61.67	0.67	0.75
2500	61.35	63.14	1.79	0.75
3150	61.60	61.70	0.10	0.75
4000	58.01	58.97	0.96	0.75

Table A1-1.21 D32$_{80}$ Indicators and
its Allowable Values, d=10cm

Freq.,Hz	SIL$_{80}$',dB	SIL$_{80}$",dB	D32,dB	L$_{allow}$,dB
125	81.92	81.94	0.02	1.5
160	79.69	79.60	0.09	1.5
200	81.13	81.09	0.04	1.0
250	80.47	80.53	0.06	1.0
315	77.93	78.51	0.58	1.0
400	70.90	71.25	0.35	1.0
500	67.71	67.80	0.09	1.0
630	73.21	73.05	0.16	1.0
800	72.30	72.03	0.27	0.75
1000	74.24	73.39	0.85	0.75
1250	72.56	72.49	0.07	0.75
1600	62.12	61.21	0.91	0.75
2000	61.90	62.10	0.20	0.75
2500	63.62	64.18	0.56	0.75
3150	63.33	62.56	0.77	0.75
4000	60.02	59.80	0.22	0.75

Table A1-1.22 $D32_{160}$ Indicators and its Allowable Values, d=10cm

Freq.,Hz	SIL_{160}',dB	SIL_{160}",dB	D32,dB	L_{allow},dB
125	81.93	81.95	0.02	1.5
160	79.64	79.69	0.05	1.5
200	81.11	81.12	0.01	1.0
250	80.50	80.50	0.00	1.0
315	78.23	78.26	0.03	1.0
400	71.08	71.10	0.02	1.0
500	67.76	67.78	0.02	1.0
630	73.13	73.17	0.04	1.0
800	72.16	72.19	0.03	0.75
1000	73.84	73.84	0.00	0.75
1250	72.53	72.53	0.00	0.75
1600	61.69	61.69	0.00	0.75
2000	62.00	62.00	0.00	0.75
2500	63.91	64.03	0.12	0.75
3150	62.96	63.26	0.30	0.75
4000	59.91	59.63	0.28	0.75

Table A1-1.23 $D32_{20}$ Indicators and its Allowable Values, d=70cm

Freq.,Hz	SIL_{20}',dB	SIL_{20}",dB	D32,dB	L_{allow},dB
125	72.43	72.60	0.17	1.5
160	69.49	69.68	0.19	1.5
200	70.23	70.49	0.26	1.0
250	70.67	71.01	0.34	1.0
315	67.31	67.72	0.41	1.0
400	60.53	60.89	0.36	1.0
500	57.58	58.03	0.45	1.0
630	62.80	63.40	0.60	1.0
800	61.92	62.97	1.05	0.75
1000	62.35	63.55	1.20	0.75
1250	61.62	62.46	0.84	0.75
1600	51.30	52.19	0.89	0.75
2000	48.63	51.17	2.54	0.75
2500	53.74	53.30	0.44	0.75
3150	51.99	51.82	0.17	0.75
4000	49.08	49.86	0.78	0.75

Table A1-1.24 $D32_{40}$ Indicators and
its Allowable Values, d=70cm

Freq.,Hz	SIL_{40}',dB	SIL_{40}'',dB	D32,dB	L_{allow},dB
125	72.30	72.46	0.16	1.5
160	69.44	69.62	0.18	1.5
200	70.20	70.42	0.22	1.0
250	70.64	70.92	0.28	1.0
315	67.31	67.63	0.32	1.0
400	60.53	60.86	0.33	1.0
500	57.58	58.02	0.44	1.0
630	62.91	63.45	0.54	1.0
800	62.16	63.31	1.15	0.75
1000	62.88	64.29	1.41	0.75
1250	61.95	62.61	0.66	0.75
1600	51.39	52.42	1.03	0.75
2000	50.33	52.01	1.68	0.75
2500	54.24	53.19	1.05	0.75
3150	52.10	51.40	0.70	0.75
4000	48.98	49.00	0.02	0.75

Table A1-1.25 $D32_{80}$ Indicators and
its Allowable Values, d=70cm

Freq.,Hz	SIL_{80}',dB	SIL_{80}'',dB	D32,dB	L_{allow},dB
125	72.12	72.39	0.27	1.5
160	69.33	69.41	0.08	1.5
200	70.20	70.29	0.09	1.0
250	70.64	70.81	0.17	1.0
315	67.51	67.67	0.16	1.0
400	60.67	60.85	0.18	1.0
500	57.61	57.85	0.24	1.0
630	63.10	62.80	0.30	1.0
800	62.94	62.29	0.65	0.75
1000	63.87	62.94	0.93	0.75
1250	61.82	61.85	0.03	0.75
1600	51.95	51.68	0.27	0.75
2000	50.63	50.82	0.19	0.75
2500	53.90	54.32	0.42	0.75
3150	51.60	52.01	0.41	0.75
4000	49.43	49.13	0.30	0.75

Table A1-1.26 $D32_{160}$ Indicators and its Allowable Values, d=70cm

Freq.,Hz	SIL_{160}',dB	SIL_{160}'',dB	D32,dB	L_{allow},dB
125	72.26	72.31	0.05	1.5
160	69.37	69.46	0.09	1.5
200	70.24	70.29	0.05	1.0
250	70.72	70.78	0.06	1.0
315	67.59	67.64	0.05	1.0
400	60.76	60.79	0.03	1.0
500	57.73	57.81	0.08	1.0
630	62.95	63.01	0.06	1.0
800	62.63	62.72	0.09	0.75
1000	63.43	63.72	0.29	0.75
1250	61.83	62.00	0.17	0.75
1600	51.82	52.02	0.20	0.75
2000	51.25	51.83	0.58	0.75
2500	54.12	54.42	0.30	0.75
3150	51.81	52.09	0.28	0.75
4000	49.28	49.44	0.16	0.75

Table A1-1.27 D41 Indicators for SWL

Freq.,Hz	$D41_{1-2}$,dB	$D41_{1-3}$,dB	$D41_{2-3}$,dB
125	0.66	0.67	0.01
160	0.25	0.09	0.16
200	0.55	0.51	0.04
250	1.62	0.60	1.02
315	0.36	0.31	0.67
400	0.77	0.00	0.77
500	0.50	0.30	0.20
630	0.26	0.11	0.15
800	0.13	0.77	0.90
1000	0.01	0.09	0.10
1250	0.07	0.27	0.34
1600	0.63	0.57	0.06
2000	0.04	0.10	0.14
2500	0.26	0.65	0.39
3150	0.48	0.85	0.37
4000	0.13	0.09	0.04

Table A1-1.28 D42 Indicators for SWL

Freq.,Hz	D42,dB	Freq.,Hz	D42,dB
125	-21.31	800	-18.78
160	-30.67	1000	-37.91
200	-22.86	1250	-27.76
250	-14.33	1600	-22.14
315	-22.23	2000	-35.62
400	-19.56	2500	-22.40
500	-24.79	3150	-20.12
630	-30.42	4000	-36.27

Table A1-1.29 Probe Reversal Test Result

Freq.,Hz	SIL$_1$,dB	SIL$_2$,dB	Er,dB	ANSI$_{allow}$	ISO$_{allow}$
125	49.5	-48.7	0.8	1.5	1.5
160	47.0	-46.8	0.2	1.5	1.5
200	47.2	-46.9	0.3	1.0	1.5
250	51.3	-50.4	0.9	1.0	1.5
315	50.7	-50.7	0.0	1.0	1.5
400	49.5	-49.1	0.4	1.0	1.5
500	47.2	-47.0	0.2	1.0	1.5
630	52.5	-52.4	0.1	1.0	1.5
800	54.1	-54.2	0.1	1.0	1.5
1000	58.9	-58.7	0.2	1.0	1.5
1250	54.6	-54.4	0.2	1.0	1.5
1600	54.1	-54.3	0.2	1.0	1.5
2000	53.6	-53.4	0.2	1.0	1.5
2500	49.7	-49.6	0.1	1.0	1.5
3150	45.7	-45.6	0.1	1.0	1.5
4000	47.3	-47.4	0.1	1.0	1.5

Table A1-1.30 Convergence Indices $\delta_{10\text{-}20}$, d=70cm

Freq.Hz	$Power_{10}$	$Power_{20}$	$\delta_{10\text{-}20}$	Tolerance
125	82.82	81.94	0.88	1.5
160	79.82	79.01	0.81	1.5
200	80.95	79.75	1.20	1.0
250	81.52	80.18	1.34	1.0
315	78.85	76.83	2.02	1.0
400	71.63	70.04	1.59	1.0
500	67.43	67.09	0.34	1.0
630	72.08	72.31	-0.23	-1.0
800	72.00	71.43	0.57	0.75
1000	73.31	71.86	1.45	0.75
1250	68.41	71.13	-2.72	-0.75
1600	60.13	60.82	-0.69	-0.75
2000	61.60	58.14	3.46	0.75
2500	65.75	63.25	2.50	0.75
3150	63.46	61.50	1.96	0.75
4000	60.19	58.59	1.60	0.75

Table A1-1.31 Convergence Indices $\delta_{20\text{-}40}$, d=70cm

Freq.Hz	$Power_{20}$	$Power_{40}$	$\delta_{20\text{-}40}$	Tolerance
125	81.94	81.81	0.13	1.5
160	79.01	78.95	0.06	1.5
200	79.75	79.71	0.04	1.0
250	80.18	80.15	0.03	1.0
315	76.83	76.82	0.01	1.0
400	70.04	70.05	-0.01	-1.0
500	67.09	67.09	0.00	1.0
630	72.31	72.42	-0.11	-1.0
800	71.43	71.67	-0.24	-0.75
1000	71.86	72.39	-0.53	-0.75
1250	71.13	71.46	-0.33	-0.75
1600	60.82	60.90	-0.08	-0.75
2000	58.14	59.84	-1.70	-0.75
2500	63.25	63.75	-0.50	-0.75
3150	61.50	61.61	-0.11	-0.75
4000	58.59	58.50	0.09	0.75

Table A1-1.32 Convergence Indices δ_{40-80}, d=70cm

Freq.Hz	Power_{40}	Power_{80}	δ_{40-80}	Tolerance
125	81.81	81.63	0.18	1.5
160	78.95	78.84	0.11	1.5
200	79.71	79.71	0.00	1.0
250	80.15	80.15	0.00	1.0
315	76.82	77.02	-0.2	-1.0
400	70.05	70.18	-0.13	-1.0
500	67.09	67.12	-0.03	-1.0
630	72.42	72.62	-0.20	-1.0
800	71.67	72.45	-0.78	-0.75
1000	72.39	73.39	-1.00	-0.75
1250	71.46	71.33	0.13	0.75
1600	60.90	61.46	-0.56	-0.75
2000	59.84	61.15	-1.31	-0.75
2500	63.75	63.41	0.34	-0.75
3150	61.61	61.12	0.49	0.75
4000	58.50	58.94	-0.44	-0.75

Table A1-1.33 Convergence Indices δ_{80-160}, d=70cm

Freq.Hz	Power_{80}	Power_{160}	δ_{80-160}	Tolerance
125	81.63	81.77	-0.14	-1.5
160	78.84	78.89	-0.05	-1.5
200	79.71	79.76	-0.05	-1.0
250	80.15	80.24	-0.09	-1.0
315	77.02	77.11	-0.09	-1.0
400	70.18	70.28	-0.10	-1.0
500	67.12	67.25	-0.13	-1.0
630	72.62	72.47	0.15	1.0
800	72.45	72.14	0.31	0.75
1000	73.39	72.94	0.45	0.75
1250	71.33	71.35	-0.02	-0.75
1600	61.46	61.33	0.13	0.75
2000	61.15	60.76	0.39	0.75
2500	63.41	63.63	-0.22	-0.75
3150	61.12	61.33	-0.21	-0.75
4000	58.94	58.80	0.14	0.75

Table A1-1.34 Convergence Indices $\delta_{160-320}$, d=70cm

Freq.Hz	$Power_{160}$	$Power_{320}$	$\delta_{160-320}$	Tolerance
125	81.77	81.79	-0.02	-1.5
160	78.89	78.93	-0.04	-1.5
200	79.76	79.78	-0.02	-1.0
250	80.24	80.26	-0.02	-1.0
315	77.11	77.12	-0.01	-1.0
400	70.28	70.28	0.00	1.0
500	67.25	67.28	-0.03	-1.0
630	72.47	72.49	-0.02	-1.0
800	72.14	72.18	-0.04	-0.75
1000	72.94	73.09	-0.15	-0.75
1250	71.35	71.43	-0.08	-0.75
1600	61.33	61.43	-0.10	-0.75
2000	60.76	61.06	-0.30	-0.75
2500	63.63	63.78	-0.15	-0.75
3150	61.33	61.46	-0.13	-0.75
4000	58.80	58.87	-0.07	-0.75

Table A1-1.35 Convergence Indices δ_{10-20}, d=10cm

Freq.Hz	$Power_{10}$	$Power_{20}$	δ_{10-20}	Tolerance
125	81.93	80.90	1.03	1.5
160	79.55	78.55	1.00	1.5
200	80.71	80.04	0.67	1.0
250	80.00	79.38	0.62	1.0
315	78.12	77.30	0.82	1.0
400	70.57	70.04	0.53	1.0
500	67.28	66.47	0.81	1.0
630	72.29	71.58	0.71	1.0
800	71.69	70.50	1.19	0.75
1000	73.00	72.10	0.90	0.75
1250	70.52	70.99	-0.47	-0.75
1600	61.30	59.95	1.35	0.75
2000	62.54	59.91	2.63	0.75
2500	63.25	60.69	2.56	0.75
3150	59.47	60.79	-1.32	-0.75
4000	57.10	56.70	0.40	0.75

Table A1-1.36 Convergence Indices δ_{20-40}, d=10cm

Freq.Hz	$Power_{20}$	$Power_{40}$	δ_{20-40}	Tolerance
125	80.90	80.87	0.03	1.5
160	78.55	78.54	0.01	1.5
200	80.04	79.97	0.07	1.0
250	79.38	79.34	0.04	1.0
315	77.30	77.11	0.19	1.0
400	70.04	69.95	0.09	1.0
500	66.47	66.54	-0.07	-1.0
630	71.58	71.71	-0.13	-1.0
800	70.50	70.78	-0.28	-0.75
1000	72.10	72.54	-0.44	-0.75
1250	70.99	71.10	-0.11	-0.75
1600	59.95	60.59	-0.64	-0.75
2000	59.91	60.16	-0.25	-0.75
2500	60.69	60.51	0.18	0.75
3150	60.79	60.76	0.03	0.75
4000	56.70	57.17	-0.47	-0.75

Table A1-1.37 Convergence Indices δ_{40-80}, d=10cm

Freq.Hz	$Power_{40}$	$Power_{80}$	δ_{40-80}	Tolerance
125	80.87	81.09	-0.22	-1.5
160	78.54	78.86	-0.32	-1.5
200	79.97	80.30	-0.33	-1.0
250	79.34	79.64	-0.30	-1.0
315	77.11	77.09	0.02	1.0
400	69.95	70.07	-0.12	-1.0
500	66.54	66.88	-0.34	-1.0
630	71.71	72.38	-0.67	-1.0
800	70.78	71.47	-0.69	-0.75
1000	72.54	73.41	-0.87	-0.75
1250	71.10	71.73	-0.63	-0.75
1600	60.59	61.28	-0.69	-0.75
2000	60.16	61.07	-0.91	-0.75
2500	60.51	62.78	-2.27	-0.75
3150	60.76	62.50	-1.74	-0.75
4000	57.17	59.19	-2.02	-0.75

Table A1-1.38 Convergence Indices $\delta_{80\text{-}160}$, d=10cm

Freq.Hz	Power_{80}	Power_{160}	$\delta_{80\text{-}160}$	Tolerance
125	81.09	81.10	-0.01	-1.5
160	78.86	78.81	0.05	1.5
200	80.30	80.28	0.02	1.0
250	79.64	79.67	-0.03	-1.0
315	77.09	77.40	-0.31	-1.0
400	70.07	70.25	-0.18	-1.0
500	66.88	66.92	-0.04	-1.0
630	72.38	72.30	0.08	1.0
800	71.47	71.33	0.14	0.75
1000	73.41	73.01	0.40	0.75
1250	71.73	71.70	0.03	0.75
1600	61.28	60.86	0.42	0.75
2000	61.07	61.17	-0.10	-0.75
2500	62.78	63.07	-0.29	-0.75
3150	62.50	62.13	0.37	0.75
4000	59.19	59.08	0.11	0.75

Table A1-1.39 Convergence Indices $\delta_{160\text{-}320}$, d=10cm

Freq.Hz	Power_{160}	Power_{320}	$\delta_{160\text{-}320}$	Tolerance
125	81.10	81.12	-0.02	-1.5
160	78.81	78.84	-0.03	-1.5
200	80.28	80.29	-0.01	-1.0
250	79.67	79.66	0.01	1.0
315	77.40	77.43	-0.03	-1.0
400	70.25	70.28	-0.03	-1.0
500	66.92	66.98	-0.06	-1.0
630	72.30	72.38	-0.08	-1.0
800	71.33	71.41	-0.08	-0.75
1000	73.01	73.00	0.01	0.75
1250	71.70	71.70	0.00	0.75
1600	60.86	60.86	0.00	0.75
2000	61.17	61.16	0.01	0.75
2500	63.07	63.13	-0.06	-0.75
3150	62.13	62.31	-0.18	-0.75
4000	59.08	58.96	0.12	0.75

TABLES FOR CHAPTER 4

1-D: TRANSMISSION LOSS TESTS

Table A1-2.1 TL at Different Distance

Freq.,Hz	d=10cm,dB	d=30cm,dB	d=40cm,dB
125	5.16	5.95	5.92
160	4.73	4.98	5.46
200	2.65	3.21	3.35
250	4.03	4.41	5.03
315	5.28	5.33	6.13
400	9.31	9.77	10.99
500	13.34	13.80	14.65
630	16.47	16.76	17.44
800	18.13	19.44	19.50
1000	20.94	20.07	20.49
1250	22.67	22.22	22.46
1600	24.66	24.04	24.16
2000	26.16	24.89	24.83
2500	28.38	26.60	25.97
3150	29.05	28.84	27.81
4000	29.45	30.49	29.62

Table A1-2.2 Surface Intensity Level for TL Tests

Freq.Hz	d=10cm,dB	d=30cm,dB	d=40cm,dB
125	78.46	79.73	74.05
160	78.93	79.17	77.37
200	78.14	77.85	78.60
250	79.43	79.21	78.07
315	78.30	78.30	76.59
400	73.11	72.66	71.12
500	69.38	68.84	69.47
630	63.81	63.59	66.22
800	64.03	62.92	62.98
1000	61.04	62.07	61.75
1250	61.07	61.64	60.25
1600	59.74	60.38	58.59
2000	58.50	59.84	58.25
2500	55.64	57.49	57.67
3150	55.24	55.47	55.09
4000	55.58	54.62	53.46

Table A1-2.3 Surface Pressure Level for TL Tests

Freq.Hz	d=10cm,dB	d=30cm,dB	d=40cm,dB
125	80.96	81.18	76.58
160	81.95	80.55	79.99
200	81.14	79.75	81.41
250	82.74	81.49	81.41
315	82.24	80.63	80.19
400	77.77	75.54	75.45
500	75.38	72.41	74.32
630	70.52	68.06	71.19
800	70.43	68.53	68.97
1000	69.10	66.86	67.30
1250	68.15	66.33	66.07
1600	66.00	64.92	63.90
2000	63.87	63.57	62.70
2500	61.39	61.49	62.38
3150	60.59	60.19	60.28
4000	60.26	59.55	59.24

Table A1-2.4 Random Error of TL Tests

Freq.,Hz	Er,dB	Er_{allow}	Freq.,Hz	Er,dB	Er_{allow}
125	0.45	3	800	0.77	1
160	0.37	3	1000	0.44	1
200	0.37	2	1250	0.23	1
250	0.50	2	1600	0.33	1
315	0.48	1	2000	0.75	1
400	0.87	1	2500	1.25	1
500	0.66	1	3150	0.66	1
630	0.50	1	4000	0.56	1

Table A1-2.5 Residual Pressure-Intensity Index of Instrumentation for TL Tests

Freq.,Hz	PII,dB	Freq.,Hz	PII,dB
125	12.6	800	20.7
160	17.2	1000	22.1
200	14.4	1250	20.5
250	15.3	1600	19.0
315	18.4	2000	18.1
400	13.4	2500	19.6
500	21.6	3150	19.3
630	19.3	4000	13.7

Table A1-2.6 Phase Mismatch Errors on TL Tests

Freq.,Hz	d=10cm	d=30cm	d=40cm
125	0.45	0.35	0.45
160	0.17	0.12	0.15
200	0.33	0.25	0.31
250	0.28	0.22	0.29
315	0.16	0.11	0.15
400	0.62	0.40	0.57
500	0.12	0.07	0.09
630	0.25	0.15	0.16
800	0.16	0.14	0.15
1000	0.17	0.08	0.10
1250	0.20	0.12	0.15
1600	0.24	0.16	0.19
2000	0.23	0.16	0.19
2500	0.18	0.12	0.14
3150	0.18	0.15	0.17
4000	0.58	0.62	0.76

