ACOUSTIC DESIGN CHARTS

ACOUSTIC DESIGN CHARTS

By

FRANK MASSA, B.S., M.Sc.
In Charge of the Acoustic Division
The Brush Development Company, Cleveland, Ohio
Past Swope Fellow at the Massachusetts Institute of Technology

THE BLAKISTON COMPANY
Philadelphia

PRINTED IN U. S. A.
THE MAPLE PRESS COMPANY, YORK, PA.

PREFACE

"Acoustic Design Charts" is a compilation of acoustical engineering data prepared for the express purpose of providing a comprehensive source of quantitative design information. It is intended to serve as a quick, handy reference for the convenient use of any one interested in the design or construction of electro-acoustic apparatus. In the preparation of these charts, the author has chosen such scales that constant precision may be obtained in reading the large range of values that are plotted. By providing families of curves on many of the charts, it is possible to see immediately the quantitative effect of varying the parameters of a system without the necessity of spending long hours in mathematical computations. Many sample problems have been worked out throughout the text in order to illustrate clearly the use of each chart.

The author gratefully appreciates the kind interest shown in this work by Mr. W. R. Burwell, Chairman of the Board, and Mr. A. L. Williams, President of The Brush Development Company. He is also grateful to his brother, E. A. Massa, for his valuable assistance in checking many of the laborious computations that were necessary in the preparation of these charts.

The author wishes to make particular mention of the untiring assistance and encouragement given by his wife in the preparation of the manuscript.

CLEVELAND, OHIO,
March, 1942.

FRANK MASSA.

CONTENTS

SECTION 1

FUNDAMENTAL RELATIONS IN PLANE AND SPHERICAL SOUND WAVES

SECTION 2

ATTENUATION OF SOUND AND VIBRATIONS

SECTION 3

MECHANICAL VIBRATING SYSTEMS

SECTION 4

ACOUSTICAL ELEMENTS AND VIBRATING SYSTEMS

SECTION 5

RADIATION OF SOUND FROM PISTONS (DIRECT RADIATOR LOUD SPEAKERS)

SECTION 6
DIRECTIONAL RADIATION CHARACTERISTICS

SECTION 7
REVERBERATION AND SOUND REPRODUCTION

SECTION 8

EXPONENTIAL HORN LOUD SPEAKERS

SECTION 9

ELECTRO-MAGNETIC DESIGN DATA

SECTION 10

MISCELLANEOUS DATA

SECTION 1

Fundamental Relations in Plane and Spherical Sound Waves

CHART 1. Frequency vs. wavelength in air.

CHART 2. Frequency vs. wavelength in water.

CHART 3. Frequency vs. $2\pi/\lambda$ in air.

CHART 4. Frequency vs. $(2\pi/\lambda)^2$ in air.

CHART 5. Sound pressure vs. particle displacement in plane waves in air.

CHART 6. Sound pressure vs. particle velocity in plane waves in air and water.

CHART 7. Increase in the ratio of particle velocity to sound pressure in a spherical wave vs. distance from the source of sound.

CHART 8. Phase shift between particle velocity and sound pressure in a spherical wave vs. distance from the source of sound.

CHART 9. Sound pressure vs. acoustic power per unit area of wave front in a plane or spherical wave in air.

CHART 10. Reflected energy resulting from the passage of a plane wave from one medium to another vs. ratio of the radiation resistance of each medium.

Chart 1 gives the relation between the wavelength of sound in air at 20 deg. C. and 760 mm. pressure vs. frequency. Chart 2 gives the relation between the wavelength in fresh water at 20 deg. C. and the frequency. The wavelength in feet may be read from the left hand ordinate scales and the wavelength in inches or centimeters may be read on the right hand ordinate scales.

Sample Problem

Find the frequencies at which the wavelength of sound in air and water is 20 inches.

Solution

On chart 1, at the intersection of 20 inches on the right hand ordinate scale with the curve marked "IN." read the abscissa = 700 cycles, which is the frequency in air. To find the frequency in water, find the intersection of 20 inches on the right hand ordinate scale on chart 2 with the curve marked "IN." and read the abscissa = 2,800 cycles.

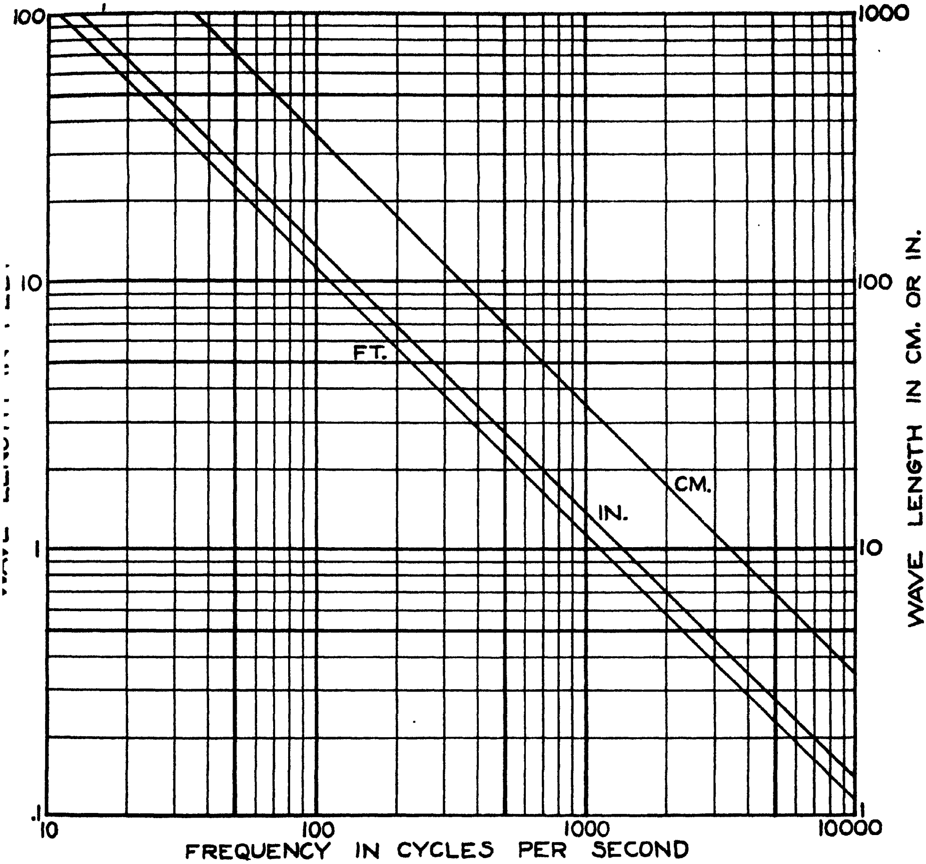


CHART NO. 1

Wave length of sound in air as a function of frequency.