Table A1-2.7 TL and its Total Error Bounds

Freq.,Hz	TL,dB	E_{total}	Freq.,Hz	TL,dB	E_{total}
125	5.68	2.74	800	19.02	1.54
160	5.06	1.73	1000	20.50	1.01
200	3.07	1.34	1250	22.45	0.97
250	4.49	1.27	1600	24.29	1.30
315	5.58	1.24	2000	25.29	1.52
400	10.02	2.02	2500	26.98	1.88
500	13.93	1.28	3150	28.57	1.37
630	16.89	1.38	4000	29.85	2.01

Table A1-2.8 Indicator T2 and Dynamic Capability Index Ld values for TL Tests

Freq.Hz	Ld,dB	T2,dB		
		d=10cm	d=30cm	d=40cm
125	2.60	2.50	1.45	2.53
160	7.20	3.02	1.38	2.63
200	4.40	3.00	1.90	2.81
250	5.30	3.30	2.28	3.33
315	8.40	3.95	2.33	3.59
400	3.40	4.66	2.88	4.33
500	11.60	5.99	3.57	4.86
630	9.30	6.71	4.47	4.97
800	10.70	6.40	5.61	5.99
1000	12.10	8.05	4.78	5.54
1250	10.50	7.09	4.69	5.82
1600	9.00	6.26	4.55	5.29
2000	8.10	5.36	3.73	4.45
2500	9.60	5.74	4.00	4.71
3150	9.30	5.35	4.72	5.19
4000	3.70	4.68	4.93	5.78

Table A1-2.9 Normalized Surface Intensity Standard Deviation(dB) on TL Tests

Freq.,Hz	d=10cm	d=30cm	d=40cm
125	0.34	0.49	0.82
160	0.29	0.42	0.67
200	0.30	0.35	0.57
250	0.30	0.35	0.57
315	0.24	0.30	0.52
400	0.39	0.37	0.55
500	0.40	0.27	0.51
630	0.35	0.37	0.61
800	0.64	0.51	0.71
1000	0.92	0.59	0.78
1250	0.78	0.60	0.89
1600	0.97	0.71	1.10
2000	1.78	1.40	1.56
2500	1.97	1.39	1.48
3150	2.20	1.14	1.34
4000	1.97	1.19	1.26

Table A1-2.10 Adequacy of Measurement Points on 10cm Surface for TL Tests

Freq.,Hz	N_{USED}	$N_{PRE.}$	$N_{ENG.}$
125	143	20	20
160	143	20	20
200	143	20	20
250	143	20	20
315	143	20	20
400	143	20	20
500	143	20	20
630	143	20	20
800	143	37	20
1000	143	76	24
1250	143	55	20
1600	143	85	27
2000	143	286	89
2500	143	350	109
3150	143	436	136
4000	143	350	109

Table A1-2.11 Adequacy of Measurement Points on 30cm Surface for TL Tests

Freq.,Hz	N_{USED}	$N_{PRE.}$	$N_{ENG.}$
125	143	20	20
160	143	20	20
200	143	20	20
250	143	20	20
315	143	20	20
400	143	20	20
500	143	20	20
630	143	20	20
800	143	24	20
1000	143	32	20
1250	143	33	20
1600	143	46	20
2000	143	177	55
2500	143	174	55
3150	143	117	37
4000	143	128	40

Table A1-2.12 Adequacy of Measurement Points on 40cm Surface for TL Tests

Freq.,Hz	N_{USED}	$N_{PRE.}$	$N_{ENG.}$
125	191	20	20
160	191	20	20
200	191	20	20
250	191	20	20
315	191	20	20
400	191	20	20
500	191	20	20
630	191	20	20
800	191	46	20
1000	191	55	20
1250	191	72	23
1600	191	109	34
2000	191	220	69
2500	191	198	62
3150	191	162	51
4000	191	143	45

TABLES FOR CHAPTER 5

3-D: SOUND POWER AND TL TESTS

Table A1-3.1 Sound Power Level from 3-D Tests

Freq.Hz	d=10cm,dB	d=30cm,dB	d=70cm,dB
125	82.00	82.89	83.57
160	80.44	81.26	81.58
200	81.60	82.55	82.44
250	81.99	83.52	82.10
315	78.98	79.78	79.38
400	72.38	73.07	72.78
500	68.96	69.44	69.75
630	74.63	74.81	75.20
800	72.27	72.85	73.58
1000	74.55	75.90	75.29
1250	72.86	74.47	73.08
1600	63.80	64.63	64.55
2000	64.25	64.59	64.47
2500	65.43	66.63	66.59
3150	64.42	65.49	65.51
4000	61.28	62.76	62.00

Table A1-3.2 Average SIL from 3-D Tests

Freq.Hz	d=10cm,dB	d=30cm,dB	d=70cm,dB
125	82.86	78.34	74.05
160	81.30	76.72	72.07
200	82.46	78.01	72.92
250	82.85	78.98	72.58
315	79.84	75.24	69.86
400	73.23	68.53	63.27
500	69.82	64.90	60.24
630	75.49	70.27	65.69
800	73.13	68.31	64.07
1000	75.41	71.36	65.77
1250	73.71	69.93	63.57
1600	64.66	60.09	55.03
2000	65.11	60.05	54.96
2500	66.29	62.08	57.08
3150	65.27	60.95	55.99
4000	62.14	58.21	52.48

Table A1-3.3 Average SPL from 3-D Tests

Freq.Hz	d=10cm,dB	d=30cm,dB	d=70cm,dB
125	83.72	78.38	73.20
160	82.13	77.30	72.82
200	83.10	79.04	74.96
250	83.13	79.20	73.39
315	80.13	75.02	70.81
400	74.05	68.32	63.63
500	70.35	65.64	60.87
630	76.36	71.40	65.12
800	73.89	68.80	65.06
1000	76.46	72.35	67.40
1250	74.32	70.15	63.65
1600	65.72	61.00	56.21
2000	66.18	60.80	56.09
2500	67.34	62.84	58.18
3150	66.38	61.67	56.83
4000	63.59	59.32	53.90

Table A1-3.4 Variation of Source for 3-D SWL Tests

Freq.Hz	σ,dB	Freq.Hz	σ,dB
125	0.65	800	0.21
160	0.55	1000	0.29
200	0.36	1250	0.21
250	0.06	1600	0.15
315	0.29	2000	0.21
400	0.30	2500	0.26
500	0.70	3150	0.06
630	0.38	4000	0.21

Table A1-3.5 Random Errors on 3-D SWL Tests

Freq.Hz	Er,dB	$\text{Allow}_{\text{Pre.}}$,dB	$\text{Allow}_{\text{Eng.}}$,dB
125	0.79	2.0	3.0
160	0.59	2.0	3.0
200	0.52	1.5	2.0
250	0.85	1.5	2.0
315	0.40	1.5	2.0
400	0.35	1.5	2.0
500	0.40	1.5	2.0
630	0.29	1.5	2.0
800	0.66	1.0	1.5
1000	0.68	1.0	1.5
1250	0.87	1.0	1.5
1600	0.46	1.0	1.5
2000	0.17	1.0	1.5
2500	0.68	1.0	1.5
3150	0.62	1.0	1.5
4000	0.74	1.0	1.5

Table A1-3.6 Residual Pressure-intensity Indices of 3-D Probe for SWL Tests

Freq.Hz	Pair 1,dB	Pair 2,dB	Pair 3,dB
125	10.4	16.2	13.0
160	10.8	10.3	13.6
200	10.9	12.3	14.4
250	17.1	14.4	16.0
315	10.1	10.7	16.2
400	16.5	19.2	23.5
500	13.2	14.1	17.1
630	16.4	18.0	20.9
800	15.0	18.1	21.7
1000	15.1	18.7	24.9
1250	15.1	18.7	22.2
1600	14.4	19.4	23.6
2000	15.1	19.6	28.3
2500	14.8	19.7	33.7
3150	15.7	26.3	20.1
4000	15.6	23.2	24.1

Table A1-3.7 Phase Mismatch Errors on 3-D SWL Tests

Freq.Hz	d=10cm,dB	d=30cm,dB	d=70cm,dB
125	0.27	0.23	0.27
160	0.24	0.22	0.23
200	0.19	0.20	0.26
250	0.12	0.12	0.13
315	0.11	0.11	0.13
400	0.02	0.02	0.02
500	0.10	0.10	0.10
630	0.04	0.05	0.04
800	0.04	0.03	0.04
1000	0.02	0.02	0.02
1250	0.03	0.03	0.03
1600	0.02	0.02	0.02
2000	0.01	0.01	0.01
2500	0.00	0.00	0.00
3150	0.06	0.05	0.05
4000	0.02	0.02	0.02

Table A1-3.8 Mean SWL and Total Error Bounds

Freq.Hz	SWL,dB	Er_{tot},dB	Freq.Hz	SWL,dB	Er_{tot},dB
125	82.82	1.08	800	72.90	0.71
160	81.09	0.84	1000	75.25	0.72
200	82.20	0.79	1250	73.47	0.94
250	82.54	0.99	1600	64.33	0.55
315	79.38	0.54	2000	64.44	0.31
400	72.74	0.38	2500	66.22	0.89
500	69.38	0.51	3150	65.14	1.02
630	74.88	0.68	4000	62.01	1.32

Table A1-3.9 Dynamic Capability Index and F2 Indicators for 3-D SWL Tests

Freq. Hz	Ld,dB	F2,dB		
		d=10cm	d=30cm	d=70cm
125	3.0	0.81	0.13	-0.85
160	3.6	0.86	0.70	0.75
200	4.4	0.65	1.16	2.10
250	6.0	0.28	0.34	0.92
315	6.2	0.35	-0.22	1.05
400	13.5	0.90	-0.21	0.38
500	7.1	0.56	0.78	0.57
630	10.9	0.87	1.21	-0.57
800	11.7	0.76	0.53	1.00
1000	14.9	1.08	1.08	1.75
1250	12.2	0.60	0.32	0.09
1600	13.6	1.07	0.99	1.24
2000	18.3	1.10	0.81	1.25
2500	23.7	1.06	0.82	1.16
3150	10.1	1.18	0.77	0.94
4000	14.1	1.49	1.15	1.49

Table A1-3.10 Adequacy of Measuring Array of 3-D SWL Tests at 10cm surface

Freq.Hz	F4,dB	No.$_{used}$	No.$_{precision}$	No.$_{engineering}$
125	0.93	180	20	20
160	0.74	180	20	20
200	0.62	180	20	20
250	0.58	180	20	20
315	0.64	180	20	20
400	1.04	180	31	20
500	1.54	180	67	36
630	1.63	180	75	40
800	1.70	180	262	82
1000	1.20	180	131	41
1250	0.80	180	58	20
1600	0.91	180	74	23
2000	1.23	180	136	43
2500	1.15	180	119	37
3150	1.11	180	112	35
4000	1.00	180	90	28

Table A1-3.11 Adequacy of Measuring Array of 3-D SWL Tests at 30cm surface

Freq.Hz	F4,dB	$No._{used}$	$No._{precision}$	$No._{engineering}$
125	0.44	180	20	20
160	0.44	180	20	20
200	0.46	180	20	20
250	0.48	180	20	20
315	0.52	180	20	20
400	0.84	180	20	20
500	1.42	180	57	31
630	1.60	180	73	39
800	1.77	180	281	88
1000	1.37	180	170	53
1250	0.93	180	78	25
1600	0.95	180	82	26
2000	1.66	180	247	77
2500	1.17	180	124	39
3150	1.03	180	95	30
4000	1.34	180	162	51

Table A1-3.12 Adequacy of Measuring Array of 3-D SWL Tests at 70cm surface

Freq.Hz	F4,dB	$No._{used}$	$No._{precision}$	$No._{engineering}$
125	0.40	180	20	20
160	0.38	180	20	20
200	0.30	180	20	20
250	0.47	180	20	20
315	0.58	180	20	20
400	0.93	180	25	20
500	1.41	180	56	30
630	1.53	180	66	35
800	1.94	180	338	105
1000	1.40	180	178	56
1250	0.88	180	71	22
1600	0.88	180	71	22
2000	1.32	180	158	49
2500	0.98	180	86	27
3150	1.07	180	103	32
4000	0.92	180	77	24

Table A1-3.13 TL from 3-D Tests

Freq.Hz	d=10cm,dB	d=30cm,dB	d=40cm,dB
125	20.36	19.66	19.39
160	21.65	21.75	21.36
200	20.08	19.88	19.45
250	20.54	20.08	19.83
315	23.87	23.44	23.03
400	24.80	25.69	25.65
500	25.87	28.07	27.81
630	27.29	29.50	29.34
800	29.80	32.26	32.25
1000	32.07	32.95	33.33
1250	33.18	32.93	33.16
1600	34.71	35.06	35.58
2000	34.81	35.45	35.56
2500	37.76	37.32	38.10
3150	38.73	39.05	39.57
4000	38.86	37.65	37.57

Table A1-3.14 Average SIL from 3-D TL Tests

Freq.Hz	d=10cm,dB	d=30cm,dB	d=40cm,dB
125	55.02	55.52	55.17
160	55.08	54.76	54.54
200	56.69	56.66	56.48
250	54.35	54.53	54.20
315	49.67	49.73	49.58
400	50.74	49.71	49.08
500	55.56	53.32	52.90
630	50.02	47.59	47.12
800	43.64	40.81	40.08
1000	38.36	37.22	36.09
1250	41.07	40.98	39.98
1600	45.13	44.38	43.05
2000	49.37	48.19	47.16
2500	48.91	48.58	47.03
3150	46.16	44.67	43.38
4000	43.11	43.22	42.76

Table A1-3.15 Average SPL from 3-D TL Tests

Freq.Hz	d=10cm,dB	d=30cm,dB	d=40cm,dB
125	58.52	56.81	56.83
160	58.93	57.29	57.11
200	61.48	59.58	59.30
250	59.09	57.23	56.97
315	54.92	52.74	52.53
400	55.97	52.95	52.69
500	60.64	56.66	56.26
630	54.80	50.81	50.14
800	48.00	44.34	43.92
1000	44.01	40.99	40.41
1250	47.37	44.83	44.21
1600	51.12	48.29	47.62
2000	54.33	51.63	51.15
2500	53.80	51.68	51.10
3150	50.64	48.10	47.85
4000	48.22	46.89	47.38

Table A1-3.16 Random Error of 3-D TL Tests

Freq.Hz	Er,dB	Er_{allow},dB	Freq.Hz	Er,dB	Er_{allow},dB
125	0.50	3	800	1.42	1
160	0.20	3	1000	0.65	1
200	0.32	2	1250	0.14	1
250	0.36	2	1600	0.44	1
315	0.42	1	2000	0.41	1
400	0.50	1	2500	0.39	1
500	1.20	1	3150	0.42	1
630	1.23	1	4000	0.72	1

Table A1-3.17 Residual Pressure-intensity Indices of 3-D Probe for TL Tests

Freq.Hz	Pair 1,dB	Pair 2,dB	Pair 3,dB
125	17.2	24.4	11.7
160	24.3	16.3	12.2
200	25.3	16.8	13.5
250	27.6	17.7	14.0
315	15.1	13.8	12.5
400	20.2	22.1	16.2
500	21.6	20.3	16.8
630	17.8	21.1	15.9
800	17.4	19.9	16.5
1000	[illegible].6	21.6	18.5
1250	16.5	20.4	17.7
1600	17.6	24.7	18.7
2000	16.9	21.8	19.9
2500	17.6	22.9	23.4
3150	17.5	20.3	18.6
4000	18.0	19.4	17.3

Table A1-3.18 Probe Reversal Test Result for Each Pair of 3-D Probe

Freq.Hz	1st,dB	2nd,dB	3rd,dB	$\text{ANSI}_{\text{allow}}$	$\text{ISO}_{\text{allow}}$
125	0.6	1.3	1.4	1.5	1.5
160	1.5	0.1	0.4	1.5	1.5
200	0.2	0.5	0.7	1.0	1.5
250	0.2	0.4	0.2	1.0	1.5
315	0.2	0.2	0.1	1.0	1.5
400	0.0	0.1	0.4	1.0	1.5
500	0.6	0.3	0.5	1.0	1.5
630	0.0	0.4	0.1	1.0	1.5
800	0.2	0.8	0.2	1.0	1.5
1000	0.2	0.6	0.2	1.0	1.5
1250	0.2	0.6	0.1	1.0	1.5
1600	0.1	0.3	0.1	1.0	1.5
2000	0.2	0.5	0.1	1.0	1.5
2500	0.3	0.3	0.4	1.0	1.5
3150	0.3	0.1	0.8	1.0	1.5
4000	0.3	0.6	0.0	1.0	1.5

Table A1-3.19 Phase Mismatch Errors on 3-D TL Tests

Freq.Hz	d=10cm,dB	d=30cm,dB	d=40cm,dB
125	0.71	0.41	0.45
160	0.69	0.50	0.50
200	0.63	0.40	0.39
250	0.55	0.33	0.34
315	0.91	0.52	0.51
400	0.36	0.23	0.25
500	0.30	0.20	0.20
630	0.35	0.24	0.23
800	0.27	0.23	0.24
1000	0.23	0.15	0.17
1250	0.33	0.18	0.20
1600	0.24	0.15	0.17
2000	0.14	0.10	0.11
2500	0.06	0.05	0.05
3150	0.17	0.13	0.17
4000	0.27	0.19	0.24

Table A1-3.20 Mean TL and Total Error Bounds

Freq.Hz	TL,dB	Er_{tot},dB	Freq.Hz	TL,dB	Er_{tot},dB
125	19.80	2.66	800	31.44	2.06
160	21.59	1.37	1000	32.78	1.07
200	19.80	1.73	1250	33.09	0.74
250	20.15	1.19	1600	35.12	1.29
315	23.45	1.74	2000	35.27	0.96
400	25.38	1.11	2500	37.73	0.85
500	27.25	1.83	3150	39.12	1.28
630	28.71	1.94	4000	38.03	1.82

Table A1-3.21 Dynamic Capability Index Ld$_{TL}$ and T2 Indicators for 3-D TL Tests

Freq. Hz	Ld,dB	T2,dB		
		d=10cm	d=30cm	d=40cm
125	4.7	3.50	1.29	1.66
160	5.2	3.85	2.54	2.57
200	6.5	4.79	2.92	2.82
250	7.0	4.74	2.70	2.77
315	5.5	5.25	3.01	2.95
400	9.2	5.23	3.24	3.61
500	9.8	5.08	3.34	3.36
630	8.9	4.78	3.22	3.02
800	9.5	4.36	3.53	3.84
1000	11.5	5.65	3.77	4.32
1250	10.7	6.30	3.85	4.23
1600	11.7	5.99	3.91	4.57
2000	12.9	4.96	3.44	3.99
2500	16.4	4.89	3.10	4.07
3150	11.6	4.48	3.43	4.47
4000	10.3	5.11	3.67	4.62

Table A1-3.22 Adequacy of Measuring Array of 3-D TL Tests at 10cm surface

Freq.Hz	T3,dB	No.$_{used}$	No.$_{required}$
125	1.15	143	20
160	1.53	143	20
200	2.07	143	65
250	1.63	143	40
315	1.88	143	54
400	1.78	143	48
500	1.95	143	58
630	2.17	143	71
800	2.52	143	178
1000	2.12	143	126
1250	1.78	143	89
1600	1.28	143	46
2000	1.61	143	73
2500	2.05	143	118
3150	2.16	143	131
4000	1.60	143	72

Table A1-3.23 Adequacy of Measuring Array of 3-D TL Tests at 30cm surface

Freq.Hz	T3,dB	$No._{used}$	$No._{required}$
125	0.81	143	20
160	1.04	143	20
200	1.32	143	27
250	1.13	143	20
315	1.04	143	20
400	0.94	143	20
500	0.83	143	20
630	0.97	143	20
800	1.19	143	40
1000	0.94	143	25
1250	1.30	143	48
1600	1.04	143	31
2000	1.35	143	52
2500	1.80	143	91
3150	1.30	143	48
4000	1.29	143	47

Table A1-3.24 Adequacy of Measuring Array of 3-D TL Tests at 40cm surface

Freq.Hz	T3,dB	$No._{used}$	$No._{required}$
125	0.77	191	20
160	0.91	191	20
200	1.06	191	20
250	0.83	191	20
315	0.72	191	20
400	0.62	191	20
500	0.53	191	20
630	0.60	191	20
800	0.80	191	20
1000	0.77	191	20
1250	1.06	191	32
1600	0.88	191	22
2000	1.10	191	34
2500	1.31	191	49
3150	1.16	191	38
4000	1.67	191	79

APPENDEX 2[1]