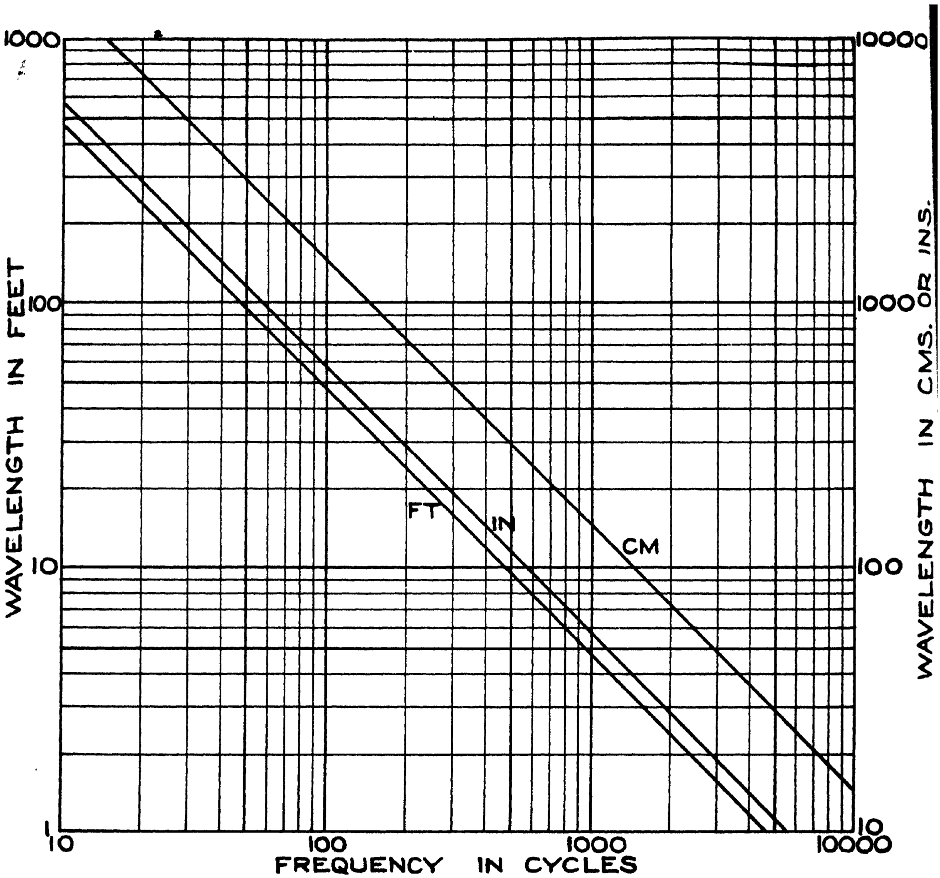


CHART NO. 2

Wavelength of sound in fresh water at 20° C. (For ocean water, multiply ordinates by 1.02.)

Chart 3 shows the relation between frequency and the quantity k, where $k = 2\pi/\lambda$. Chart 4 shows the relation between the frequency and the quantity k^2. Three curves are shown on each chart, one for wavelength in feet, one in inches and another in centimeters.

The use of these charts is obvious without need for sample problems. The quantities k and k^2 appear frequently in the solution of acoustical problems.

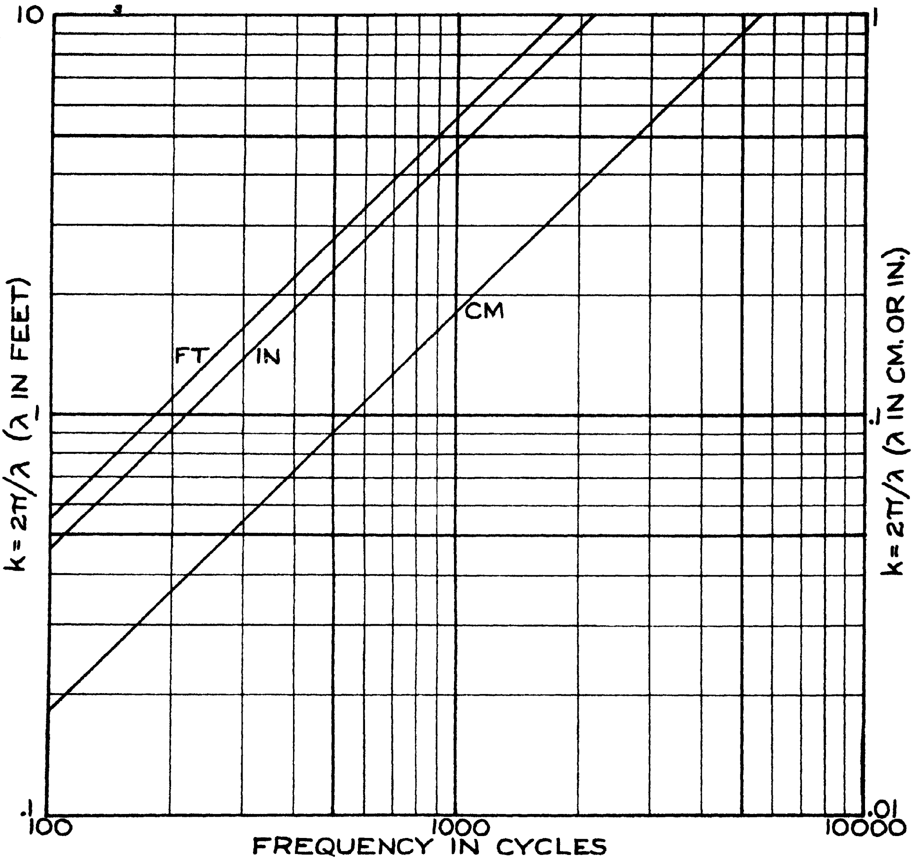


CHART NO. 3

Relation between frequency and the quantity k in air at 20° C. and 760 mm. pressure. $k = 2\pi/\lambda$, where λ = wavelength of sound.

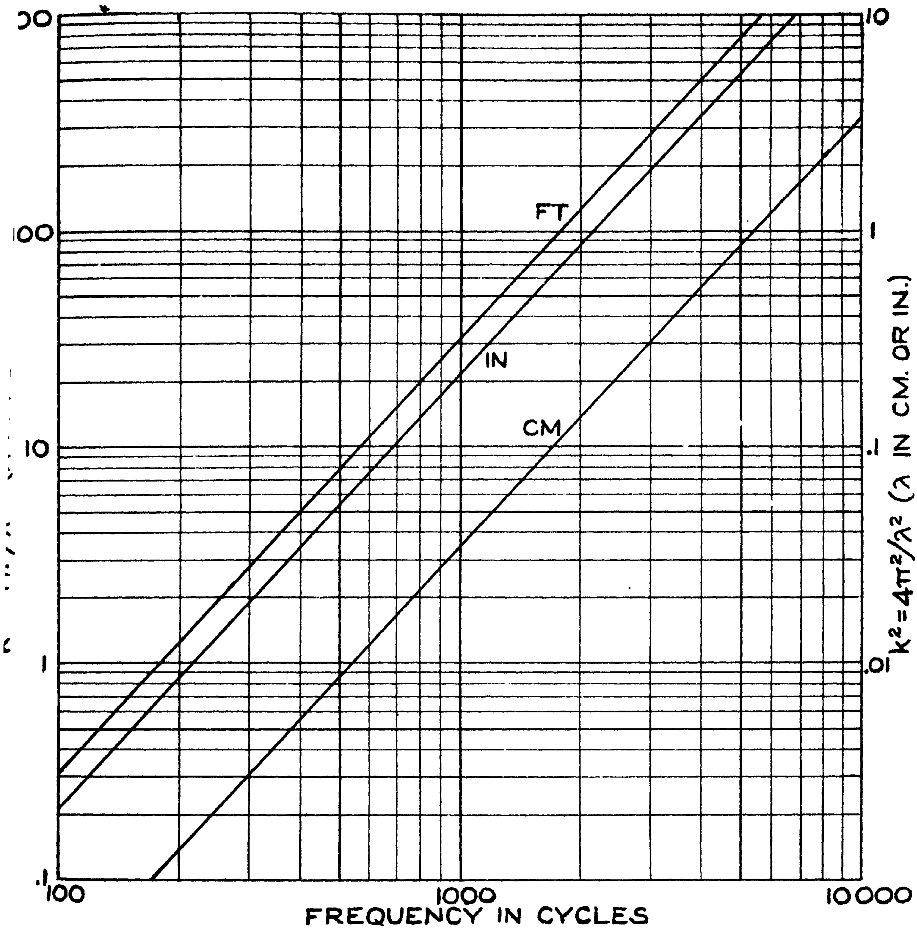


CHART NO. 4

Relation between frequency and the quantity k^2 in air at 20° C. and 760 mm. pressure. $k = 2\pi/\lambda$, where λ = wavelength of sound.

Chart No. 5 shows the relation between the peak particle displacement and the r.m.s. sound pressure in a plane progressive wave in air for various frequencies.

Sample Problem

Find the particle displacement which accompanies a sound pressure of 10 dynes/cm.^{2} in a plane wave in air at a frequency of 1,000 cycles.

Solution

At the intersection of 10 dynes/cm.^{2} with 1,000 cycle frequency find the displacement equal to 5.4×10^{-5} cm.

NOTE.—This is peak displacement while the sound pressure is given in r.m.s. value.