List of Program for Sound Power Measurement

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[1] Whenever there are two or three consecutive underlined lines, they form only a single statement.

```
rem     **************** POWERa.bas ****************
rem     *       power measurement program            *
rem     *       for  1/3 octave band                 *
rem     *       Started on : 07.23.90                *
rem     *       Last modified : 07.27.90             *
rem     ********************************************

COMMON SHARED IBSTA%, IBERR%, IBCNT%
GPIB$ = "GPIB0"
BKP$ = "bk2134p":BKD$ = "bk2134d"
M$ = "Micro"
CALL IBFIND(GPIB$,BD%)
CALL IBFIND(M$,M%)
CALL IBFIND(BKP$,BKP%):CALL IBFIND(BKD$,BKD%)
color 11,0
DIM SPL1(42),SPL2(42),SPEC%(150),FLAG%(42),ILZ(42),Area(144)
DIM Freq(42),Pt(144,2),Virt(144,2),TI$(13),Power(42),temp$(13)
DIM FreqChoice$(6),ILX(42),ILY(42),numpoints(10)
FreqChoice$(1) = "250 Hz - 10 KHz"
FreqChoice$(2) = "125 Hz - 5 KHz"
FreqChoice$(3) = "125 Hz - 5 KHz"
FreqChoice$(4) = "31.5 Hz - 1.25 KHz"
Freq(16) = 50:Freq(15) = 40:Freq(14) = 31.5:Freq(17) = 63
Freq(18) = 80:Freq(19) = 100:Freq(20) = 125:Freq(21) = 160
Freq(22) = 200:Freq(23) = 250:Freq(24) = 315:Freq(25) = 400
Freq(26) = 500:Freq(27) = 630:Freq(28) = 800:Freq(29) = 1000
Freq(30) = 1250:Freq(31) = 1600:Freq(32) = 2000
Freq(33) = 2500:Freq(34) = 3150:Freq(35) = 4000
Freq(36) = 5000:Freq(37) = 6300:Freq(38) = 8000:Freq(39)=10000
TI$(1) = "03":TI$(2) = "04":TI$(3) = "05":TI$(4) = "06"
TI$(5) = "07":TI$(6) = "08":TI$(7) = "09":TI$(8) = "0:"
TI$(9) = "0;":TI$(10) = "0<":TI$(11) = "0=":TI$(12) = "0>"
TI$(13) = "0?"
CLS
ANA = 1
PRINT:PRINT "What sort of analysis is it?";:PRINT
PRINT:PRINT "1) One - Third Octave Analysis"
PRINT "2) Octave Band Analysis"
PRINT:PRINT"Choose an option please --> ";
Genloop1: ANA$ = INKEY$:IF ANA$ = "" THEN GOTO Genloop1
IF VAL(ANA$) = 2 THEN ANA = 2
CNT% = 301
CODE$="J>"
IF ANA = 1 THEN CODE$=CODE$ + "K>"
IF ANA = 2 THEN CODE$=CODE$ + "K?"
CALL IBWRT(BKP%,CODE$)
if ANA = 2 then RESET:run "powerb.exe":end
PRINT:Print
PRINT"PLEASE make sure that the 3360 is on DIRECT input..."
PRINT"Press any key to continue..."
Genloop2: ANA$ = INKEY$:IF ANA$ = "" THEN GOTO Genloop2
cls
```

```
RESET:shell "RBK1D.exe"
cls
Info$ = "Info.dat"
Print "What is the name of the parameter"
Print "    file(default:Info.dat)? "
Input Some$
If Some$ <> "" then Info$ = Some$
cls
DAT$ = "Test.dat"
Input "What's the name of data file(default:Test.dat)?",Kiron$
If Kiron$ <> "" then DAT$ = Kiron$
Cls
OPEN "O",#1,Dat$
Open "O",#3,Info$
cls
Input"What is the title for this experiment? ",Title$
Print #3,"Title: ";Title$
print #3,
Print #3,"Sound power measurement by intensity technique."
Print #3,"             1/3 octave band."
cls
PRINT:PRINT "What dimension of the analysis is it?";:PRINT
PRINT:PRINT "1)  1  Dimensional Analysis"
PRINT "2)  3  Dimensional Analysis"
PRINT:PRINT"Choose an option please --> ";
oop1: ANA$ = INKEY$:IF ANA$ = "" THEN GOTO oop1
if VAL(ANA$)=1 then dimen$="1D"
if VAL(ANA$)=2 then dimen$="3D"
Print #3,dimen$
cls
Input"What is the Room Temperature (degrees Celcius)? ",Temp
Print #3,"Environment temperature: ";Temp;" deg.(C)"
cls
Input"What is the Relative Humidity (%)? ",Humid
Print #3,"Relative humidity: ";Humid;"%"
cls
Input"What is the Barometric Pressure (mbar)? ",baro
Print #3,"Barometric pressure: ";baro;" mbar"
cls
Input"What is today's date(mm-dd-yy)? ",Dat$
Print #3,"Date of test done: ";Dat$
cls
Print"ASSEMBLE THE PROBE SYSTEM AND LOCATE"
Print "     AS REQUIRED,PLEASE!"
Print:Print:Print:Print
Print"Press any key to continue..."
Genloop3: A$ = inkey$:If A$ = "" then goto Genloop3
cls
Print"SWITCH SOURCE SOUND ON,PLEASE!"
Print:Print:Print:Print
Print"Press any key to continue..."
Genloop4: A$ = inkey$:If A$ = "" then goto Genloop4
```

```
cls
nec0:
Print "Microphone Selection Menu"
Print "-------------------------"
Print "1) 1/4 inch, 6 millimetre spacing"
Print "2) 1/4 inch, 12 millimetre spacing"
Print "3) 1/2 inch, 12 millimetre spacing"
Print "4) 1/2 inch, 50 millimetre spacing"
Print
Print "Please choose an item --> "
Nec1: ms$ = inkey$ : if ms$ = "" then goto nec1
ms = val(ms$)
print
print "The frequency range is ";freqchoice$(ms)
print
print "Are you satisfied with this range?(y/n)"
Nec2: answer$ = inkey$ :if answer$ = "" then goto nec2
if answer$ = "N" or answer$ = "n" then goto nec0
if ms = 1 or ms = 2 then corri = 20
if ms = 3 or ms = 4 then corri = 0
if ms = 1 then first = 23:last = 39
if ms = 2 then first = 20:last = 36
if ms = 3 then first = 20:last = 36
if ms = 4 then first = 14:last = 30
if ms=1 then print #3,"Mic. type is 1/4 inch 6mm spacing."
if ms = 2 then print #3,"Mic. type is 1/4 inch 12 mm spacing."
if ms = 3 then print #3,"Mic. type is 1/2 inch 12 mm spacing."
if ms = 4 then print #3,"Mic. type is 1/2 inch 50 mm spacing."
print #3,"Frequence range  : ";freqchoice$(ms);" (";ms
if corri=20 then Print"Set Ref. Adjust to +20 dB and press a
key" else goto gencloop3
Genbloop2: A$ = inkey$:If A$ = "" then goto Genbloop2
Gencloop3:
cls
Print "Please change the microphone spacing and sizes if"
Print "necessary to conform to the previous selections!"
Gendloop1: a$ = inkey$ : if a$ = "" then goto gendloop1
cls
Input"Will you be using A - weighting(y/n)? ",we$
IF ((we$ = "N") or (we$ = "n")) then goto NoAWeight
Print"SWITCH A-WEIGHTING ON,PLEASE!"
print #3,"The test results are A weighted!"
print:print:print
Print"Press any key to continue!"
Genloop5: A$ = inkey$ :If A$ = "" then goto Genloop5
NoAWeight: cls
print #3,"The test results are not weighted!"
OU = 1
Print TAB(24);
Print"What sort of output do you wish to have?"; :Print
Print:Print"1) To Disk (Default)":Print "2) To Printer"
Print "3) Both"
```

```
Print:Print"Choose an option please --> ";
Genloop9: OUT$ = INKEY$:IF OUT$ = "" THEN GOTO Genloop9
IF VAL(OUT$) = 2 THEN OU = 2
IF VAL(OUT$) = 3 THEN OU = 3
cls
TIM$ = "0;"
Print
temp$(1)="1/32sec.":temp$(2)="1/16sec.":temp$(3)="1/8sec."
temp$(4)="1/4sec.":temp$(5)="1/2sec.":temp$(6)="1sec."
temp$(7)="2sec.":temp$(8)="4sec.":temp$(9)="8sec."
temp$(10)="16sec.":temp$(11)="32sec.":temp$(12)="64sec."
temp$(13)="128sec."
for it=1 to 13
  print it;")  ";temp$(it)
next it
print:print
Input "Choose an Time Index('9'(8 sec.) default) ---> ",TIM
IF TIM < 1 or TIM > 13 then TIM = 9
TIM$ = TI$(TIM)
print #3,"The Averaging Time is ";temp$(TIM)
cls
MANU = 2
Input"Is the probe movement manual (Y/N)? ",ANAS$
If ((ANAS$ = "Y") or (ANAS$ = "y")) then MANU = 1
IF MANU = 1 then goto Unmanual
cls
Print"Switch on stepper motor controls and press a key!"
moto:a$ = inkey$:if a$ = "" then goto moto
OPEN "COM1:2400,N,7,2,CS,DS,CD" AS 5
PRINT #5,"W01 04"
Unmanual:
cls
input"How many measuring surfaces are there?",plane%
print #3,plane%;" measuring surfaces in this test. "
numtot=0
rem
for jloop=1 to plane%
cls
screen 0:color 11,0
print"Please set up the surface no. ";jloop;" and the probe."
print:print:print:print
print"Press a key to continue..."
lkj:ANA$=INKEY$:IF ANA$="" THEN GOTO lkj
print #3,
print #3,"Surface no. ";jloop
cls
REG = 1
PRINT "What's type of grid for surface ";jloop;" ?":PRINT
PRINT:PRINT "1) Rectangular"
PRINT "2) Variable size"
PRINT:PRINT"Choose an option please --> ";
Genloop10: REG$ = INKEY$:IF REG$ = "" THEN GOTO Genloop10
```

```
IF VAL(REG$) = 2 THEN REG = 2
IF REG = 2 THEN GOTO Variable
CLS
placedimen1:
color 11,0
print "Dimension of surface no. ";jloop
print
INPUT"Input the overall width of the surface(meter) ",WID
Genloop11: INPUT"Input number of measurement columns ",COLUMNS
IF COLUMNS > 15 OR COLUMNS < 1 THEN PRINT"Bad column
input.":GOTO Genloop11
Rem
INPUT"Input the overall height of the surface(metres) ",HEIGHT
Genloop12: INPUT"Input the number of measurement rows ",ROWS
IF ROWS > 15 OR ROWS < 1 THEN PRINT"Bad Row input.":GOTO
Genloop12
Rem
INPUT"On which coordinate plane are the mesh
distributed(x,y,z)? ",plan$
Rem
input "What is the coordinate from source to measuring
surface(+ - meter)?",DISTANCE
NUMPOINTS(jloop) = ROWS * COLUMNS
numtot=numtot+NUMPOINTS(jloop)
IF NUMPOINTS(jloop) > 144 THEN PRINT "Ooops you cannot have
more than 144 points":GOTO Genloop11
area(jloop)=WID*HEIGHT/NUMPOINTS(jloop)
Print #3,"Rectangular plane: "
print #3,"     ";wid;" meter width."
print #3,"     ";height;" meters height."
print #3,numpoints(jloop);" measuring points corresponding to
";numpoints(jloop);" segments on this surface."
Rem
print #3,area(jloop);" square meters measuring area for each
segment on this surface."
print #3,"The constant coordinate plane is ";plan$
Print #3,Distance;" meters is the coordinate from the centre
of source to surface."
print #3,"Measuring mesh:"
Print #3,"     ";Columns;" Columns."
print #3,"     ";Rows;" Rows."
SCREEN 8
FOR I = 1 TO ROWS
     Y = (360/(2 * ROWS)) * (I - 1)
     FOR J = 1 TO COLUMNS
          X = (600/COLUMNS) * (J - 1) + 20
          LINE(X,Y) - (X+4,Y+4),4,BF
     NEXT J
NEXT I
WINC = INT((WID*100)/COLUMNS * 47.259)
HINC = INT((HEIGHT*100)/ROWS * 50.556)
POSX = 0
```

```
POSY = 0
rem ***** plot the grid... *****
LOCATE 23,13,,7,7
PRINT"To changes, press C else press any key to continue";
Genloop13: ANA$ = INKEY$: IF ANA$ = "" THEN GOTO Genloop13
IF ANA$ = "C" or ana$ = "c" THEN GOTO Placedimen1
LOCATE 23,13,,7,7
PRINT"Set the microphone at the 1st point and press a key   ";
Genloop14: ANA$ = INKEY$:IF ANA$ = "" THEN GOTO Genloop14
CNT% = 301
IF Manu = 2 then Close #5
FOR IJ = 1 TO ROWS
     IF (IJ = 1) OR (Manu = 1) then goto Unmanual1
     if plan$<>"y" and plan$<>"Y" then goto ord
     locate 23,10,,7,7
     if IJ/2=INT(IJ/2) then print"set probe at far left of
row";IJ;", press a key to continue"
Rem
     if IJ/2<>INT(IJ/2) then print"set probe at far right of
row";IJ;", press a key to continue"
aqq:    A$ = INKEY$ : if a$="" then goto aqq
     locate 23,10,,7,7
     print
     goto nomore
ord:    LOCATE 23,18,,7,7
     POSY = POSY + HINC
     for MotCount = 1 to 2000:Next MotCount
     NUMBER = HINC
     OPEN "COM1:2400,N,7,2,CS,DS,CD" AS 5
     PRINT #5,"W01 00"
     for MotCount = 1 to 10000:Next MotCount
     CLOSE #5
     CW$ = "+"
     Gosub MoveProbe
nomore:
     For MotCount = 1 to 2000:Next MotCount
     OPEN "COM1:2400,N,7,2,CS,DS,CD" AS 5
          PRINT #5,"W01 04"
          for MotCount = 1 to 10000:Next MotCount
     CLOSE #5
UnManual1:
     Y = (360/(2*ROWS)) * (IJ-1)
     IF IJ/2 = INT(IJ/2) then GOTO drg2:
     FOR J = 1 TO COLUMNS
          x = (600/columns) * (j-1) + 20
          LINE(X,Y) - (X+4,Y+4),9,BF
          If Manu = 1 then goto Unmanual2
          LOCATE 23,18,,7,7
          IF J = 1 then GOTO Manual1
          POSX = POSX + WINC
          NUMBER = WINC
          CW$ = "-"
```

```
          GOSUB MoveProbe
          for Motcount = 1 to 15000:Next Motcount
Unmanual2:
          LOCATE 23,18,,7,7
          IF MANU = 2 then goto Manual1
          Beep
          Print" Press a key to Move to the new point";
Genloop15:      A$ = Inkey$: IF A$ = "" then goto Genloop15
Manual1:
          LOCATE 23,18,,7,7
          POINTNUMBER = (IJ - 1) * COLUMNS + J
          PRINT"Currently processing point number ";
          PRINT POINTNUMBER;"         ";
          GOSUB Analysis
NexPoint:       LINE(X,Y) - (X+4,Y+4),2,BF
          LOCATE 23,13,,7,7
          PRINT
          LOCATE 24,2,,7,7
          PRINT
     NEXT J
     GOTO finrow
drg2:   FOR J = COLUMNS to 1 step -1
          x = (600/columns) * (j-1) + 20
          LINE(X,Y) - (X+4,Y+4),9,BF
          If Manu = 1 then goto Unmanual2a
          IF J = Columns then GOTO Manual2
          POSX = POSX - WINC
          NUMBER = Winc
          CW$ = "+"
          GOSUB MoveProbe
          for Motcount = 1 to 15000:Next Motcount
Unmanual2a:
          LOCATE 23,18,,7,7
          IF MANU = 2 then goto Manual2
          Beep
          Print" Press a key to Move to the new point";
Genloop15a:     A$ = Inkey$: IF A$ = "" then goto Genloop15a
Manual2:
          LOCATE 23,18,,7,7
          POINTNUMBER = (IJ - 1) * COLUMNS + J
          PRINT"Currently processing point number ";
          PRINT POINTNUMBER;"         ";
          GOSUB Analysis
NexPointa:      LINE(X,Y) - (X+4,Y+4),2,BF
          LOCATE 23,13,,7,7
          PRINT
          LOCATE 24,2,,7,7
          PRINT
     NEXT J
finrow:
NEXT IJ
```

```
Rem Horizontal Reset

IF Manu = 1 then goto UnManual3
CW$ = "-"
IF POSX > 0 then CW$ = "+"
POSX = ABS(POSX)
NUMBER = POSX
gosub MoveProbe
for MotCount = 1 to 15000:next MotCount

VERTR:

Rem Vertical Reset

CW$ = "+"
IF POSY > 0 then CW$ = "-"
POSY = ABS(POSY)
NUMBER = POSY
OPEN "COM1:2400,N;7,2,CS,DS,CD" AS 5
PRINT #5,"W01 00"
close #5
for MotCount = 1 to 10000:Next MotCount
Gosub MoveProbe
unmanual3:
rem
next jloop
rem
print #3,
print #3,
print #3,numtot;" points totally on the entire surface."
REM
close
END

Analysis:
COMM$ = "DU"
CALL IBWRT(M%,COMM$)
LOCATE 23,13,,7,7
Print" Setting optimal lower level, Channel A, Microphone 5";
GOSUB SetLowerLevel
LOCATE 23,13,,7,7
Print" Reading Sound Pressure Level, Channel A, Microphone 5";
CODE$ = "E=L?"+TIM$+"C>M?M="
CALL IBWRT(BKP%,CODE$)
CODE$ = "M"
CALL IBWRT(BKP%,CODE$)
RETC$ = SPACE$(1)
GenLoop17: CALL IBRD(BKP%,RETC$)
IF RETC$ <> ">" THEN goto Genloop17
CODE$ = "E?"
CALL IBWRT(BKP%,CODE$)
CALL IBRDI(BKD%,varptr(SPEC%(0)),CNT%)
```

```
C% = 0
FOR I% = 0 TO 144 STEP 7
      X$ = ""
      FOR J% = 0 TO 6
            A$ = MKI$(SPEC%(I%+J%))
            FOR X% = 1 TO 2
            IF ASC(MID$(A$,X%,1)) < 40 THEN MID$(A$,X%,1) = " "
            NEXT X%
            X$ = X$+A$
      NEXT J%
      FLAG%(C%) = 1:FLAG%(C%+1) = 1
IF MID$(X$,4,1) = "*" THEN MID$(X$,4,1) = ".":FLAG%(C%) = -1
IF MID$(X$,11,1) = "*" THEN MID$(X$,4,1) = "."
FLAG%(C%+1) = -1
IF MID$(X$,4,1) = "<" THEN FLAG%(C%) = 1:MID$(X$,4,1) = "."
IF MID$(X$,11,1) = "<" THEN FLAG%(C%+1) = 1
MID$(X$,11,1) = "."
      SPL1(C%) = VAL(MID$(X$,1,5))*FLAG%(C%)
      SPL1(C%+1) = VAL(MID$(X$,8,5))*FLAG%(C%+1)
      C% = C%+2
NEXT I%
LOCATE 23,13,,7,7
Print" Reading Sound Pressure Level, Channel B, Microphone 6";
CODE$ = "E=L?"+TIM$+"C?M?M="
CALL IBWRT(BKP%,CODE$)
CODE$ = "M"
CALL IBWRT(BKP%,CODE$)
RETC$ = SPACE$(1)
GenLoop17b: CALL IBRD(BKP%,RETC$)
IF RETC$ <> ">" THEN goto Genloop17b
CODE$ = "E?"
CALL IBWRT(BKP%,CODE$)
CALL IBRDI(BKD%,varptr(SPEC%(0)),CNT%)
C% = 0
FOR I% = 0 TO 144 STEP 7
      X$ = ""
      FOR J% = 0 TO 6
            A$ = MKI$(SPEC%(I%+J%))
            FOR X% = 1 TO 2
            IF ASC(MID$(A$,X%,1)) < 40 THEN MID$(A$,X%,1) = " "
            NEXT X%
            X$ = X$+A$
      NEXT J%
      FLAG%(C%) = 1:FLAG%(C%+1) = 1
IF MID$(X$,4,1) = "*" THEN MID$(X$,4,1) = ".":FLAG%(C%) = -1
IF MID$(X$,11,1) = "*" THEN MID$(X$,4,1) = "."
FLAG%(C%+1) = -1
IF MID$(X$,4,1) = "<" THEN FLAG%(C%) = 1:MID$(X$,4,1) = "."
IF MID$(X$,11,1) = "<" THEN FLAG%(C%+1) = 1
MID$(X$,11,1) = "."
      SPL2(C%) = VAL(MID$(X$,1,5))*FLAG%(C%)
      SPL2(C%+1) = VAL(MID$(X$,8,5))*FLAG%(C%+1)
```

```
     C% = C%+2
NEXT I%
rem
if dimen$="1D" then goto oneDonly
rem
REM ****** switch to Channel 1 & 2
COMM$ = "@Q"
CALL IBWRT(M%,COMM$)
CODE$ = "E=L?"+TIM$+"C=M?M="
CALL IBWRT(BKP%,CODE$)
LOCATE 23,13,,7,7
Print" Reading Intensity Level, Microphone 1,2    ";
CODE$ = "M"
CALL IBWRT(BKP%,CODE$)
RETC$ = SPACE$(1)
Genloop18: CALL IBRD(BKP%,RETC$)
IF RETC$ <> ">" THEN goto Genloop18
CODE$ = "E?"
CALL IBWRT(BKP%,CODE$)
CALL IBRDI(BKD%,varptr(SPEC%(0)),CNT%)
C% = 0
FOR I% = 0 TO 144 STEP 7
     X$ = ""
     FOR J% = 0 TO 6
          A$ = MKI$(SPEC%(I%+J%))
          FOR X% = 1 TO 2
          IF ASC(MID$(A$,X%,1)) < 40 THEN MID$(A$,X%,1) = " "
          NEXT X%
          X$ = X$+A$
     NEXT J%
     FLAG%(C%) = 1:FLAG%(C%+1) = 1
IF MID$(X$,4,1) = "*" THEN MID$(X$,4,1) = ".":FLAG%(C%) = -1
IF MID$(X$,11,1) = "*" THEN MID$(X$,4,1) = "."
FLAG%(C%+1) = -1
IF MID$(X$,4,1) = "<" THEN FLAG%(C%) = 1:MID$(X$,4,1) = "."
IF MID$(X$,11,1) = "<" THEN FLAG%(C%+1) = 1
MID$(X$,11,1) = "."
     ILX(C%) = VAL(MID$(X$,1,5))*FLAG%(C%)
     ILX(C%+1) = VAL(MID$(X$,8,5))*FLAG%(C%+1)
     C% = C%+2
NEXT I%
rem ******* Switch to channels 3 and 4 (2811)*****
COMM$ = "BS"
CALL IBWRT(M%,COMM$)
REM
LOCATE 23,13,,7,7
Print" Reading Intensity Level, Microphone 3,4  ";
CODE$ = "E=L?"+TIM$+"C=M?"
CALL IBWRT(BKP%,CODE$)
CODE$ = "M="
CALL IBWRT(BKP%,CODE$)
CODE$ = "M"
```

```
CALL IBWRT(BKP%,CODE$)
RETC$ = SPACE$(1)
Genloop19: CALL IBRD(BKP%,RETC$)
IF RETC$ <> ">" THEN goto Genloop19
CODE$ = "E?"
CALL IBWRT(BKP%,CODE$)
CALL IBRDI(BKD%,varptr(SPEC%(0)),CNT%)
C% = 0
FOR I% = 0 TO 144  STEP 7
     X$ = ""
     FOR J% = 0 TO 6
          A$ = MKI$(SPEC%(I%+J%))
          FOR X% = 1 TO 2
          IF ASC(MID$(A$,X%,1)) < 40 THEN MID$(A$,X%,1) = " "
          NEXT X%
          X$ = X$+A$
     NEXT J%
     FLAG%(C%) = 1:FLAG%(C%+1) = 1
IF MID$(X$,4,1) = "*" THEN MID$(X$,4,1) = ".":FLAG%(C%) = -1
IF MID$(X$,11,1) = "*" THEN MID$(X$,4,1) = "."
FLAG%(C%+1) = -1
IF MID$(X$,4,1) = "<" THEN FLAG%(C%) = 1:MID$(X$,4,1) = "."
IF MID$(X$,11,1) = "<" THEN FLAG%(C%+1) = 1
MID$(X$,11,1) = "."
ILY(C%) = VAL(MID$(X$,1,5))*FLAG%(C%)
ILY(C%+1) = VAL(MID$(X$,8,5))*FLAG%(C%+1)
     C% = C%+2
NEXT I%
rem
oneDonly:
rem ******** Switch to channels 5 and 6 (2811)*****
COMM$ = "DU"
CALL IBWRT(M%,COMM$)
rem
CODE$ = "E=L?"+TIM$+"C=M?M="
CALL IBWRT(BKP%,CODE$)
LOCATE 23,13,,7,7
Print" Reading Intensity Level, Microphone 5,6 ";
CODE$ = "M"
CALL IBWRT(BKP%,CODE$)
RETC$ = SPACE$(1)
Genloop18C: CALL IBRD(BKP%,RETC$)
IF RETC$ <> ">" THEN goto Genloop18C
CODE$ = "E?"
CALL IBWRT(BKP%,CODE$)
CALL IBRDI(BKD%,varptr(SPEC%(0)),CNT%)
C% = 0
FOR I% = 0 TO 144  STEP 7
     X$ = ""
     FOR J% = 0 TO 6
          A$ = MKI$(SPEC%(I%+J%))
          FOR X% = 1 TO 2
```

```
        IF ASC(MID$(A$,X%,1)) < 40 THEN MID$(A$,X%,1) = " "
        NEXT X%
        X$ = X$+A$
    NEXT J%
    FLAG%(C%) = 1:FLAG%(C%+1) = 1
IF MID$(X$,4,1) = "*" THEN MID$(X$,4,1) = ".":FLAG%(C%) = -1
IF MID$(X$,11,1) = "*" THEN MID$(X$,4,1) = "."
FLAG%(C%+1) = -1
IF MID$(X$,4,1) = "<" THEN FLAG%(C%) = 1:MID$(X$,4,1) = "."
IF MID$(X$,11,1) = "<" THEN FLAG%(C%+1) = 1
MID$(X$,11,1) = "."
    ILZ(C%) = VAL(MID$(X$,1,5))*FLAG%(C%)
    ILZ(C%+1) = VAL(MID$(X$,8,5))*FLAG%(C%+1)
    C% = C%+2
NEXT I%
rem ******Store info for this point!!!**********
For I = First to Last
Rem
if Ou<>2 and dimen$="1D" then Print #1,using"####  ###.##
#  #  #  .  #  #    #  .  #  #  #  #
###.##";FREQ(I);SPL1(I);ILZ(I);area(jloop);SPL2(I)
Rem
If Ou <> 1 and dimen$="1D" then Lprint using "####  ###.##
#  #  #  .  #  #    #  .  #  #  #  #
###.##";FREQ(I);SPL1(I);ILZ(I);area(jloop);SPL2(I)
Rem
If Ou <> 2 and dimen$="3D" then Print #1, using "#### ###.##
###.##   ###.##   ###.##   #.####   ###.##";
FREQ(I);SPL1(I);ILX(I);ILY(I);ILZ(I);area(jloop);SPL2(I)
Rem
If Ou <> 1 and dimen$="3D" then Lprint using "#### ###.##
###.##   ###.##   ###.##   #.####   ###.##";
FREQ(I);SPL1(I);ILX(I);ILY(I);ILZ(I);area(jloop);SPL2(I)
Rem
Next I
RETURN


Variable:
rem *******Variable size grid i.e. irregular shape****
cls
print"Surface no. ";jloop
print
print "Variable type grid"
print:Input"How many points are there(max. 144 points)? ",Numb
If Numb > 144 then goto Variable
Print #3,"Irregular surface:"
Print #3,Numb;" points correspoinding ";numb;" segments ."
print
print"****Input measuring points and segments areas now!****"
print
For I = 1 to Numb
```

```
     Print"X coordinate of measuring point ",I;:Input Pt(I,1)
     Print"Y coordinate of measuring point ",I;:Input Pt(I,2)
     print"Area of the segment ",I;:Input Area(i)
     Print
Next I
input "On which coordinate plane are the mesh
distributed(x,y,z)? ",plan$
Rem
INPUT"What is the coordinate from source to surface(+,-
metres)? ",DISTANCE
drawit:
MaxX = 0:MaxY = 0:MinX = 10000:MinY = 10000
For I = 1 to Numb
     If Pt(I,1) > MaxX then MaxX = Pt(I,1)
     If Pt(I,1) < MinX then MinX = Pt(I,1)
     If Pt(I,2) > MaxY then MaxY = Pt(I,2)
     If Pt(I,2) < MinY then MinY = Pt(I,2)
Next I
Xrange = MaxX - MinX
Yrange = MaxY - MinY
Screen 8
For I = 1 to Numb
     Virt(I,1) = 620/Xrange * (Pt(I,1) - MinX)
     Virt(I,2) = 180/Yrange * (Pt(I,2) - MinY)
LINE(Virt(I,1),Virt(I,2)) - (Virt(I,1)+4,Virt(I,2)+4),4,BF
Next I
POSX = 0
POSY = 0
rem ******* plot the grid... ************
LOCATE 23,13,,7,7
PRINT"Press C to make change, else press any key ";
genloop22: ANA$ = INKEY$: IF ANA$ = "" THEN GOTO genloop22
IF ANA$ = "C" or ana$ = "c" THEN LOCATE 23,13,,7,7
Print"                        ";:GOTO ChangePoint
print #3,"The constant coordinate plane is ";plan$
Print #3,Distance;" meters is coordinate of surface"
print #3,"measuring points coordinates:"
For I = 1 to Numb
     Print #3,I,(Maxx-Pt(I,1)),(Maxy-Pt(I,2))
Next I
numtot=numtot+numb
LOCATE 23,13,,7,7
PRINT"Set the microphone at the home and press a key";
genloop23: ANA$ = INKEY$:IF ANA$ = "" THEN GOTO genloop23
CNT% = 301
If manu = 2 then Close #5
FOR IAB = 1 TO Numb
     LINE(Virt(IAB,1),Virt(IAB,2)) -
(Virt(IAB,1)+4,Virt(IAB,2)+4),9,BF
     LOCATE 23,13,,7,7
IF MANU = 2 then goto Unman1
beep
```

```
Print"Press a key to Move to the new point        ";
genloop24: A$ = Inkey$: IF A$ = "" then goto genloop24
Unmanl:
locate 23,13,,7,7
PRINT"Currently processing point number ";:print IAB;
goto Analysis2
Nextpoint:
locate 23,13,,7,7
print"                    ";
locate 24,2,,7,7
print"        ";
        LINE(Virt(IAB,1),Virt(IAB,2)) -
(Virt(IAB,1)+4,Virt(IAB,2)+4),2,BF
If ((manu = 1) or (IAB = Numb)) then goto manul
CW$ = "-"
delh = Pt(IAB+1,1) - Pt(IAB,1)
if delh = 0 then goto norem
if Delh < 0 then CW$ = "+"
POSX = POSX + Int(Delh * 4725.9)
Hinc = int(abs(Delh) * 4725.9)
number = Hinc
Open "Com1:2400,N,7,2,CS,DS,CD" as 5
     Print #5,"W01 04"
     For Motcount = 1 to 10000:Next Motcount
Close #5
Gosub MoveProbe
for MotCount = 1 to 10000:Next MotCount
NoRem:
CW$ = "+"
Delv = Pt(IAB+1,2) - Pt(IAB,2)
if delv = 0 then goto norem2
If Delv < 0 then CW$ = "-"
POSY = POSY + Int(Delv * 5055.6)
Vinc = int(abs(Delv)*5055.6)
number = Vinc
Open "Com1:2400,N,7,2,CS,DS,CD" as 5
Print #5,"W01 00"
For Motcount = 1 to 10000:Next Motcount
Close #5
Gosub MoveProbe
for MotCount = 1 to 10000:Next MotCount
NoRem2:
manul:
next IAB

Rem Horizontal Reset

IF Manu = 1 then goto UnManual30
CW$ = "-"
IF POSX > 0 then CW$ = "+"
POSX = ABS(POSX)
Number = Posx
```

```
OPEN "COM1:2400,N,7,2,CS,DS,CD" AS 5
      PRINT #5,"W01 04"
      for MotCount = 1 to 1000:Next MotCount
CLOSE #5
gosub MoveProbe
for MotCount = 1 to 10000:next MotCount
VERTAR:

Rem Vertical Reset

CW$ = "+"
IF POSY > 0 then CW$ = "-"
POSY = ABS(POSY)
NUMBER = POSY
      OPEN "COM1:2400,N,7,2,CS,DS,CD" AS 5
            PRINT #5,"W01 00"
            for MotCount = 1 to 10000:Next MotCount
      CLOSE #5
      Gosub MoveProbe
      for MotCount = 1 to 1000:Next MotCount
nomore20:
OPEN "COM1:2400,N,7,2,CS,DS,CD" AS 5
PRINT #5,"W01 04"
for MotCount = 1 to 10000:Next MotCount
CLOSE #5
UnManual30:
if jloop<>plane% then goto unmanual3
print #3,
print #3,
print #3,numtot;" points totally on the entire surface."
END

Analysis2:
2300 COMM$ = "DU"
CALL IBWRT(M%,COMM$)
locate 23,13,,7,7
print"Setting optimal lower level, Channel A, Microphone 5 ";
GOSUB SetLowerLevel
LOCATE 23,13,,7,7
Print" Reading Sound Pressure Level, Channel A, Microphone 5";
CODE$ = "E=L?"+TIM$+"C>M?M="
CALL IBWRT(BKP%,CODE$)
CODE$ = "M"
CALL IBWRT(BKP%,CODE$)
RETC$ = SPACE$(1)
Genloop25: CALL IBRD(BKP%,RETC$)
IF RETC$ <> ">" THEN goto Genloop25
CODE$ = "E?"
CALL IBWRT(BKP%,CODE$)
CALL IBRDI(BKD%,varptr(SPEC%(0)),CNT%)
C% = 0
FOR I% = 0 TO 144 STEP 7
```

```
     X$ = ""
     FOR J% = 0 TO 6
          A$ = MKI$(SPEC%(I%+J%))
          FOR X% = 1 TO 2
          IF ASC(MID$(A$,X%,1)) < 40 THEN MID$(A$,X%,1) = " "
          NEXT X%
          X$ = X$+A$
     NEXT J%
     FLAG%(C%) = 1:FLAG%(C%+1) = 1
IF MID$(X$,4,1) = "*" THEN MID$(X$,4,1) = ".":FLAG%(C%) = -1
IF MID$(X$,11,1) = "*" THEN MID$(X$,4,1) = "."
FLAG%(C%+1) = -1
IF MID$(X$,4,1) = "<" THEN FLAG%(C%) = 1:MID$(X$,4,1) = "."
IF MID$(X$,11,1) = "<" THEN FLAG%(C%+1) = 1
MID$(X$,11,1) = "."
     SPL1(C%) = VAL(MID$(X$,1,5))*FLAG%(C%)
     SPL1(C%+1) = VAL(MID$(X$,8,5))*FLAG%(C%+1)
     C% = C%+2
NEXT I%
LOCATE 23,13,,7,7
Print" Reading Sound Pressure Level, Channel B, Microphone 6";
CODE$ = "E=L?"+TIM$+"C?M?M="
CALL IBWRT(BKP%,CODE$)
CODE$ = "M"
CALL IBWRT(BKP%,CODE$)
RETC$ = SPACE$(1)
Genloop25b: CALL IBRD(BKP%,RETC$)
IF RETC$ <> ">" THEN goto Genloop25b
CODE$ = "E?"
CALL IBWRT(BKP%,CODE$)
CALL IBRDI(BKD%,varptr(SPEC%(0)),CNT%)
C% = 0
FOR I% = 0 TO 144 STEP 7
     X$ = ""
     FOR J% = 0 TO 6
          A$ = MKI$(SPEC%(I%+J%))
          FOR X% = 1 TO 2
          IF ASC(MID$(A$,X%,1)) < 40 THEN MID$(A$,X%,1) = " "
          NEXT X%
          X$ = X$+A$
     NEXT J%
     FLAG%(C%) = 1:FLAG%(C%+1) = 1
IF MID$(X$,4,1) = "*" THEN MID$(X$,4,1) = ".":FLAG%(C%) = -1
IF MID$(X$,11,1) = "*" THEN MID$(X$,4,1) = "."
FLAG%(C%+1) = -1
IF MID$(X$,4,1) = "<" THEN FLAG%(C%) = 1:MID$(X$,4,1) = "."
IF MID$(X$,11,1) = "<" THEN FLAG%(C%+1) = 1
MID$(X$,11,1) = "."
     SPL2(C%) = VAL(MID$(X$,1,5))*FLAG%(C%)
     SPL2(C%+1) = VAL(MID$(X$,8,5))*FLAG%(C%+1)
     C% = C%+2
NEXT I%
```

```
rem
if dimen$="1D" then goto oneDonlyB
rem
REM ****** switch to Channel 1 & 2
COMM$ = "@Q"
CALL IBWRT(M%,COMM$)
CODE$ = "E=L?"+TIM$+"C=M?M="
CALL IBWRT(BKP%,CODE$)
LOCATE 23,13,,7,7
Print" Reading Intensity Level, Microphone 1,2    ";
CODE$ = "M"
CALL IBWRT(BKP%,CODE$)
RETC$ = SPACE$(1)
Genloop18B: CALL IBRD(BKP%,RETC$)
IF RETC$ <> ">" THEN goto Genloop18B
CODE$ = "E?"
CALL IBWRT(BKP%,CODE$)
CALL IBRDI(BKD%,varptr(SPEC%(0)),CNT%)
C% = 0
FOR I% = 0 TO 144 STEP 7
      X$ = ""
      FOR J% = 0 TO 6
            A$ = MKI$(SPEC%(I%+J%))
            FOR X% = 1 TO 2
            IF ASC(MID$(A$,X%,1)) < 40 THEN MID$(A$,X%,1) = " "
            NEXT X%
            X$ = X$+A$
      NEXT J%
      FLAG%(C%) = 1:FLAG%(C%+1) = 1
IF MID$(X$,4,1) = "*" THEN MID$(X$,4,1) = ".":FLAG%(C%) = -1
IF MID$(X$,11,1) = "*" THEN MID$(X$,4,1) = "."
FLAG%(C%+1) = -1
IF MID$(X$,4,1) = "<" THEN FLAG%(C%) = 1:MID$(X$,4,1) = "."
IF MID$(X$,11,1) = "<" THEN FLAG%(C%+1) = 1
MID$(X$,11,1) = "."
      ILX(C%) = VAL(MID$(X$,1,5))*FLAG%(C%)
      ILX(C%+1) = VAL(MID$(X$,8,5))*FLAG%(C%+1)
      C% = C%+2
NEXT I%
rem ****** Switch to channels 3 and 4 (2811)*****
COMM$ = "BS"
CALL IBWRT(M%,COMM$)
REM
LOCATE 23,13,,7,7
Print" Reading Intensity Level, Microphone 3,4    ";
CODE$ = "E=L?"+TIM$+"C=M?"
CALL IBWRT(BKP%,CODE$)
CODE$ = "M="
CALL IBWRT(BKP%,CODE$)
CODE$ = "M"
CALL IBWRT(BKP%,CODE$)
RETC$ = SPACE$(1)
```

```
Genloop19B: CALL IBRD(BKP%,RETC$)
IF RETC$ <> ">" THEN goto Genloop19B
CODE$ = "E?"
CALL IBWRT(BKP%,CODE$)
CALL IBRDI(BKD%,varptr(SPEC%(0)),CNT%)
C% = 0
FOR I% = 0 TO 144 STEP 7
     X$ = ""
     FOR J% = 0 TO 6
          A$ = MKI$(SPEC%(I%+J%))
          FOR X% = 1 TO 2
          IF ASC(MID$(A$,X%,1)) < 40 THEN MID$(A$,X%,1) = " "
          NEXT X%
          X$ = X$+A$
     NEXT J%
     FLAG%(C%) = 1:FLAG%(C%+1) = 1
IF MID$(X$,4,1) = "*" THEN MID$(X$,4,1) = ".":FLAG%(C%) = -1
IF MID$(X$,11,1) = "*" THEN MID$(X$,4,1) = "."
FLAG%(C%+1) = -1
IF MID$(X$,4,1) = "<" THEN FLAG%(C%) = 1:MID$(X$,4,1) = "."
IF MID$(X$,11,1) = "<" THEN FLAG%(C%+1) = 1
MID$(X$,11,1) = "."
     ILY(C%) = VAL(MID$(X$,1,5))*FLAG%(C%)
     ILY(C%+1) = VAL(MID$(X$,8,5))*FLAG%(C%+1)
     C% = C%+2
NEXT I%
rem
oneDonlyB:
rem ****** Switch to channels 5 and 6 (2811)*****
COMM$ = "DU"
CALL IBWRT(M%,COMM$)
REM
CODE$ = "E=L?"+TIM$+"C=M?M="
CALL IBWRT(BKP%,CODE$)
LOCATE 23,13,,7,7
Print" Reading Intensity Level, Microphone 5,6 ";
CODE$ = "M"
CALL IBWRT(BKP%,CODE$)
RETC$ = SPACE$(1)
Genloop26: CALL IBRD(BKP%,RETC$)
IF RETC$ <> ">" THEN goto Genloop26
CODE$ = "E?"
CALL IBWRT(BKP%,CODE$)
CALL IBRDI(BKD%,varptr(SPEC%(0)),CNT%)
C% = 0
FOR I% = 0 TO 144 STEP 7
     X$ = ""
     FOR J% = 0 TO 6
          A$ = MKI$(SPEC%(I%+J%))
          FOR X% = 1 TO 2
          IF ASC(MID$(A$,X%,1)) < 40 THEN MID$(A$,X%,1) = " "
          NEXT X%
```

```
          X$ = X$+A$
      NEXT J%
      FLAG%(C%) = 1:FLAG%(C%+1) = 1
IF MID$(X$,4,1) = "*" THEN MID$(X$,4,1) = ".":FLAG%(C%) = -1
IF MID$(X$,11,1) = "*" THEN MID$(X$,4,1) = "."
FLAG%(C%+1) = -1
IF MID$(X$,4,1) = "<" THEN FLAG%(C%) = 1:MID$(X$,4,1) = "."
IF MID$(X$,11,1) = "<" THEN FLAG%(C%+1) = 1
MID$(X$,11,1) = "."
      ILZ(C%) = VAL(MID$(X$,1,5))*FLAG%(C%)
      ILZ(C%+1) = VAL(MID$(X$,8,5))*FLAG%(C%+1)
      C% = C%+2
NEXT I%
rem
rem ****Store info for this point!!!*****
rem
For I = First to Last
If Ou <> 2 and dimen$="1D" then Print #1, using "####  ###.##
#    #    #    .    #    #        #    .    #    #    #    #
###.##";FREQ(I);SPL1(I);ILZ(I);area(iab);SPL2(I)
Rem
If Ou <> 1 and dimen$="1D" then  Lprint using "####  ###.##
#    #    #    .    #    #        #    .    #    #    #    #
###.##";FREQ(I);SPL1(I);ILZ(I);area(iab);SPL2(I)
Rem
If Ou <> 2 and dimen$="3D" then Print #1, using "#### ###.##
# # # . # #    # # # . # #    # # # . # #    # . # # # #
###.##";FREQ(I);SPL1(I);ILX(I);ILY(I);ILZ(I);area(iab);SPL2(I)
Rem
If Ou <> 1 and dimen$="3D" then  Lprint using "#### ###.##
# # # . # #    # # # . # #    # # # . # #    # . # # # #
###.##";FREQ(I);SPL1(I);ILX(I);ILY(I);ILZ(I);area(iab);SPL2(I)

Rem
Next I
rem
goto nextpoint

ChangePoint:
rem *******change a point routine*******
I = 1
morepts:
If I > Numb then I = 1
If I < 1 then I = Numb
LINE(Virt(I,1),Virt(I,2)) - (Virt(I,1) + 4,Virt(I,2) + 4),2,BF
circ : Some$ = INKEY$:If Some$ = "" then goto circ
Rem
If Asc(Some$) = 43 then LINE(Virt(I,1),Virt(I,2)) - (Virt(I,1)
+ 4,Virt(I,2) + 4),4,BF:I = I + 1: goto morepts
Rem
If Asc(Some$) = 45 then LINE(Virt(I,1),Virt(I,2)) - (Virt(I,1)
+ 4,Virt(I,2) + 4),4,BF:I = I - 1: goto morepts
```

```
Rem
If Some$ = "Q" or Some$ = "q" then cls:goto drawit
If Asc(Some$) <> 13 then goto morepts
Locate 23,13
Print"Input new X-value for point number",I;:Input Pt(I,1)
Locate 23,13 : Print"            ";
Locate 23,13
Print"Input new Y-value for point number",I;:Input Pt(I,2)
goto morepts
```

```
SetLowerLevel:
CNT% = 113
CODE$ = "E=L?O;C>M?M=K?N:"
CALL IBWRT(BKP%,CODE$)
CODE$ = "M"
CALL IBWRT(BKP%,CODE$)
RETC$ = SPACE$(1)
Loopa: CALL IBRD(BKP%,RETC$)
IF RETC$ <> ">" THEN goto loopa
CODE$ = "E?"
CALL IBWRT(BKP%,CODE$)
CALL IBRDI(BKD%,varptr(SPEC%(0)),CNT%)
C% = 0:FOR I% = 0 TO 144 STEP 7
X$ = ""
FOR J% = 0 TO 6
    A$ = MKI$(SPEC%(I%+J%))
    FOR X% = 1 TO 2
     IF ASC(MID$(A$,X%,1)) < 40 THEN MID$(A$,X%,1) = " "
    NEXT X%
    X$ = X$+A$
NEXT J%
FLAG%(C%) = 1:FLAG%(C%+1) = 1
IF MID$(X$,4,1) = "*" THEN MID$(X$,4,1) = ".":FLAG%(C%) = -1
IF MID$(X$,11,1) = "*" THEN MID$(X$,4,1) = "."
FLAG%(C%+1) = -1
IF MID$(X$,4,1) = "<" THEN FLAG%(C%) = 1:MID$(X$,4,1) = "."
IF MID$(X$,11,1) = "<" THEN FLAG%(C%+1) = 1
MID$(X$,11,1) = "."
SPL1(C%) = VAL(MID$(X$,1,5))*FLAG%(C%)
SPL1(C%+1) = VAL(MID$(X$,8,5))*FLAG%(C%+1)
C% = C%+2
NEXT I%
CNT% = 301
if SPL1(15)>70 then goto in1
SPL1(15)=60
in1:SET = INT((SPL1(15)+5)/10)*10 - 50 - corri
Lowerlevel = Set
```

```
If Lowerlevel < 0 then Lowerlevel = 0
IF SET => 100 then CODE$ = "N5"
IF SET = 90 THEN CODE$ = "N6"
IF SET = 80 THEN CODE$ = "N7"
IF SET = 70 THEN CODE$ = "N8"
IF SET = 60 THEN CODE$ = "N9"
IF SET = 50 THEN CODE$ = "N:"
IF SET = 40 THEN CODE$ = "N;"
IF SET = 30 THEN CODE$ = "N<"
IF SET = 20 THEN CODE$ = "N="
IF SET = 10 THEN CODE$ = "N>"
IF SET <= 0 THEN CODE$ = "N?"
CALL IBWRT(BKP%,CODE$)
CODE$ = "K>"
CALL IBWRT(BKP%,CODE$)
RETURN



MoveProbe:
OPEN "COM1:2400,N,7,2,CS,DS,CD" AS 5
LOOP=1
FIRSTRATE=5
RATE = 12
SLOPE = 20
DIVIDER = 1
DELAY = 250
ABSOLUTE = 0
STEPEN$=CHR$(61)
ENABLE$= "C"
DISABLE$= "B"
FIRSTRATE$ ="F" + STR$(FIRSTRATE)
RATE$= "R" + STR$ (RATE)
DIVIDER$= "Z" + STR$ (DIVIDER)
SLOPE$ = "S" + STR$(SLOPE)
DELAY$ = "D" + STR$(DELAY)
NUMBER$ = "N" + STR$(NUMBER)
ABSOLUTE$ = "A" + STR$(ABSOLUTE)
HOME$ ="P" + STR$(ABSOLUTE)
GO$="G"
EXECUTE$="X"
STARTLOOP$="A$"
ENDLOOP$="L" +STR$(LOOP) + "," +"A"
EDMODE$="E"
ENDPROGRAM$="O"
QUIT$="Q "
CREG$="W02"
WPORT$="W01"
RPORT$= "R01"
STATUS$="R00"
LEDON$= WPORT$ + CHR$(61)
LEDOFF$= WPORT$ + CHR$ (60)
```

```
PRINT #5, WPORT$ + STEPEN$
PRINT #5, CREG$ + SLOPE$
PRINT #5, CREG$ + RATE$
PRINT #5, CREG$ + FIRSTRATE$
PRINT #5, CREG$ + NUMBER$
PRINT #5, CREG$ + DIVIDER$
PRINT #5, CREG$ + ABSOLUTE$
PRINT #5, CREG$ + EDMODE$
PRINT #5, CREG$ + STARTLOOP$ + ENABLE$
PRINT #5, CREG$ + DELAY$
PRINT #5, CREG$ + DELAY$
PRINT #5, CREG$ + CW$
PRINT #5, CREG$ + GO$
PRINT #5, CREG$ + DELAY$
PRINT #5, CREG$ + ENDLOOP$
PRINT #5, CREG$ + DELAY$
PRINT #5, CREG$ + DISABLE$
PRINT #5, CREG$ + ENDPROGRAM$
PRINT #5, CREG$ + QUIT$
PRINT #5, LEDOFF$
PRINT #5, CREG$ + EXECUTE$
Moveloop1: PRINT #5, STATUS$
A$ = INPUT$(2,5)
A$ = LEFT$(A$,1)
STATUS% = ASC(A$)-64
MTCMPLT=0:PE=0:PROG=0:SLEW=0:BUSY=0
IF STATUS%>=16 THEN STATUS%=STATUS%-16:MTCMPLT=1
IF STATUS%>=8 THEN STATUS%=STATUS%-8:PE=1
IF STATUS%>=4 THEN STATUS%=STATUS%-4:PROG=1
IF STATUS%>=2 THEN STATUS%=STATUS%-2:SLEW=1
IF STATUS%>=1 THEN BUSY=1
IF PE<>1 THEN LOCATE 1,1:GOTO Moveloop1
PRINT #5, LEDON$
CLOSE #5
FOR MOTCOUNT = 1 to 10000:NEXT MOTCOUNT
RETURN
```