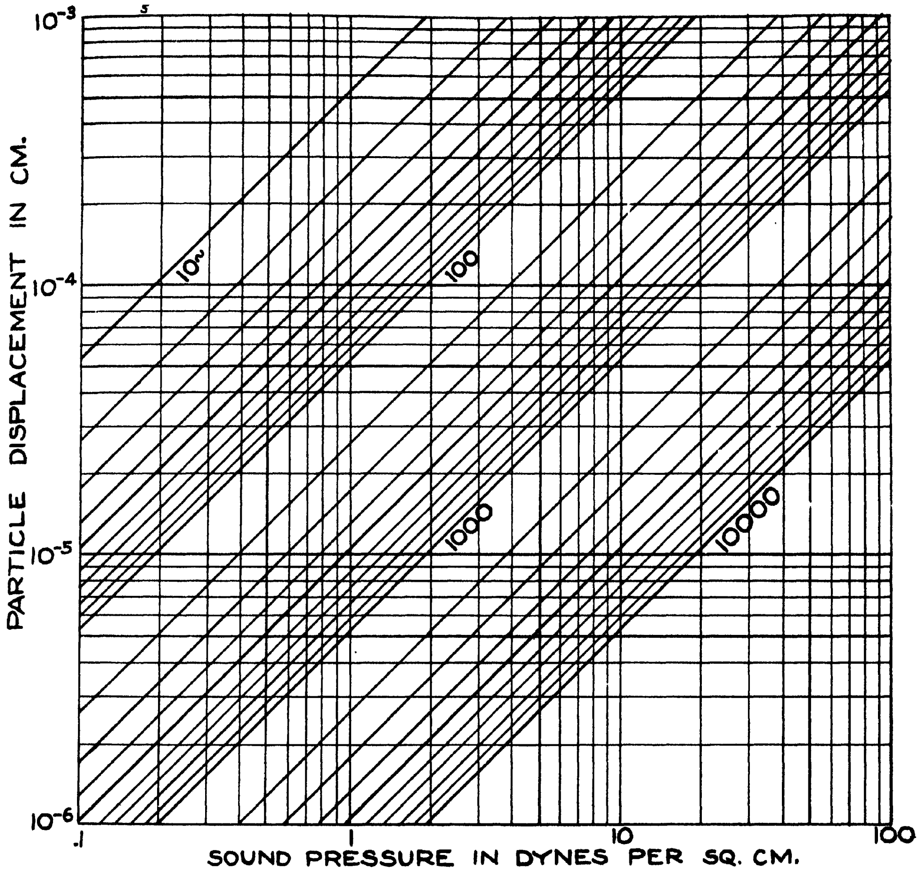


CHART NO. 5

Relation between particle displacement and sound pressure in a plane sound wave in dry air at 20° C. The particle displacement is indicated in peak values from the normal position of rest while the sound pressure is indicated in r.m.s. values as usual.

Chart 6 shows the relation between sound pressure and particle velocity in a plane wave in air and water at 20° C. and 760 mm. pressure.

Sample Problem

Find the particle velocity associated with a sound pressure of 1 dyne/cm.^{2} in a plane wave in air and water.

Solution

At the intersection of the abscissa = 1 dyne/cm.^{2} with the curve marked "AIR," read the left hand ordinate equal to a particle velocity of .024 cm./sec. At the intersection with the curve marked "WATER" read the particle velocity equal to 6.7×10^{-6} cm./sec.