APPENDEX 3[2]

List of Program for Sound Power Analysis

---

[2] Whenever there are two or three consecutive underlined lines, they form only a single statement.

```
rem*******************powerc.bas****************************
rem *  data processing program for sound power measurement  *
rem *            created on: 07-26-90                      *
rem *            last modified:08-01-90                    *
rem **************at Concordia University********************
rem
dim point0(10),x(610),y(610),freq(50),spl56(50),sil56(50)
dim spl57(50),swl56(50),plan$(10),const(10),spl10(50)
dim freqy(50),spl11(50),ilx(320),ily(320)
rem
freqy(14)=31.5:freqy(15)=40:freqy(16)=50:freqy(17)=63
freqy(18)=80:freqy(19)=100:freqy(20)=125:freqy(21)=160
freqy(22)=200:freqy(23)=250:freqy(24)=315:freqy(25)=400
freqy(26)=500:freqy(27)=630:freqy(28)=800:freqy(29)=1000
freqy(30)=1250:freqy(31)=1600:freqy(32)=2000:freqy(33)=2500
freqy(34)=3150:freqy(35)=4000:freqy(36)=5000
freqy(37)=6300:freqy(38)=8000:freqy(39)=10000
color 11,0
print"      Data processing for sound power measurement."
print:print:print:print
info$="info.dat"
input "What's information file name(default:info.dat)";info1$
if info1$<>"" then info$=info1$
open "I",#2,info$
rem
input #2,title$
input #2,junk5$
input #2,junk1$
input #2,band1$
band$=LEFT$(band1$,3)
input #2,dimen$
input #2,temp$
input #2,humidity$
input #2,pressure$
input #2,date1$
input #2,spacing$
input #2,range1$
range$=RIGHT$(range1$,1)
ms=VAL(range$)
if band$="1/1" then goto oct
if ms=1 then first=23:last=39
if ms=2 then first=20:last=36
if ms=3 then first=20:last=36
if ms=4 then first=14:last=30
goto contn
oct:
if ms=1 then first=8:last=13
if ms=2 then first=7:last=12
if ms=3 then first=7:last=12
if ms=4 then first=5:last=10
contn:
input #2,weight$
```

```
input #2,tim$
input #2,surface$
numsurf=VAL(surface$)
numpoint=0
for i=1 to numsurf
   input #2,junk2$
   input #2,junk6$
   input #2,shape$
   if shape$="Irregular surface:" then goto irregular
   input #2,wid1$
   wid=VAL(wid1$)
   input #2,height1$
   height=VAL(height1$)
   input #2,point1$
   point0(i)=VAL(point1$)
   input #2,area$
   input #2,plan1$
   plan$(i)=RIGHT$(plan1$,1)
   input #2,dist$
   const(i)=VAL(dist$)
   input #2,junk3$
   input #2,column1$
   column=VAL(column1$)
   input #2,row1$
   row=VAL(row1$)
   for lh=1 to row step 2
     for lv=1 to column
       numpoint=numpoint+1
       x(numpoint)=wid-((lv-1)*wid/column+wid/column/2)
       y(numpoint)=height-((lh-1)*height/row+height/row/2)
     next lv
     if lh=row then goto norm
     for lw=column to 1 step -1
       numpoint=numpoint+1
       x(numpoint)=wid-((lw-1)*wid/column+wid/column/2)
       y(numpoint)=height-(lh*height/row+height/row/2)
     next lw
    next lh
norm:goto fin
irregular:
   input #2,point1$
   point0(i)=VAL(point1$)
   input #2,plan1$
   plan$(i)=RIGHT$(plan1$,1)
   input #2,dist$
   const(i)=VAL(dist$)
   input #2,junk3$
   for j=1 to point0(i)
      numpoint=numpoint+1
      input #2,junk4,x(numpoint),y(numpoint)
   next j
fin:
```

```
next i
input #2,junk7$
input #2,junk8$
input #2,totnum$
totnumber=VAL(totnum$)
rem
cls
input "Do you want to sort the data file(y/n)?",sortfile$
if sortfile$="n" or sortfile$="N" then goto nosort1
cls
print:print:print
dat99$="test.dat"
input "What is the data file name(default:test.dat)";dat199$
if dat199$<>"" then dat99$=dat199$
input "How many points does the data file contain?",ptno
nosort1:
cls
dat$="test1.dat"
input "What's sorted data file name(default:test1.dat)";dat1$
if dat1$<>"" then dat$=dat1$
if sortfile$="n" or sortfile$="N" then goto nosort2
open "O",#11, dat$
cls
for f=first to last
   open "I",#10, dat99$
   for i=1 to ptno
      for k=first to last
if dimen$="1D" then input #10,freq,spl,sil,sarea,spl200
if dimen$="3D" then input
#10,freq,spl,silx,sily,silz,sarea,spl200
rem
if freq=freqy(f) and dimen$="1D" then print #11,
freq;spl;sil;sarea;spl200
rem
if freq=freqy(f) and dimen$="3D" then print #11,
freq;spl;silx;sily;silz;sarea;spl200
      next k
   next i
   close #10
   print freqy(f)
next f
close #11
nosort2:
cls
result$="result.dat"
input "What's output file name(default:result.dat)?",result1$
if result1$="" or result1$=" " then result1$=result$
open "O", #5, result1$
rem
manu:
cls
print"************************* menu *************************"
```

```
print"* (1). ANSI data indicator analysis                  *"
print"* (2). ISO data indicator analysis                   *"
print"* (3). Calculate overall sound power level of source *"
print"* (4). Prepare data for 3D graph                     *"
print"* (5). Quit                                          *"
print"******************************************************"
rem
print:print:print:print
input"Please select an index.";index
if index=1 then gosub indicator1
if index=2 then gosub indicator2
if index=3 then gosub power
if index=4 then gosub graph
if index=5 then close:END
goto manu
rem
power:
open "I",#1,dat$
cls
out$="power.dat"
input "What's output file for graph(Def.:power.dat)";outa$
if outa$<>"" then out$=outa$
out$="d:\grapher\"+out$
open "O", #3, out$
rem
cls
locate 15,10,,7,7
print "SOUND POWER CALCULATION!"
locate 17,10,,7,7
print "    --please wait!--"
for k=first to last
   sw156(k)=0
   spl10(k)=0
   spl11(k)=0
next k
rem
for j=first to last
   totarea=0
   for i=1 to totnumber
if dimen$="1D" then input
#1,freq(j),spl56(j),sil56(j),area,spl57(j)
rem
if dimen$="3D" then input
#1,freq(j),spl56(j),ilx(j),ily(j),sil56(j),area,spl57(j)
sw156(j)=sw156(j)+sgn(sil56(j))*10^(abs(sil56(j))/10)*area
      spl10(j)=spl10(j)+10^(spl56(j)/10)*area
      spl11(j)=spl11(j)+10^(spl57(j)/10)*area
      totarea=totarea+area
   next i
next j
rem
cls
```

```
print
print " freq(Hz)    power(dB)  intensity(dB)   pressure A(dB)
 pressure B(dB)"
rem
print #5," freq(Hz)     power(dB)  intensity(dB)     pressure
A(dB)   pressure B(dB)"
for k=first to last
if sw156(k)<0 then print"Data are not correct on";freq(k);"Hz"
si156(k)=sgn(sw156(k))*10*log(abs(sw156(k))/totarea)/log(10)
   sw156(k)=sgn(sw156(k))*10*log(abs(sw156(k)))/log(10)
   spl10(k)=10*log(spl10(k)/totarea)/log(10)
   spl11(k)=10*log(spl11(k)/totarea)/log(10)
print #3,using "  #####     ####.##         ####.##     ####.##
####.##";freq(k);sw156(k);si156(k);spl10(k);spl11(k)
rem
print #5,using "  #####     ####.##         ####.##     ####.##
####.##";freq(k);sw156(k);si156(k);spl10(k);spl11(k)
rem
print using "  #####     ####.##         ####.##          ####.##
####.##";freq(k);sw156(k);si156(k);spl10(k);spl11(k)
next k
locate 23,5
print "Press any key to continue..."
asd:ANA$=INKEY$:if ANA$="" then goto asd
close #1
Return
rem
graph:
open "I",#1,dat$
cls
out$="out1.dat"
input"What's file name(default:out1.dat) for surface 1";out1a$
if out1a$<>"" then out$=out1a$
out$="d:\surfer\"+out$
open "O", #4, out$
rem
if numsurf<=1 then goto next111
cls
outa12$="out2.dat"
input"What's file name(default:out2.dat) for surface 2";out2a$
if out2a$<>"" then outa12$=out2a$
outa12$="d:\surfer\"+outa12$
open "O", #14, outa12$
rem
if numsurf<=2 then goto next111
cls
outb$="out3.dat"
input"What's file name(default:out3.dat) for surface 3";out2b$
if out2b$<>"" then outb$=out2b$
outb$="d:\surfer\"+outb$
open "O", #6, outb$
rem
```

```
if numsurf<=3 then goto next111
cls
outc$="out4.dat"
input"What's file name(default:out4.dat) for surface 4";out2c$
if out2c$<>"" then outc$=out2c$
outc$="d:\surfer\"+outc$
open "O", #7, outc$
rem
if numsurf<=4 then goto next111
cls
outd$="out5.dat"
input"What's file name(default:out5.dat) for surface 5";out2d$
if out2d$<>"" then outd$=out2d$
outd$="d:\surfer\"+outd$
open "O", #8, outd$
rem
if numsurf<=5 then goto next111
cls
oute$="out6.dat"
input"What's file name(default:out6.dat) for surface 6";out2e$
if out2e$<>"" then oute$=out2e$
oute$="d:\surfer\"+oute$
open "O", #9, oute$
rem
next111:
cls
input "What frequence value are you considering(Hz)?",freq2
for k=first to last
numpoint=0
for i=1 to numsurf
   for j=1 to point0(i)
numpoint=numpoint+1
if dimen$="1D" then input #1, freq3,spl,sil,sarea,spl200
if dimen$="3D" then input #1,
freq3,spl,silx,sily,sil,sarea,spl200
rem
if(freq3=freq2 and i=1) then print
#4,x(numpoint),y(numpoint),sil
rem
if(freq3=freq2 and i=2) then print
#14,x(numpoint),y(numpoint),sil
rem
if(freq3=freq2 and i=3) then print
#6,x(numpoint),y(numpoint),sil
rem
if(freq3=freq2 and i=4) then print
#7,x(numpoint),y(numpoint),sil
rem
if(freq3=freq2 and i=5) then print
#8,x(numpoint),y(numpoint),sil
rem
if(freq3=freq2 and i=6) then print
```

```
#9,x(numpoint),y(numpoint),sil
   next j
next i
next k
close #1
rem
Return
rem
indicator2:
rem
rem This subroutine is to process the data according to the
rem        indicators in ISO/DP 9614 standard(draft)
rem
dim riz(42),sil1(320),spl1(320)
cls
input "What is the name of the reactivity file?",react$
open "I", #12, react$
for freq=1 to 42
   if dimen$="1D" then input #12,riz(freq)
   if dimen$="3D" then input #12,a100,b100,riz(freq)
next freq
close #12
rem
print #5,"============================="
print #5,"ISO standard field indicators"
print #5,"============================="
print #5,
print #5,"frequency(Hz)    LD        F2         F3          F4
criterion1   criterion2"
PRINT #5,
cls
open "I",#1,dat$
print "ISO indicators calculation!"
for k=first to last
   ld=-riz(k)-10
a=0.0:b=0.0:a1=0.0:a9=0
for i=1 to totnumber
if dimen$="1D" then input #1, freq(k),spl1(i),sil1(i),s,spl200
if dimen$="3D" then input #1,
freq(k),spl1(i),ilx(i),ily(i),sil1(i),s,spl200
   a9=a9+10^(spl1(i)/10)
   a=a+10^(abs(sil1(i))/10)
   if sil1(i)<0.0 then a1=a1-10^(abs(sil1(i))/10)
   if sil1(i)>0.0 then a1=a1+10^(abs(sil1(i))/10)
next i
   t=a/totnumber
   t1=a1/totnumber
   t2=a9/totnumber
   if t>0.0 then ssil1=10*log(abs(t))/log(10)
   if t<0.0 then ssil1=-10*log(abs(t))/log(10)
   if t1>0.0 then ssil2=10*log(abs(t1))/log(10)
   if t1<0.0 then ssil2=-10*log(abs(t1))/log(10)
```

```
   sspl=10*log(t2)/log(10)
f2=sspl-ssil1
f3=sspl-ssil2
for j=1 to totnumber
   if sil1(j)>0.0 then b=b+(10^(abs(sil1(j))/10)-t1)^2
   if sil1(j)<0.0 then b=b+(-10^(abs(sil1(j))/10)-t1)^2
next j
f4=sqr(b/(totnumber-1))/t1
rem
if ld>f2 then criterion1$="satisfied" else criterion1$="no"
rem
if freq(k)>160 then goto cc2
if  totnumber>15*f4^2  then  criterion2$="satisfied"  else
criterion2$="no"
goto cc4
cc2:if freq(k)>800 then goto cc3
if  totnumber>28*f4^2  then  criterion2$="satisfied"  else
criterion2$="no"
goto cc4
cc3:if  totnumber>90*f4^2  then  criterion2$="satisfied"  else
criterion2$="no"
cc4:
print #5, using"     ####      ##.###    ###.###    ###.###
###.###      \                        \     \
\";freq(k);ld;f2;f3;f4;criterion1$;criterion2$
rem
next k
close #1
Return
rem
rem This subroutine is to process the data according to the
rem       indicators in ANSI S12.12 standard(draft).
rem
indicator1:
print #5, "===================================="
print #5, "ANSI Standard Data Quality Indicators"
print #5, "===================================="
print #5,
menu:
cls
print:print:print:print:print
print "**************INDICATORS SELECTION MENU*************"
PRINT "*(1) Level temporal variability indicators, D1     *"
print "*(2) Parasitic noise level indicators, D2          *"
print "*(3) Surface averaging accuracy indicators, D3     *"
print "*(4) Sound power accuracy indicators, D4           *"
print "*(5) Phase indicators, D5                          *"
print "*(6) Averaging time sufficiency indicators, D6     *"
print "*(7) Measurement interference indicators, D7       *"
print "*(8) Goto to ROOT MENU                             *"
print "***********Select an index to continue*************"
print:print
```

```
loop:sel$=INKEY$:if sel$="" then goto loop
select=VAL(sel$)
if select=1 then goto D1
if select=2 then goto D2
if select=3 then goto D3
if select=4 then goto D4
if select=5 then goto D5
if select=6 then goto D6
if select=7 then goto D7
if select=8 then close:goto manu
beep:goto menu
D1:
cls
print:print:print:print:print
print "****************D1 SUBMENU****************************"
print "*(1) Surface rms sound pressure variation, D11       *"
print "*(2) Local sound pressure variation, D12             *"
print "*(3) Surface sound intensity variation, D13          *"
print "*(4) Local sound intensity variation, D14            *"
print "*(5) Return to Indicator Main Menu                   *"
print "*(6) Return to ROOT MENU                             *"
print "************Select an index to continue************"
print:print
loop1:sel1$=INKEY$:if sel1$="" then goto loop1
select1=VAL(sel1$)
if select1=6 then close:goto manu
if select1=5 then goto menu
if select1=1 then lab$="D11"
if select1=2 then lab$="D12"
if select1=3 then lab$="D13"
if select1=4 then lab$="D14"
rem
cls
print lab$;" calculation!"
dim spl(3,320),sil(3,320),s(320),sspl(10),ssil(10)
rem testimes: no. of tests repeated
print:print
input "How many times was the test repeated?",testimes
open "I",#1,dat$
rem
print #5,"Indicator ";lab$
for k=first to last
rem
for i=1 to testimes
   for j=1 to totnumber
rem
if dimen$="1D" then input #1,
freq(k),spl(i,j),sil(i,j),s(j),spl200
rem
if dimen$="3D" then input #1,
freq(k),spl(i,j),silx,sily,sil(i,j),s(j),spl200
rem
```

```
   next j
next i
rem
if select1=1 then goto D11
if select1=2 then goto D12
if select1=3 then goto D13
if select1=4 then goto D14
beep:goto D1
D11:
c=0.0
for i=1 to testimes
a=0.0:b=0.0
rem
rem  find the surface sound pressure level sspl(i)
rem  ------------------------------------------------
   for j=1 to totnumber
      a=a+s(j)*10^(spl(i,j)/10.0)
      b=b+s(j)
   next j
   sspl(i)=10.0*log(a/b)/log(10)
rem
rem  find the mean of the sspl
rem  -------------------------
   c=c+10^(sspl(i)/10)
next i
   mean=c/testimes
rem
   d=(testimes-1)*c^2
rem
e=0.0
   for i=1 to testimes
      e=e+(10^(sspl(i)/10)-mean)^2
   next i
indicator11=10*log(testimes^2*e/d)/log(10)
print #5, using "  #####    ###.##";freq(k);indicator11
goto D1end
rem
D12:
if k=first then input "Which location do you want to
consider(input an integer)?",location%
c=0.0
for i=1 to testimes
   c=c+10^(spl(i,location%)/10)
next i
   mean=c/testimes
   d=(testimes-1)*c^2
e=0.0
   for i=1 to testimes
      e=e+(10^(spl(i,location%)/10)-mean)^2
   next i
indicator12=10*log(abs(testimes^2*e/d))/log(10)
print    #5,    using    "         ###             #####
```

```
###.##";location%;freq(k);indicator12
goto D1end
rem
D13:
c=0.0
for i=1 to testimes
   a=0.0:b=0.0
   for j=1 to totnumber
if sil(i,j)<0.0 then a=a-s(j)*10^(abs(sil(i,j))/10.0)
if sil(i,j)>0.0 then a=a+s(j)*10^(abs(sil(i,j))/10.0)
b=b+s(j)
   next j
   t=a/b
   if t>0.0 then ssil(i)=10*log(abs(t))/log(10)
   if t<0.0 then ssil(i)=-10*log(abs(t))/log(10)
   if ssil(i)>0.0 then c=c+10^(abs(ssil(i))/10)
   if ssil(i)<0.0 then c=c-10^(abs(ssil(i))/10)
next i
   mean=c/testimes
   d=(testimes-1)*c^2
e=0.0
for i=1 to testimes
   if ssil(i)>0.0 then e=e+(10^(abs(ssil(i))/10)-mean)^2
   if ssil(i)<0.0 then e=e+(-10^(abs(ssil(i))/10)-mean)^2
next i
indicator13=10*log(testimes^2*abs(e/d))/log(10)
print #5, using "  #####   ###.##";freq(k);indicator13
goto D1end
rem
D14:
if k=first then input "Which location do you want to
consider(input an integer)?",location%
c=0.0
for i=1 to testimes
if sil(i,location%)>0.0 then c=c+10^(abs(sil(i,location%))/10)
if sil(i,location%)<0.0 then c=c-10^(abs(sil(i,location%))/10)
next i
   mean=c/testimes
   d=(testimes-1)*c^2
e=0.0
   for i=1 to testimes
if sil(i,location%)>0.0 then
e=e+(10^(abs(sil(i,location%))/10)-mean)^2
rem
if sil(i,location%)<0.0 then
e=e+(-10^(abs(sil(i,location%))/10)-mean)^2
   next i
indicator14=10*log(testimes^2*abs(e/d))/log(10)
print #5, using "   ###      #####
###.##";location%;freq(k);indicator14
D1end:
rem
```

```
next k
print #5,
close #1
rem
goto D1
rem
rem
D2:
cls
print:print:print:print:print
print "*********************D2 SUBMENU*********************"
print "*(1) Presence of high parasitic noise, D21         *"
print "*(2) Signal to noise ratio, D22                    *"
print "*(3) Parasitic noise and influence of geometry     *"
print "*    of the measurement surface, D23               *"
print "*(4) Parasitic noise and influence of geometry     *"
print "*    of the measurement surface, D24               *"
print "*(5) Spatial variation due to source directivity   *"
print "*    or parasitic noise, D25                       *"
print "*(6) Spatial variation due to parasitic noise, D26 *"
print "*(7) Test of presence of the parasitic noise, D27  *"
print "*(8) Return to Indicator Main Menu                 *"
print "*(9) Return to ROOT MENU                           *"
print "*************Select an index to continue************"
print:print
loop2:sel2$=INKEY$:if sel2$="" then goto loop2
select2=VAL(sel2$)
if select2=9 then close:goto manu
if select2=8 then goto menu
if select2=1 then lab$="D21"
if select2=2 then lab$="D22"
if select2=3 then lab$="D23"
if select2=4 then lab$="D24"
if select2=5 then lab$="D25"
if select2=6 then lab$="D26"
if select2=7 then lab$="D27"
print lab$;" calculation!"
open "I", #1, dat$
dim silbo(320)
print #5,"Indicator ";lab$
if select2=2 then goto D22
if select2=7 then goto D27
rem
for k=first to last
rem
for i=1 to totnumber
rem
if dimen$="1D" then input
#1,freq(k),spl1(i),sil1(i),s(i),spl200
rem
if dimen$="3D" then input
#1,freq(k),spl1(i),ilx(i),ily(i),sil1(i),s(i),spl200
```

```
next i
if select2=1 then goto D21
if select2=3 then goto D23
if select2=4 then goto D24
if select2=5 then goto D25
if select2=6 then goto D26
beep:goto D2
D21:
a=0.0:b=0.0:a1=0.0
for i=1 to totnumber
   a=a+s(i)*10^(abs(sil1(i))/10)
   if sil1(i)<0.0 then a1=a1-s(i)*10^(abs(sil1(i))/10)
   if sil1(i)>0.0 then a1=a1+s(i)*10^(abs(sil1(i))/10)
   b=b+s(i)
next i
   t=a/b
   t1=a1/b
   if t>0.0 then ssil1=10*log(abs(t))/log(10)
   if t<0.0 then ssil1=-10*log(abs(t))/log(10)
   if t1>0.0 then ssil2=10*log(abs(t1))/log(10)
   if t1<0.0 then ssil2=-10*log(abs(t1))/log(10)
indicator21=ssil1-ssil2
print #5, using "  #####   ###.##";freq(k);indicator21
goto D2end
rem
D22:
for k1=first to last
for m=1 to 2
for i=1 to totnumber
   if m=2 then goto back
if dimen$="1D" then input #1,freq(k1),spl,sil1(i),s(i),spl200
if dimen$="3D" then input #1,freq(k1),spl,silx,sily,sil1(i),s(i),spl200
   goto fin5
back:
if dimen$="1D" then input #1,freq(k),spl,silbo(i),s,spl200
if dimen$="3D" then input #1,freq(k),spl,silx,sily,silbo(i),s,spl200
fin5:
next i
next m
a=0.0:b=0.0:a1=0.0
for i=1 to totnumber
   if sil1(i)<0.0 then a=a-s(i)*10^(abs(sil1(i))/10)
   if silbo(i)<0.0 then a1=a1-s(i)*10^(abs(silbo(i))/10)
   if sil1(i)>0.0 then a=a+s(i)*10^(abs(sil1(i))/10)
   if silbo(i)>0.0 then a1=a1+s(i)*10^(abs(silbo(i))/10)
   b=b+s(i)
next i
   t=a/b
   t1=a1/b
   if t>0.0 then ssil1=10*log(abs(t))/log(10)
```

```
   if t<0.0 then ssil1=-10*log(abs(t))/log(10)
   if t1>0.0 then ssilbo=10*log(abs(t1))/log(10)
   if t1<0.0 then ssilbo=-10*log(abs(t1))/log(10)
indicator22=ssil1-ssilbo
print #5, using "  #####   ###.##";freq(k);indicator22
next k1
print #5,
close #1
goto D2
rem
rem
D23:
a=0.0:b=0.0:c=0.0
for i=1 to totnumber
   a=a+s(i)*10^(spl1(i)/10)
   if sil1(i)<0.0 then b=b-s(i)*10^(abs(sil1(i))/10)
   if sil1(i)>0.0 then b=b+s(i)*10^(abs(sil1(i))/10)
   c=c+s(i)
next i
   sspl1=10*log(a/c)/log(10)
   ssil1=10*log(abs(b/c))/log(10)
indicator23=sspl1-ssil1
print #5, using "  #####   ###.##";freq(k);indicator23
goto D2end
rem
rem
D24:
a=0.0:b=0.0:c=0.0
for i=1 to totnumber
   a=a+s(i)*10^(spl1(i)/10)
   b=b+s(i)*10^(abs(sil1(i))/10)
   c=c+s(i)
next i
   sspl1=10*log(a/c)/log(10)
   ssil2=10*log(abs(b/c))/log(10)
indicator24=sspl1-ssil2
print #5, using "  #####   ###.##";freq(k);indicator24
goto D2end
rem
rem
D25:
a=0.0:c=0.0
for i=1 to totnumber
   if sil1(i)>0.0 then a=a+10^(abs(sil1(i))/10.0)
   if sil1(i)<0.0 then a=a-10^(abs(sil1(i))/10.0)
next i
   mean=a/totnumber
rem
   b=(totnumber-1)*mean^2
for i=1 to totnumber
   if sil1(i)>0.0 then c=c+(10^(abs(sil1(i))/10)-mean)^2
   if sil1(i)<0.0 then c=c+(-10^(abs(sil1(i))/10)-mean)^2
```

```
next i
indicator25=10*log(c/b)/log(10)
print #5, using "  #####   ###.##";freq(k);indicator25
goto D2end
rem
rem
D26:
a=0.0:b=0.0
for i=1 to totnumber
   if sil1(i)>0.0 then a=a+10^(abs(sil1(i))/10)
   if sil1(i)<0.0 then a=a-10^(abs(sil1(i))/10)
   b=b+10^(spl1(i)/10)
next i
   mean1=a/totnumber
   mean2=b/totnumber
rem
   c=(totnumber-1)*mean1^2
   d=(totnumber-1)*mean2^2
e=0.0:f=0.0
for i=1 to totnumber
if sil1(i)>0.0 then e=e+(10^(abs(sil1(i))/10)-mean1)^2
if sil1(i)<0.0 then e=e+(-10^(abs(sil1(i))/10)-mean1)^2
f=f+(10^(spl1(i)/10)-mean2)^2
next i
   g=10*log(abs(e/c))/log(10)
   h=10*log(f/d)/log(10)
indicator26=g-h
print #5, using "  #####   ###.##";freq(k);indicator26
goto D2end
rem
rem
D27:
rem sil2(i): intensity level of the sound field with
additional absorpation
dim sil2(320)
for k1=first to last
for m=1 to 2
for i=1 to totnumber
   if m=2 then goto back2
if dimen$="1D" then input #1, freq(k1),spl,sil1(i),s(i),spl200
if dimen$="3D" then input #1,
freq(k1),spl,silx,sily,sil1(i),s(i),spl200
   goto fin6
back2:
if dimen$="1D" then input #1, freq(k1),spl,sil2(i),s,spl200
if dimen$="3D" then input #1,
freq(k1),spl,silx,sily,sil2(i),s,spl200
fin6:
next i
next m
a=0.0:b=0.0:c=0.0
for i=1 to totnumber
```

```
   if sil1(i)>0.0 then a=a+s(i)*10^(abs(sil1(i))/10)
   if sil1(i)<0.0 then a=a-s(i)*10^(abs(sil1(i))/10)
   if sil2(i)>0.0 then b=b+s(i)*10^(abs(sil2(i))/10)
   if sil2(i)<0.0 then b=b-s(i)*10^(abs(sil2(i))/10)
   c=c+s(i)
next i
t=a/c
t1=b/c
if t>0.0 then d=10*log(abs(t))/log(10)
if t<0.0 then d=-10*log(abs(t))/log(10)
if t1>0.0 then e=10*log(abs(t1))/log(10)
if t1<0.0 then e=-10*log(abs(t1))/log(10)
indicator27=d-e
print #5, using "  #####   ###.##";freq(k1);indicator27
next k1
rem
D2end:
next k
print #5,
close #1
goto D2
rem
rem
rem
D3:
cls
print:print:print:print:print
print "***************D3 SUBMENU****************"
print "*(1) Sample number accuracy test, D31    *"
print "*(2) Sample location accuracy test, D32 *"
print "*(3) Return to Indicator Main Menu       *"
print "*(4) Return to ROOT MENU                 *"
print "*******Select an index to continue*******"
print:print
loop3:sel3$=INKEY$:if sel3$="" then goto loop3
select3=VAL(sel3$)
if select3=4 then close:goto manu
if select3=3 then goto menu
if select3=1 then lab$="D31"
if select3=2 then lab$="D32"
print lab$;" calculation!"
open "I", #1, dat$
dim s1(320)
if select3=1 then segment2=4*totnumber
if select3=2 then segment2=totnumber
print #5,"Indicator ";lab$
for k=first to last
a=0.0:b=0.0
for i=1 to totnumber
if dimen$="1D" then input #1, freq(k),spl,sil1(i),s(i),spl200
if dimen$="3D" then input #1,
freq(k),spl,ilx(i),ily(i),sil1(i),s(i),spl200
```

```
   if sil1(i)>0.0 then a=a+s(i)*10^(abs(sil1(i))/10.0)
   if sil1(i)<0.0 then a=a-s(i)*10^(abs(sil1(i))/10.0)
   b=b+s(i)
next i
t=a/b
if t>0.0 then sila=10.0*log(abs(t))/log(10)
if t<0.0 then sila=-10.0*log(abs(t))/log(10)
c=0.0:d=0.0
for i=1 to segment2
if dimen$="1D" then input #1, freq(k),spl,sil2(i),s1(i),spl200
if dimen$="3D" then input #1,
freq(k),spl,ilx(i),ily(i),sil2(i),s1(i),spl200
   if sil2(i)>0.0 then c=c+s1(i)*10^(abs(sil2(i))/10.0)
   if sil2(i)<0.0 then c=c-s1(i)*10^(abs(sil2(i))/10.0)
   d=d+s1(i)
next i
t1=c/d
if t1>0.0 then silb=10.0*log(abs(t1))/log(10)
if t1<0.0 then silb=-10.0*log(abs(t1))/log(10)
indicator3=abs(sila-silb)
print #5,using "  #####   ###.##";freq(k);indicator3
next k
print #5,
close #1
goto D3
rem
rem
D4:
cls
print:print:print:print:print
print "************************D4 SUBMENU**********************"
print "*(1) Influence of measurement surfaces to power, D41 *"
print "*(2) Normalized standard derivation of power, D42    *"
print "*(3) R[illegible]n to Indicator Main Menu                      *"
print "*(4) [illegible]n to ROOT MENU                                 *"
print "*****[illegible]***Select an index to continue***************"
print:print
loop4:sel4$=[illegible]$:if sel4$="" then goto loop4
select4=VAL(sel[illegible])
if select4=4 then close:goto manu
if select4=3 then goto menu
if select4=1 then lab$="D41"
if select4=2 then lab$="D42"
print lab$;" calculation!"
open "I", #1, dat$
print #5,"Indicator ";lab$
if select4=2 then goto D42
input "What's no. of points on second test surface?",segment2
for k=first to last
for i=1 to totnumber
if dimen$="1D" then input #1,freq(k),spl,sil1(i),s(i),spl200
if dimen$="3D" then input
```

```
#1,freq(k),spl,ilx(i),ily(i),sil1(i),s(i),spl200
next i
for i=1 to segment2
if dimen$="1D" then input #1,freq(k),spl,sil2(i),s1(i),spl200
if dimen$="3D" then input
#1,freq(k),spl,ilx(i),ily(i),sil2(i),s1(i),spl200
next i
a=0.0
for i=1 to totnumber
   if sil1(i)>0.0 then a=a+s(i)*10^(abs(sil1(i))/10.0)
   if sil1(i)<0.0 then a=a-s(i)*10^(abs(sil1(i))/10.0)
next i
swl1=10.0*log(abs(a))/log(10)
b=0.0
for i=1 to segment2
   if sil2(i)>0.0 then b=b+s1(i)*10^(abs(sil2(i))/10.0)
   if sil2(i)<0.0 then b=b-s1(i)*10^(abs(sil2(i))/10.0)
next i
swl2=10.0*log(abs(b))/log(10)
indicator41=abs(swl1-swl2)
print #5, using "  #####   ###.##";freq(k);indicator41
next k
print #5,
close #1
goto D4
rem
rem
D42:
dim swl(320)
for k=first to last
for i=1 to totnumber
if dimen$="1D" then input #1,freq(k),spl,sil1(i),s(i),spl200
if dimen$="3D" then input
#1,freq(k),spl,ilx(i),ily(i),sil1(i),s(i),spl200
   swl(i)=abs(sil1(i))+10.0*log(s(i))/log(10)
next i
c=0.0:d=0.0
for i=1 to totnumber
   c=c+10^(swl(i)/10.0)
next i
mean=c/totnumber
for i=1 to totnumber
   d=d+(10^(swl(i)/10.0)-mean)^2
next i
indicator42=10.0*log(d/((totnumber-1)*mean^2))/log(10)
print #5, using "  #####   ###.##";freq(k);indicator42
next k
print #5,
close #1
goto D4
rem
rem
```

```
D5:
cls
print:print:print:print:print
print "*********************D5 SUBMENU***********************"
print "*(1) Reverse probe sound power level residual, D51  *"
print "*(2) Pressure-intensity index difference, D52       *"
print "*(3) Pressure-intensity index, D53                  *"
print "*(4) Pressure-velocity method phase mismatch,(n/a)  *"
print "*(5) Return to Indicator Main Menu                  *"
print "*(6) Return to ROOT MENU                            *"
print "*************Select an index to continue***************"
print:print
loop5:sel5$=INKEY$:if sel5$="" then goto loop5
select5=VAL(sel5$)
if select5=6 then close:goto manu
if select5=5 then goto menu
if select5=4 then goto D5
if select5=1 then lab$="D51"
if select5=2 then lab$="D52"
if select5=3 then lab$="D53"
print lab$;" calculation!"
open "I", #1, dat$
if select5<>2 then goto nt
cls
input "What is the name of the reactivity file?",react$
open "I", #12, react$
for freq=1 to 42
   if dimen$="1D" then input #12,riz(freq)
   if dimen$="3D" then input #12,a100,b100,riz(freq)
next freq
close #12
rem
nt:
print #5,"Indicator ";lab$
dim spl2(320)
for k=first to last
for i=1 to totnumber
if dimen$="1D" then input
#1,freq(k),spl1(i),sil1(i),s(i),spl200
rem
if dimen$="3D" then input
#1,freq(k),spl1(i),ilx(i),ily(i),sil1(i),s(i),spl200
next i
if select5=2 then goto D52
if select5=3 then goto D53
for i=1 to totnumber
if dimen$="1D" then input
#1,freq(k),spl2(i),sil2(i),s1(i),spl200
rem
if dimen$="3D" then input
#1,freq(k),spl2(i),ilx(i),ily(i),sil2(i),s1(i),spl200
next i
```

```
a=0.0:c=0.0
for i=1 to totnumber
if sil1(i)>0.0 then a=a+s(i)*10^(abs(sil1(i))/10.0)
if sil1(i)<0.0 then a=a-s(i)*10^(abs(sil1(i))/10.0)
if sil2(i)>0.0 then c=c+s1(i)*10^(abs(sil2(i))/10.0)
if sil2(i)<0.0 then c=c-s1(i)*10^(abs(sil2(i))/10.0)
next i
swl1=10.0*log(abs(a))/log(10)
swl2=10.0*log(abs(c))/log(10)
indicator51=(swl1-swl2)/2
print #5, using "  #####   ###.##";freq(k);indicator51
goto D5end
rem
rem
D52:
a=0.0:b=0.0:c=0.0:d=0.0:e=0.0:f=0.0
for i=1 to totnumber
   a=a+s(i)*10^(spl1(i)/10.0)
   if  sil1(i)>0.0  then  b=b+s(i)*10^(abs(sil1(i))/10.0)
   if  sil1(i)<0.0  then  b=b-s(i)*10^(abs(sil1(i))/10.0)
   c=c+s(i)
next i
spla=10.0*log(a/c)/log(10)
sila=10.0*log(abs(b/c))/log(10)
indicator52=-riz(k)-spla+sila
print #5, using "  #####   ###.##";freq(k);indicator52
goto D5end
rem
rem
D53:
a=0.0:b=0.0:c=0.0
for i=1 to totnumber
   a=a+s(i)*10^(spl1(i)/10.0)
   if  sil1(i)>0.0  then  b=b+s(i)*10^(abs(sil1(i))/10.0)
   if  sil1(i)<0.0  then  b=b-s(i)*10^(abs(sil1(i))/10.0)
   c=c+s(i)
next i
spla=10.0*log(a/c)/log(10)
sila=10.0*log(abs(b/c))/log(10)
indicator53=spla-sila
print #5, using "  #####   ###.##";freq(k);indicator53
D5end:
next k
print #5,
close #1
goto D5
rem
rem
D6:
cls
print:print:print:print:print
print "********************D6 SUBMENU*************************"
```

```
print "*(1) Intensity temporal deviation, D61                    *"
print "*(2) Individual intensity temporal deviation, D62         *"
print "*(3) Pressure temporal standard deviation, D63            *"
print "*(4) Individual pressure temporal deviation, D64          *"
print "*(5) Return to Indicator Main Menu                        *"
print "*(6) Return to ROOT MENU                                  *"
print "************Select an index to continue*************"
print:print
loop6:sel6$=INKEY$:if sel6$="" then goto loop6
select6=VAL(sel6$)
if select6=6 then close:goto manu
if select6=5 then goto menu
if select6=1 then lab$="D61"
if select6=2 then lab$="D62"
if select6=3 then lab$="D63"
if select6=4 then lab$="D64"
print lab$;" calculation!"
open "I", #1, dat$
input "How many times was the test repeated?", testimes
print #5,"Indicator ";lab$
for k=first to last
for i=1 to testimes
   for j=1 to totnumber
if dimen$="1D" then input #1,
freq(k),spl(i,j),sil(i,j),s(j),spl200
rem
if dimen$="3D" then input #1,
freq(k),spl(i,j),silx,sily,sil(i,j),s(j),spl200
   next j
next i
if select6=1 then goto D61
if select6=2 then goto D62
if select6=3 then goto D63
if select6=4 then goto D64
beep:goto D6
D61:
c=0.0
for i=1 to testimes
   a=0.0:b=0.0
   for j=1 to totnumber
if sil(i,j)>0.0 then a=a+s(j)*10^(abs(sil(i,j))/10.0)
if sil(i,j)<0.0 then a=a-s(j)*10^(abs(sil(i,j))/10.0)
b=b+s(j)
   next j
   ssil(i)=10.0*log(a/b)/log(10)
   if ssil(i)>0.0 then c=c+10^(abs(ssil(i))/10.0)
   if ssil(i)<0.0 then c=c-10^(abs(ssil(i))/10.0)
next i
mean=c/testimes
d=(testimes-1)*mean^2
e=0.0
for i=1 to testimes
```

```
   if ssil(i)>0.0 then e=e+(10^(abs(ssil(i))/10.0)-mean)^2
   if ssil(i)<0.0 then e=e+(-10^(abs(ssil(i))/10.0)-mean)^2
next i
indicator61=10.0*log(abs(e/d))/log(10)
print #5, using "  #####   ###.##";freq(k);indicator61
goto D6end
rem
rem
D62:
if k=first then input "Which location do you want to
consider?(input an integer)";location%
c=0.0
for i=1 to testimes
if sil(i,location%)>0.0 then
c=c+10^(abs(sil(i,location%))/10.0)
rem
if sil(i,location%)<0.0 then
c=c-10^(abs(sil(i,location%))/10.0)
next i
   mean=c/testimes
   d=(testimes-1)*mean^2
   e=0.0
for i=1 to testimes
if sil(i,location%)>0.0 then
e=e+(10^(abs(sil(i,location%))/10.0)-mean)^2
rem
if sil(i,location%)<0.0 then
e=e+(-10^(abs(sil(i,location%))/10.0)-mean)^2
next i
indicator62=10*log(abs(e/d))/log(10)
print #5, using "      ###        #####
###.##";location%;freq(k);indicator62
goto D6end
rem
rem
D63:
c=0.0
for i=1 to testimes
   a=0.0:b=0.0
   for j=1 to totnumber
      a=a+s(j)*10^(spl(i,j)/10.0)
      b=b+s(j)
   next j
   sspl(i)=10.0*log(a/b)/log(10)
   c=c+a/b
next i
mean=c/testimes
d=(testimes-1)*mean^2
e=0.0
for i=1 to testimes
   e=e+(10^(sspl(i)/10.0)-mean)^2
next i
```

```
indicator63=10.0*log(e/d)/log(10)
print #5, using "  #####   ###.##";freq(k);indicator63
goto D6end
rem
rem
D64:
if k=first then input "Which location do you want to consider?(input an integer)",location%
c=0.0
for i=1 to testimes
   c=c+10^(spl(i,location%)/10.0)
next i
   mean=c/testimes
   d=(testimes-1)*mean^2
e=0.0
for i=1 to testimes
   e=e+(10^(spl(i,location%)/10.0)-mean)^2
next i
indicator64=10.0*log(e/d)/log(10)
print #5, using "  ###   #####   ###.##";location%;freq(k);indicator64
D6end:
next k
print #5,
close #1
goto D6
rem
rem
D7:
cls
print:print:print:print:print
print "********************D7 SUBMENU*************************"
print "*(1) Interference influence to intensity, D71          *"
print "*(2) Interference influence to local intensity, D72    *"
print "*(3) Interference influence to local intensity, D73    *"
print "*(4) Return to Indicator Main Menu                     *"
print "*(5) Return to ROOT MENU                               *"
print "****************Select an index to continue***********"
print:print
loop7:sel7$=INKEY$:if sel7$="" then goto loop7
select7=VAL(sel7$)
if select7=5 then close:goto manu
if select7=4 then goto menu
if select7=3 then goto D73
if select7=1 then lab$="D71"
if select7=2 then lab$="D72"
if select7=3 then lab$="D73"
print lab$;" calculation!"
open "I", #1, dat$
print #5,"Indicator ";lab$
for k=first to last
for i=1 to totnumber
```

```
if dimen$="1D" then input #1, freq(k),spl,sil1(i),s(i),spl200
if dimen$="3D" then input #1,
freq(k),spl,ilx(i),ily(i),sil1(i),s(i),spl200
next i
for i=1 to totnumber
if dimen$="1D" then input #1, freq(k),spl,sil2(i),s,spl200
if dimen$="3D" then input #1,
freq(k),spl,ilx(i),ily(i),sil2(i),s,spl200
next i
rem
if select7=2 then goto D72
D71:
a=0.0:b=0.0:c=0.0
for i=1 to totnumber
   if sil1(i)>0.0 then a=a+s(i)*10^(abs(sil1(i))/10.0)
   if sil1(i)<0.0 then a=a-s(i)*10^(abs(sil1(i))/10.0)
   if sil2(i)>0.0 then b=b+s(i)*10^(abs(sil2(i))/10.0)
   if sil2(i)<0.0 then b=b-s(i)*10^(abs(sil2(i))/10.0)
   c=c+s(i)
next i
t=a/c
t1=b/c
if t>0.0 then sila=10.0*log(abs(t))/log(10)
if t<0.0 then sila=-10.0*log(abs(t))/log(10)
if t1>0.0 then silb=10.0*log(abs(t1))/log(10)
if t1<0.0 then silb=10.0*log(abs(t1))/log(10)
indicator71=abs(sila-silb)
print #5, using "  #####   ###.##";freq(k);indicator71
goto D7end
rem
rem
D72:
if k=first then input "Which location do you want to
consider?(input an integer)",location%
indicator72=abs(sil1(location%)-sil2(location%))
print #5, using "  #####   ###.##";freq(k);indicator72
goto D7end
D73:
print "D73 calculation!"
if k=first then input "which location do you want to
consider?(input an integer)";location%
rem
print "What's maximum intensity level for frequency";freq(k)
input max
print "What's minimum intensity level for frequency";freq(k)
input min
indicator73=10.0*log(abs(max-min))/log(10)
print #5, using "  #####   ###.##";freq(k);indicator73
D7end:
next k
close #1
goto D7
```

```
rem
rem
Return
```