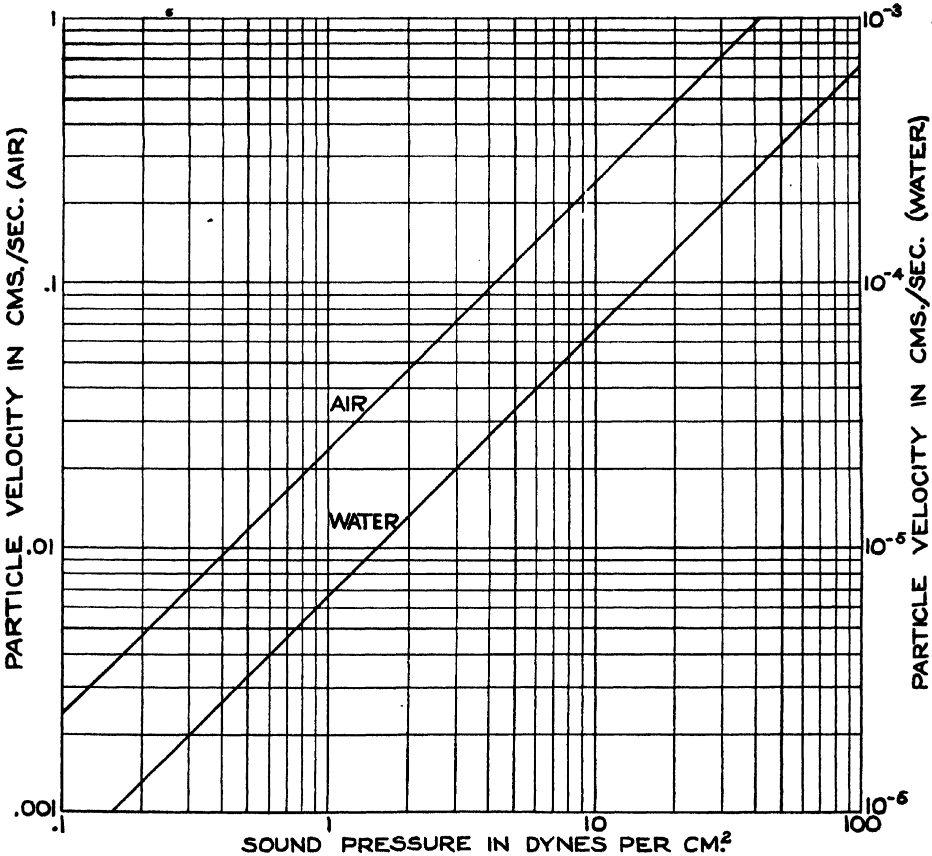


CHART NO. 6

Relations between sound pressure and particle velocity in a plane sound wave in air and in water at 20° C.

Chart No. 7 shows the increase in magnitude of the ratio of particle velocity to sound pressure as one approaches a point source of sound. This chart is useful in showing the degree of frequency distortion which is produced when talking close to a microphone which measures the particle velocity in a sound wave.

Sample Problem

Assume a velocity microphone is flat when calibrated in a plane wave. Find the degree of exaggerated response which will occur at 100 cycles when talking two inches from the microphone.

Solution

At 100 cycles, the wave length is 135 inches; therefore two inches from source is—

$$2/135 = .0148 \text{ wavelengths}$$

Referring to the chart, it is found that for a distance of .015 wavelengths from the source, the increase in the "velocity response" is about 21 db. above what it would have been in a plane wave.