APPENDEX 4[3]

List of Program for Calibrations

---

[3] Whenever there are two or three consecutive underlined lines, they form only a single statement.

```
REM RBK3d.bas
Rem last modified 30/08/90
Rem Reactivity calibration 3d, 1/3 octave
COMMON SHARED IBSTA%, IBERR%, IBCNT%
GPIB$ = "GPIB0"
BKP$ = "bk2134p":BKD$ = "bk2134d"
M$ = "Micro"
CALL IBFIND(GPIB$,BD%)
CALL IBFIND(M$,M%)
CALL IBFIND(BKP$,BKP%):CALL IBFIND(BKD$,BKD%)
DIM SPEC%(150),FLAG%(42),SPL1(42),SPL2(42)
DIM PRC(42),INTE(42),RIX(42),RIY(42),RIZ(42),Freq(42)
Freq(1)=1.6:Freq(2)=2:Freq(3)=2.5:Freq(4)=3.15:Freq(5)=4
Freq(6)=5:Freq(7)=6.3:Freq(8)=8:Freq(9)=10:Freq(10)=12.5
Freq(11)=16:Freq(12)=20:Freq(13)=25:Freq(14)=31.5
Freq(15)=40:Freq(16)=50:Freq(17)=63:Freq(18)=80:Freq(19)=100
Freq(20)=125:Freq(21)=160:Freq(22)=200:Freq(23)=250
Freq(24)=315:Freq(25)=400:Freq(26)=500:Freq(27)=630
Freq(28)=800:Freq(29)=1000:Freq(30)=1250:Freq(31)=1600
Freq(32)=2000:Freq(33)=2500:Freq(34)=3150:Freq(35)=4000
Freq(36)=5000:Freq(37)=6300:Freq(38)=8000
Freq(39)=10000:Freq(40)=12500:Freq(41)=16000:Freq(42)=20000
rem
CNT% = 301
CLS
color 11,0
Input"Do you wish to do pressure calibration (Y/N) ",WISH$
IF (WISH$ = "N" or WISH$ = "n") then goto jum
REM ************DO PRE-CALIBRATION
cls
Print"Step 1) Connect up all cables to the multiplexer"
Print
Print"together with their respective microphone"
Print
Print"cartridges/pre-amplifiers/elbows as appropriate."
Print
Print"DO NOT ASSEMBLE THE 3D PROBE YET!!!"
Print:Print:Print:Print
Print "Press a key when you are ready to continue..."
aloopa: ANA$ = INKEY$: IF ana$ = "" then goto aloopa
cls
Print"Step 2) Connect the multiplexer 'main' to direct input"
Print
Print"Channel 'A' and multiplexer 'subsidiary' to direct"
Print
Print"input Channel 'B' "
Print:Print:Print:Print
Print "Press a key when you are ready to continue..."
bloopa: ANA$ = INKEY$: IF ana$ = "" then goto bloopa
cls
Print"Step 3) Switch on all systems,  selecting analyzer and"
Print
```

```
Print"multiplexer controls as required, and leave for about"
Print
Print"10 minutes"
Print:Print:Print:Print
Print "Press a key when you are ready to continue..."
cloopa: ANA$ = INKEY$: IF ana$ = "" then goto cloopa
COMM$ = "@Q"
CALL IBWRT(M%,COMM$)
CLS
Print "PREPARE FOR PRE-CALIBRATION OF MICROPHONE PAIR 1"
Print
Print"Step 1) Apply piston phone to microphone of Channel 1,"
Print
Print"selecting analyzer pressure,  Channel A."
Print
Print"Step 2) Change reference adjust to +20 dB and"
Print
Print"manipulate either analyzer or multiplexer sensitivity"
Print
Print"controls to acheive calibration"
Print:Print:Print:Print
Print "Press a key when you are ready to continue..."
someloopa: ANA$ = INKEY$: IF ana$ = "" then goto someloopa
cls
Print"Step 3) Apply piston phone to microphone of Channel 2,"
Print
Print"selecting analyzer pressure,  Channel B."
Print
Print"Step 4) Adjust either analyzer or multiplexer"
Print
Print"sensitivity controls to acheive calibration"
Print:Print:Print:Print
Print "Press a key when you are ready to continue..."
dloopa: ANA$ = INKEY$: IF ana$ = "" then goto dloopa
COMM$ = "BS"
CALL IBWRT(M%,COMM$)
CLS
Print "PREPARE FOR PRE-CALIBRATION OF MICROPHONE PAIR 2"
Print
Print"Step 1) Apply piston phone to microphone of Channel 3,"
Print
Print"selecting analyzer pressure,  Channel A."
Print
Print"Step 2) Adjust only multiplexer sensitivity controls"
Print
Print"to acheive calibration"
Print:Print:Print
Print "Press a key when you are ready to continue..."
eloopa: ANA$ = INKEY$: IF ana$ = "" then goto eloopa
cls
Print"Step 3) Apply piston phone to microphone of Channel 4,"
Print
```

```
Print"selecting analyzer pressure,  Channel B."
Print
Print"Step 4) Adjust only multiplexer sensitivity controls"
Print
Print"to acheive calibration"
Print:Print:Print:Print
Print "Press a key when you are ready to continue..."
floopa: ANA$ = INKEY$: IF ana$ = "" then goto floopa
COMM$ = "DU"
CALL IBWRT(M%,COMM$)
CLS
Print "PREPARE FOR PRE-CALIBRATION OF MICROPHONE PAIR 3"
Print
Print"Step 1) Apply piston phone to microphone of Channel 5,"
Print
Print"selecting analyzer pressure,  Channel A."
Print
Print"Step 2) Adjust only multiplexer sensitivity controls"
Print"to acheive calibration"
Print:Print:Print:Print
Print "Press a key when you are ready to continue..."
gloopa: ANA$ = INKEY$: IF ana$ = "" then goto gloopa
cls
Print"Step 3) Apply piston phone to microphone of Channel 6,"
Print
Print"selecting analyzer pressure,  Channel B."
Print
Print"Step 4) Adjust only multiplexer sensitivity controls"
Print
Print"to acheive calibration"
Print:Print:Print:Print
Print "Press a key when you are ready to continue..."
hloopa: ANA$ = INKEY$: IF ana$ = "" then goto hloopa
cls
COMM$ = "F"
CALL IBWRT(M%,COMM$)
Print"CALIBRATION OF SOURCE ROOM MICROPHONE (0.5 INCH)..."
Print
CODE$ = "C>N6"
CALL IBWRT(BKP%,CODE$)
Print"Step 1) Apply piston phone to source microphone and"
Print
Print"raise the input attenuation to avoid overload signal"
Print
Print"Step 2) Adjust Channel 7 multiplexer sensitivity"
Print
Print"until 144 dB is read on the analyzer."
Print:Print
Print"PRESSURE CALIBRATION IS NOW COMPLETE"
Print:Print:Print:Print
Print "Press a key when you are ready to continue..."
someloop3: ANA$ = INKEY$: IF ana$ = "" then goto someloop3
```

```
CODE$ = "N:"
CALL IBWRT(BKP%,CODE$)
jum:
REM **** DO Reactivity Calibration and calculate RI
CLS
For I% = 1 to 42
     RIX(I%) = -10
     RIY(I%) = -10
     RIZ(I%) = -10
Next I%
Print"REACTIVITY CALIBRATION MENU"
Print
Print"Do you wish to ..."
Print"1) Manually input full spectrum"
Print"2) have automatic input"
Print"3) have a single value assigned to full spectrum"
Print"4) have default -10 for full spectrum"
Print"Choose an option ===>  ";
Somelo: A$ = Inkey$:If A$ = "" then goto Somelo
A = val(A$)
If A = 2 then goto AUTOMATIC
If A = 3 then goto SING
If A = 4 then goto Continu
CLS
for I% = 1 to 42
     cls
     Print"Please input RIX(";I%;") --> ";:Input RIX(I%)
     Print"Please input RIY(";I%;") --> ";:Input RIY(I%)
     Print"Please input RIZ(";I%;") --> ";: Input RIZ(I%)
next I%
goto Continu
SING:
cls
Input"What value do you wish to use for the full spectrum ",VA
For I% = 1 to 42
     RIX(I%) = va
     RIY(I%) = va
     RIZ(I%) = va
Next I%
goto Continu
AUTOMATIC:
cls
resul$="react.dat"
PRINT:INPUT "What's result filename(default:react.dat)";resu$
if resu$<>"" then resul$=resu$
open "O", #9, resul$
rem
cls
Print"REACTIVITY CALIBRATION FOR MICROPHONE PAIR 1"
Print"The following calibration will be done with each"
Print
Print"direction pair in turn, mounted within the reactivity"
```

```
Print
Print" coupler :"
Print
Print"Step 1) Using a straight 12 mm spacer,  assemble"
Print
Print"channels 1 & 2 microphones within 3D microphone holder"
Print
Print"Step 2) Insert microphone and spacer assembly within"
Print
Print"reactivity calibrator and switch calibration source ON"
Print:Print:Print:Print
Print "Press a key when you are ready to continue..."
Print:Print
Print"THE NEXT PORTION OF THE CALIBRATION IS AUTOMATED;"
Print
Print"AWAIT FURTHER PROMPTS"
iloopa: ANA$ = INKEY$: IF ana$ = "" then goto iloopa
COMM$ = "@Q"
CALL IBWRT(M%,COMM$)
COLOR 10,0
LOCATE 23,13,,7,7
PRINT "Setting optimal lower level, Channel A, microphone 1";
GOSUB SETLEVEL
Rem
locate 23,13,,7,7
print "Reading Sound Pressure Level, Channel A, Microphone 1";
CODE$ = "E=L?C>O=K>M?M="
CALL IBWRT(BKP%,CODE$)
CODE$ = "M"
CALL IBWRT(BKP%,CODE$)
RETC$ = SPACE$(1)
SomeaLoop: CALL IBRD(BKP%,RETC$)
IF RETC$ <> ">" THEN goto Somealoop
CODE$ = "E?"
CALL IBWRT(BKP%,CODE$)
CALL IBRDI(BKD%,varptr(SPEC%(0)),CNT%)
C% = 0:FOR I% = 0 TO 144 STEP 7
X$ = ""
FOR J% = 0 TO 6
    A$ = MKI$(SPEC%(I%+J%))
    FOR X% = 1 TO 2
     IF ASC(MID$(A$,X%,1)) < 40 THEN MID$(A$,X%,1) = " "
    NEXT X%
    X$ = X$+A$
NEXT J%
FLAG%(C%) = 1:FLAG%(C%+1) = 1
IF MID$(X$,4,1) = "*" THEN MID$(X$,4,1) = ".":FLAG%(C%) = -1
IF MID$(X$,11,1) = "*" THEN MID$(X$,4,1) = "."
FLAG%(C%+1) = -1
IF MID$(X$,4,1) = "<" THEN FLAG%(C%) = 1:MID$(X$,4,1) = "."
IF MID$(X$,11,1) = "<" THEN FLAG%(C%+1) = 1
MID$(X$,11,1) = "."
```

```
PRC(C%) = VAL(MID$(X$,1,5))*FLAG%(C%)
PRC(C%+1) = VAL(MID$(X$,8,5))*FLAG%(C%+1)
C% = C%+2
NEXT I%
locate 23,13,,7,7
print "Reading Sound Pressure Level, Channel B, Microphone 2";
CODE$ = "E=L?C?O=K>M?M="
CALL IBWRT(BKP%,CODE$)
CODE$ = "M"
CALL IBWRT(BKP%,CODE$)
RETC$ = SPACE$(1)
SomebLoop: CALL IBRD(BKP%,RETC$)
IF RETC$ <> ">" THEN goto Somebloop
CODE$ = "E?"
CALL IBWRT(BKP%,CODE$)
CALL IBRDI(BKD%,varptr(SPEC%(0)),CNT%)
C% = 0:FOR I% = 0 TO 144 STEP 7
X$ = ""
FOR J% = 0 TO 6
    A$ = MKI$(SPEC%(I%+J%))
    FOR X% = 1 TO 2
     IF ASC(MID$(A$,X%,1)) < 40 THEN MID$(A$,X%,1) = " "
    NEXT X%
    X$ = X$+A$
NEXT J%
FLAG%(C%) = 1:FLAG%(C%+1) = 1
IF MID$(X$,4,1) = "*" THEN MID$(X$,4,1) = ".":FLAG%(C%) = -1
IF MID$(X$,11,1) = "*" THEN MID$(X$,4,1) = "."
FLAG%(C%+1) = -1
IF MID$(X$,4,1) = "<" THEN FLAG%(C%) = 1:MID$(X$,4,1) = "."
IF MID$(X$,11,1) = "<" THEN FLAG%(C%+1) = 1
MID$(X$,11,1) = "."
SPL2(C%) = VAL(MID$(X$,1,5))*FLAG%(C%)
SPL2(C%+1) = VAL(MID$(X$,8,5))*FLAG%(C%+1)
C% = C%+2
NEXT I%
REM
locate 23,13,,7,7
print "Reading Sound Intensity Level, Microphone 1 and 2";
CODE$ = "E=L?O=C=M?"
CALL IBWRT(BKP%,CODE$)
CODE$ = "M="
CALL IBWRT(BKP%,CODE$)
CODE$ = "M"
CALL IBWRT(BKP%,CODE$)
RETC$ = SPACE$(1)
Loopa2: CALL IBRD(BKP%,RETC$)
IF RETC$ <> ">" THEN goto loopa2
CODE$ = "E?"
CALL IBWRT(BKP%,CODE$)
CALL IBRDI(BKD%,varptr(SPEC%(0)),CNT%)
C% = 0:FOR I% = 0 TO 144 STEP 7
```

```
X$ = ""
FOR J% = 0 TO 6
    A$ = MKI$(SPEC%(I%+J%))
    FOR X% = 1 TO 2
     IF ASC(MID$(A$,X%,1)) < 40 THEN MID$(A$,X%,1) = " "
    NEXT X%
    X$ = X$+A$
NEXT J%
FLAG%(C%) = 1:FLAG%(C%+1) = 1
IF MID$(X$,4,1) = "*" THEN MID$(X$,4,1) = ".":FLAG%(C%) = -1
IF MID$(X$,11,1) = "*" THEN MID$(X$,4,1) = "."
FLAG%(C%+1) = -1
IF MID$(X$,4,1) = "<" THEN FLAG%(C%) = 1:MID$(X$,4,1) = "."
IF MID$(X$,11,1) = "<" THEN FLAG%(C%+1) = 1
MID$(X$,11,1) = "."
INTE(C%) = ABS(VAL(MID$(X$,1,5))*FLAG%(C%))
INTE(C%+1) = ABS(VAL(MID$(X$,8,5))*FLAG%(C%+1))
C% = C%+2
NEXT I%
REM
print #9, "Freq.(Hz)   SPL1(dB)       SPL2(dB)       SIL1(dB)"
FOR I%=20 TO 36
PRINT #9, USING"  ####         ###.##           ###.##
###.##";FREQ(I%);PRC(I%);SPL2(I%);INTE(I%)
NEXT I%
PRINT #9,
for I% = 1 to 42
     if Inte(I%) < lowerlevel then Inte(I%) = lowerlevel
     RIX(I%) = ABS(Inte(I%)) - Prc(I%)
next I%
REM
REM *****Start RIY calculations