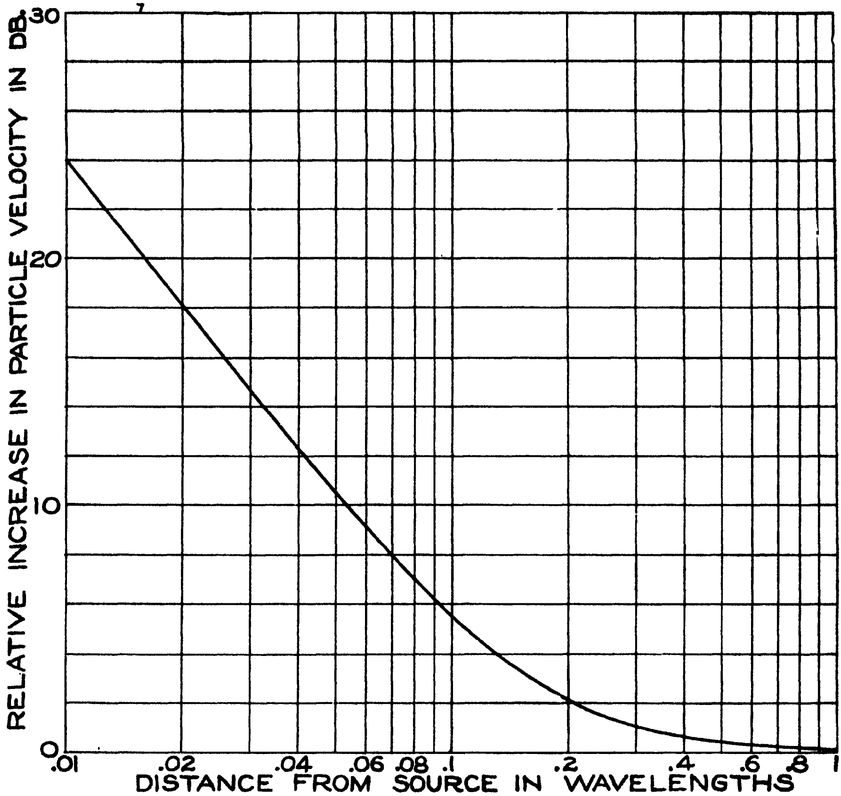


CHART NO. 7

Relative increase in the ratio of the particle velocity to sound pressure in a spherical wave as a function of the distance from the source. The reference ratio of 0 db. is for a plane wave.

Chart No. 8 shows the phase shift between the particle velocity and sound pressure as one approaches a point source of sound.

Sample Problem

For the conditions of the problem illustrating chart No. 7, find the phase angle between the sound pressure and particle velocity at the microphone location.

Solution

From the problem on chart No. 7, the microphone is located .015 wavelengths from the source. Referring to chart No. 8, at the intersection of the abscissa = .015 with the curve, read the phase angle between the particle velocity and sound pressure as 85 degrees.

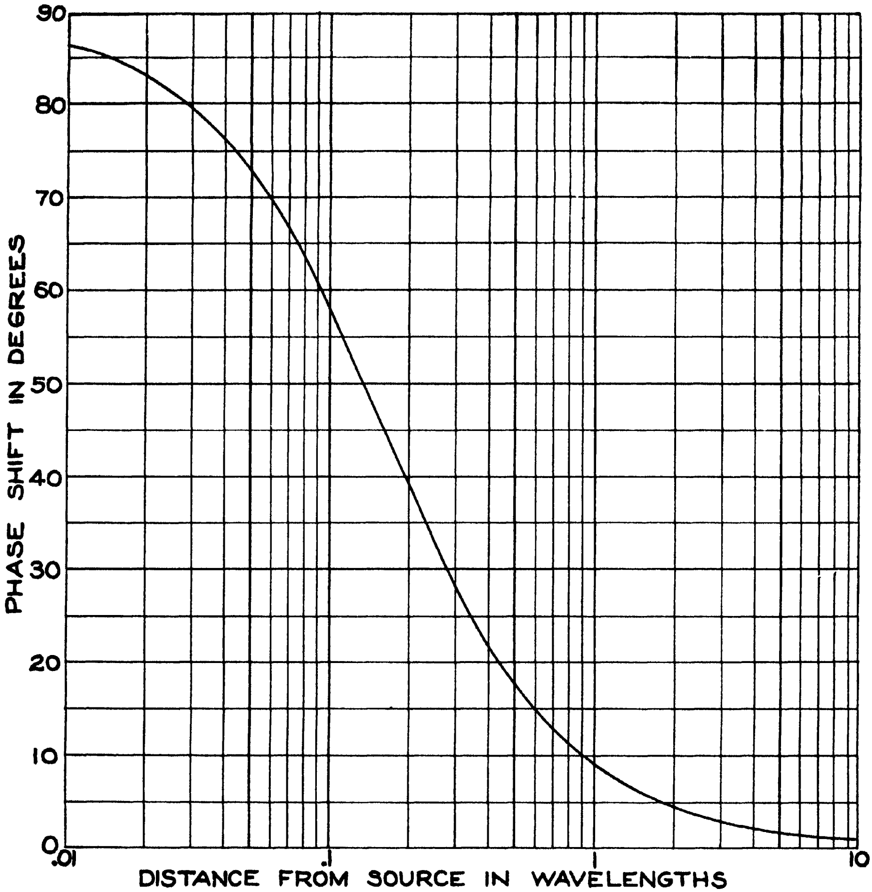


CHART NO. 8

Phase shift between particle velocity and sound pressure in a spherical wave as a function of distance from the source.