cls
color 11,0
Print"REACTIVITY CALIBRATION FOR MICROPHONE PAIR 2"
Print"Step 1) Using a straight 12 mm spacer,  assemble"
Print
Print"channels 3 & 4 microphones within 3D microphone holder"
Print
Print"Step 2) Insert microphone and spacer assembly within"
Print
Print"reactivity calibrator and switch calibration source ON"
Print:Print:Print:Print
Print "Press a key when you are ready to continue..."
Print:Print
Print"THE NEXT PORTION OF THE CALIBRATION IS AUTOMATED;"
Print
Print"AWAIT FURTHER PROMPTS "
jloopa: ANA$ = INKEY$: IF ana$ = "" then goto jloopa
COMM$ = "BS"
CALL IBWRT(M%,COMM$)
LOCATE 23,13,,7,7
```

```
color 10,0
PRINT "Setting optimal lower level, Channel A, microphone 3";
GOSUB SETLEVEL
Rem
locate 23,13,,7,7
print "Reading Sound Pressure Level, Channel A, Microphone 3";
CODE$ = "E=L?C>O=K>M?M="
CALL IBWRT(BKP%,CODE$)
CODE$ = "M"
CALL IBWRT(BKP%,CODE$)
RETC$ = SPACE$(1)
SomeaCLoop: CALL IBRD(BKP%,RETC$)
IF RETC$ <> ">" THEN goto SomeaCloop
CODE$ = "E?"
CALL IBWRT(BKP%,CODE$)
CALL IBRDI(BKD%,varptr(SPEC%(0)),CNT%)
C% = 0:FOR I% = 0 TO 144 STEP 7
X$ = ""
FOR J% = 0 TO 6
    A$ = MKI$(SPEC%(I%+J%))
    FOR X% = 1 TO 2
     IF ASC(MID$(A$,X%,1)) < 40 THEN MID$(A$,X%,1) = " "
    NEXT X%
    X$ = X$+A$
NEXT J%
FLAG%(C%) = 1:FLAG%(C%+1) = 1
IF MID$(X$,4,1) = "*" THEN MID$(X$,4,1) = ".":FLAG%(C%) = -1
IF MID$(X$,11,1) = "*" THEN MID$(X$,4,1) = "."
FLAG%(C%+1) = -1
IF MID$(X$,4,1) = "<" THEN FLAG%(C%) = 1:MID$(X$,4,1) = "."
IF MID$(X$,11,1) = "<" THEN FLAG%(C%+1) = 1
MID$(X$,11,1) = "."
PRC(C%) = VAL(MID$(X$,1,5))*FLAG%(C%)
PRC(C%+1) = VAL(MID$(X$,8,5))*FLAG%(C%+1)
C% = C%+2
NEXT I%
locate 23,13,,7,7
print "Reading Sound Pressure Level, Channel B, Microphone 4";
CODE$ = "E=L?C?O=K>M?M="
CALL IBWRT(BKP%,CODE$)
CODE$ = "M"
CALL IBWRT(BKP%,CODE$)
RETC$ = SPACE$(1)
SomeaDLoop: CALL IBRD(BKP%,RETC$)
IF RETC$ <> ">" THEN goto SomeaDloop
CODE$ = "E?"
CALL IBWRT(BKP%,CODE$)
CALL IBRDI(BKD%,varptr(SPEC%(0)),CNT%)
C% = 0:FOR I% = 0 TO 144 STEP 7
X$ = ""
FOR J% = 0 TO 6
    A$ = MKI$(SPEC%(I%+J%))
```

```
    FOR X% = 1 TO 2
     IF ASC(MID$(A$,X%,1)) < 40 THEN MID$(A$,X%,1) = " "
    NEXT X%
    X$ = X$+A$
NEXT J%
FLAG%(C%) = 1:FLAG%(C%+1) = 1
IF MID$(X$,4,1) = "*" THEN MID$(X$,4,1) = ".":FLAG%(C%) = -1
IF MID$(X$,11,1) = "*" THEN MID$(X$,4,1) = "."
FLAG%(C%+1) = -1
IF MID$(X$,4,1) = "<" THEN FLAG%(C%) = 1:MID$(X$,4,1) = "."
IF MID$(X$,11,1) = "<" THEN FLAG%(C%+1) = 1
MID$(X$,11,1) = "."
SPL2(C%) = VAL(MID$(X$,1,5))*FLAG%(C%)
SPL2(C%+1) = VAL(MID$(X$,8,5))*FLAG%(C%+1)
C% = C%+2
NEXT I%
REM
locate 23,13,,7,7
print "Reading Sound Intensity Level, Microphone 3 and 4";
CODE$ = "E=L?O=C=M?"
CALL IBWRT(BKP%,CODE$)
CODE$ = "M="
CALL IBWRT(BKP%,CODE$)
CODE$ = "M"
CALL IBWRT(BKP%,CODE$)
RETC$ = SPACE$(1)
Loopaa2: CALL IBRD(BKP%,RETC$)
IF RETC$ <> ">" THEN goto loopaa2
CODE$ = "E?"
CALL IBWRT(BKP%,CODE$)
CALL IBRDI(BKD%,varptr(SPEC%(0)),CNT%)
C% = 0:FOR I% = 0 TO 144 STEP 7
X$ = ""
FOR J% = 0 TO 6
    A$ = MKI$(SPEC%(I%+J%))
    FOR X% = 1 TO 2
     IF ASC(MID$(A$,X%,1)) < 40 THEN MID$(A$,X%,1) = " "
    NEXT X%
    X$ = X$+A$
NEXT J%
FLAG%(C%) = 1:FLAG%(C%+1) = 1
IF MID$(X$,4,1) = "*" THEN MID$(X$,4,1) = ".":FLAG%(C%) = -1
IF MID$(X$,11,1) = "*" THEN MID$(X$,4,1) = "."
FLAG%(C%+1) = -1
IF MID$(X$,4,1) = "<" THEN FLAG%(C%) = 1:MID$(X$,4,1) = "."
IF MID$(X$,11,1) = "<" THEN FLAG%(C%+1) = 1
MID$(X$,11,1) = "."
INTE(C%) = ABS(VAL(MID$(X$,1,5))*FLAG%(C%))
INTE(C%+1) = ABS(VAL(MID$(X$,8,5))*FLAG%(C%+1))
C% = C%+2
NEXT I%
print #9, "Freq.(Hz)   SPL3(dB)      SPL4(dB)      SIL2(dB)"
```

```
FOR I%=20 TO 36
PRINT #9, USING"  ####         ###.##          ###.##
###.##";FREQ(I%);PRC(I%);SPL2(I%);INTE(I%)
NEXT I%
PRINT #9,
REM
for I% = 1 to 42
     if Inte(I%) < lowerlevel then Inte(I%) = lowerlevel
     RIY(I%) = ABS(Inte(I%)) - Prc(I%)
next I%
REM *****RIY calculations finished!!!
REM *****Start RIZ calculations
cls
color 11,0
Print "REACTIVITY CALIBRATION FOR MICROPHONE PAIR 3"
Print
Print"Step 1) Using a straight 12 mm spacer,  assemble"
Print
Print"channels 5 & 6 microphones within main probe mount"
Print
Print"Step 2) Insert microphone and spacer assembly within"
Print
Print"reactivity calibrator and switch calibration source ON"
Print:Print:Print:Print
Print "Press a key when you are ready to continue..."
Print
Print"THE NEXT PORTION OF THE CALIBRATION IS AUTOMATED;"
Print
Print"AWAIT FURTHER PROMPTS"
kloopa: ANA$ = INKEY$: IF ana$ = "" then goto kloopa
COMM$ = "DU"
CALL IBWRT(M%,COMM$)
LOCATE 23,13,,7,7
color 10,0
PRINT "Setting optimal lower level, Channel A, microphone 5";
GOSUB SETLEVEL
Rem
locate 23,13,,7,7
print "Reading Sound Pressure Level, Channel A, Microphone 5";
CODE$ = "E=L?C>O=K>M?M="
CALL IBWRT(BKP%,CODE$)
CODE$ = "M"
CALL IBWRT(BKP%,CODE$)
RETC$ = SPACE$(1)
SomeabaLoop: CALL IBRD(BKP%,RETC$)
IF RETC$ <> ">" THEN goto Someabaloop
CODE$ = "E?"
CALL IBWRT(BKP%,CODE$)
CALL IBRDI(BKD%,varptr(SPEC%(0)),CNT%)
C% = 0:FOR I% = 0 TO 144 STEP 7
X$ = ""
FOR J% = 0 TO 6
```

```
    A$ = MKI$(SPEC%(I%+J%))
    FOR X% = 1 TO 2
     IF ASC(MID$(A$,X%,1)) < 40 THEN MID$(A$,X%,1) = " "
    NEXT X%
    X$ = X$+A$
NEXT J%
FLAG%(C%) = 1:FLAG%(C%+1) = 1
IF MID$(X$,4,1) = "*" THEN MID$(X$,4,1) = ".":FLAG%(C%) = -1
IF MID$(X$,11,1) = "*" THEN MID$(X$,4,1) = "."
FLAG%(C%+1) = -1
IF MID$(X$,4,1) = "<" THEN FLAG%(C%) = 1:MID$(X$,4,1) = "."
IF MID$(X$,11,1) = "<" THEN FLAG%(C%+1) = 1
MID$(X$,11,1) = "."
PRC(C%) = VAL(MID$(X$,1,5))*FLAG%(C%)
PRC(C%+1) = VAL(MID$(X$,8,5))*FLAG%(C%+1)
C% = C%+2
NEXT I%
locate 23,13,,7,7
print "Reading Sound Pressure Level, Channel B, Microphone 6";
CODE$ = "E=L?C?O=K>M?M="
CALL IBWRT(BKP%,CODE$)
CODE$ = "M"
CALL IBWRT(BKP%,CODE$)
RETC$ = SPACE$(1)
SomeabeLoop: CALL IBRD(BKP%,RETC$)
IF RETC$ <> ">" THEN goto Someabeloop
CODE$ = "E?"
CALL IBWRT(BKP%,CODE$)
CALL IBRDI(BKD%,varptr(SPEC%(0)),CNT%)
C% = 0:FOR I% = 0 TO 144 STEP 7
X$ = ""
FOR J% = 0 TO 6
    A$ = MKI$(SPEC%(I%+J%))
    FOR X% = 1 TO 2
     IF ASC(MID$(A$,X%,1)) < 40 THEN MID$(A$,X%,1) = " "
    NEXT X%
    X$ = X$+A$
NEXT J%
FLAG%(C%) = 1:FLAG%(C%+1) = 1
IF MID$(X$,4,1) = "*" THEN MID$(X$,4,1) = ".":FLAG%(C%) = -1
IF MID$(X$,11,1) = "*" THEN MID$(X$,4,1) = "."
FLAG%(C%+1) = -1
IF MID$(X$,4,1) = "<" THEN FLAG%(C%) = 1:MID$(X$,4,1) = "."
IF MID$(X$,11,1) = "<" THEN FLAG%(C%+1) = 1
MID$(X$,11,1) = "."
SPL2(C%) = VAL(MID$(X$,1,5))*FLAG%(C%)
SPL2(C%+1) = VAL(MID$(X$,8,5))*FLAG%(C%+1)
C% = C%+2
NEXT I%
REM
locate 23,13,,7,7
print "Reading Sound Intensity Level, Microphone 5 and 6  ";
```

```
CODE$ = "E=L?O=C=M?"
CALL IBWRT(BKP%,CODE$)
CODE$ = "M="
CALL IBWRT(BKP%,CODE$)
CODE$ = "M"
CALL IBWRT(BKP%,CODE$)
RETC$ = SPACE$(1)
Loopaba2: CALL IBRD(BKP%,RETC$)
IF RETC$ <> ">" THEN goto loopaba2
CODE$ = "E?"
CALL IBWRT(BKP%,CODE$)
CALL IBRDI(BKD%,varptr(SPEC%(0)),CNT%)
C% = 0:FOR I% = 0 TO 144 STEP 7
X$ = ""
FOR J% = 0 TO 6
    A$ = MKI$(SPEC%(I%+J%))
    FOR X% = 1 TO 2
     IF ASC(MID$(A$,X%,1)) < 40 THEN MID$(A$,X%,1) = " "
    NEXT X%
    X$ = X$+A$
NEXT J%
FLAG%(C%) = 1:FLAG%(C%+1) = 1
IF MID$(X$,4,1) = "*" THEN MID$(X$,4,1) = ".":FLAG%(C%) = -1
IF MID$(X$,11,1) = "*" THEN MID$(X$,4,1) = "."
FLAG%(C%+1) = -1
IF MID$(X$,4,1) = "<" THEN FLAG%(C%) = 1:MID$(X$,4,1) = "."
IF MID$(X$,11,1) = "<" THEN FLAG%(C%+1) = 1
MID$(X$,11,1) = "."
INTE(C%) = ABS(VAL(MID$(X$,1,5))*FLAG%(C%))
INTE(C%+1) = ABS(VAL(MID$(X$,8,5))*FLAG%(C%+1))
C% = C%+2
NEXT I%
print #9, "Freq.(Hz)   SPL5(dB)       SPL6(dB)       SIL3(dB)"
FOR I%=20 TO 36
PRINT #9, USING"   ####        ###.##          ###.##
###.##";FREQ(I%);PRC(I%);SPL2(I%);INTE(I%)
NEXT I%
PRINT #9,
PRINT #9,
COLOR 11,0
REM *****finished getting intensity...
for I% = 1 to 42
     if Inte(I%) < lowerlevel then Inte(I%) = lowerlevel
     RIZ(I%) = Abs(Inte(I%)) - Prc(I%)
next I%
REM
cls
Print "One-Third Octave Band"
Print
Print  "Frequency  RIX        RIY      RIZ"
print #9,
Print #9,  "Frequency  RIX        RIY      RIZ"
```

```
For I% = 20 to 36
Print  using  "  #####           ###.##          ###.##
###.##";Freq(I%);ABS(RIX(I%));ABS(RIY(I%));ABS(RIZ(I%))
rem
Print  #9,using  "  #####          ###.##          ###.##
###.##";Freq(I%);ABS(RIX(I%));ABS(RIY(I%));ABS(RIZ(I%))
Next I%
Someloo: A$ = inkey$: If A$ = "" then goto Someloo
Cls
Print
Input "Are you satisfied with the results ? (Y/N) ";SAT$
IF SAT$ = "Y" or SAT$ = "y" then goto continu
Print"Do you wish to change values or quit ? (C/Q) ";SAT$
IF SAT$ = "Q" or SAT$ = "q" then END
for I% = 1 to 42
     cls
     Print"Please input RIX(";I%;") --> ";:Input RIX(I%)
     Print"Please input RIY(";I%;") --> ";:Input RIY(I%)
     Print"Please input RIZ(";I%;") --> ";: Input RIZ(I%)
next I%
continu: cls
datf$="ri.dat"
Input"What's name of data file (Ri.dat default) -> ";datf1$
If datf1$ ="" then datf1$ = datf$
OPEN "O",#1,datf1$
For I% = 1 to 42
Print    #1,USING    "###.##                  ###.##
###.##";RIX(I%);RIY(I%);RIZ(I%)
Next I%
Close #1
End


SETLEVEL:
CNT%=113
CODE$ = "E=L?O;C>K?N8M?"
CALL IBWRT(BKP%,CODE$)
for I=1 TO 500:NEXT I
CODE$= "M="
CALL IBWRT(BKP%,CODE$)
CODE$ = "M"
CALL IBWRT(BKP%,CODE$)
RETC$ = SPACE$(1)
Loopa: CALL IBRD(BKP%,RETC$)
IF RETC$ <> ">" THEN goto loopa
CODE$ = "E?"
CALL IBWRT(BKP%,CODE$)
CALL IBRDI(BKD%,varptr(SPEC%(0)),CNT%)
C% = 0:FOR I% = 0 TO 144 STEP 7
X$ = ""
FOR J% = 0 TO 6
```

```
    A$ = MKI$(SPEC%(I%+J%))
    FOR X% = 1 TO 2
     IF ASC(MID$(A$,X%,1)) < 40 THEN MID$(A$,X%,1) = " "
    NEXT X%
    X$ = X$+A$
NEXT J%
FLAG%(C%) = 1:FLAG%(C%+1) = 1
IF MID$(X$,4,1) = "*" THEN MID$(X$,4,1) = ".":FLAG%(C%) = -1
IF MID$(X$,11,1) = "*" THEN MID$(X$,4,1) = ".":FLAG%(C%+1) =
-1
IF MID$(X$,4,1) = "<" THEN FLAG%(C%) = 1:MID$(X$,4,1) = "."
IF MID$(X$,11,1) = "<" THEN FLAG%(C%+1) = 1:MID$(X$,11,1) =
"."
SPL1(C%) = VAL(MID$(X$,1,5))*FLAG%(C%)
SPL1(C%+1) = VAL(MID$(X$,8,5))*FLAG%(C%+1)
C% = C%+2
NEXT I%
CNT%=301
if SPL1(15)>70 then goto in1
SPL1(15)=60
in1:SET=int((SPL1(15)+5)/10)*10-80
lowerlevel=SET
If Lowerlevel < 0 then Lowerlevel = 0
IF lowerlevel => 100 then CODE$ = "N5"
IF lowerlevel = 90 THEN CODE$ = "N6"
IF lowerlevel = 80 THEN CODE$ = "N7"
IF lowerlevel = 70 THEN CODE$ = "N8"
IF lowerlevel = 60 THEN CODE$ = "N9"
IF lowerlevel = 50 THEN CODE$ = "N:"
IF lowerlevel = 40 THEN CODE$ = "N;"
IF lowerlevel = 30 THEN CODE$ = "N<"
IF lowerlevel = 20 THEN CODE$ = "N="
IF lowerlevel = 10 THEN CODE$ = "N>"
IF lowerlevel = 0 THEN CODE$ = "N?"
CALL IBWRT(BKP%,CODE$)
FOR IA = 1 to 2000:Next IA
RETURN
```