Chart No. 9 shows the relation between sound pressure and acoustic power being transmitted in a plane or spherical wave. The chart is useful for computing acoustic power requirements in cases where a particular sound pressure is desired over a certain area.

Sample Problem

Find the acoustic power required to produce a sound pressure of 10 dynes per sq. cm. over an area 300 ft. × 300 ft. assuming a free progressive wave over the area.

Solution

Total area = $300 \times 300 \times 144 = 13 \times 10^6$ sq. in.

For a sound pressure of 10 dynes per sq. cm. (reading from the curve marked "IN") the intensity is read as about 1.55 microwatts per sq. in.

The acoustic power requirement for the problem is,

$$P_a = 13 \times 10^6 \times 1.55 \times 10^{-6} = 20.2 \text{ watts}$$

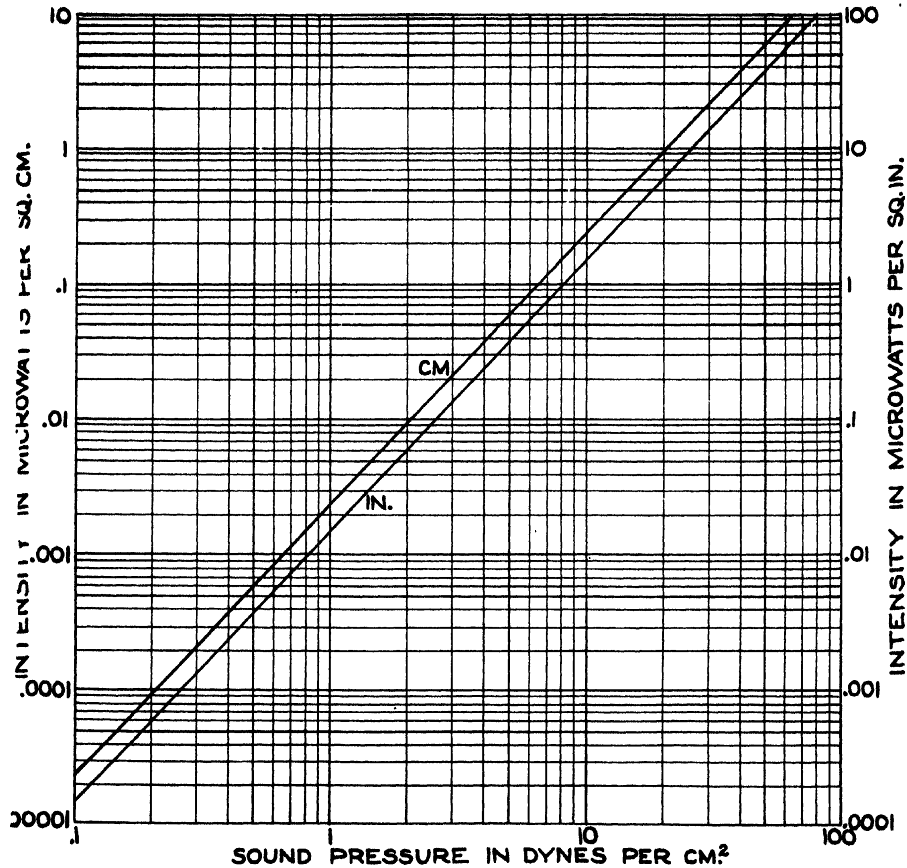


CHART NO. 9

Acoustic power transmitted through unit area of wave front in a free progressive sound wave in air at 20° C. as a function of the sound pressure over the area.

Chart No. 10 shows the reflected energy which results when a plane wave passes from one medium to another.

Sample Problem

Find the percentage of the energy in a plane wave that is transmitted from one medium to another of 10 times the specific acoustic resistance.

Solution

For $R_1/R_2 = 10$, find the reflected energy = 67%. Therefore, the transmitted energy is

$$E_t = 100 - 67 = 33\%$$

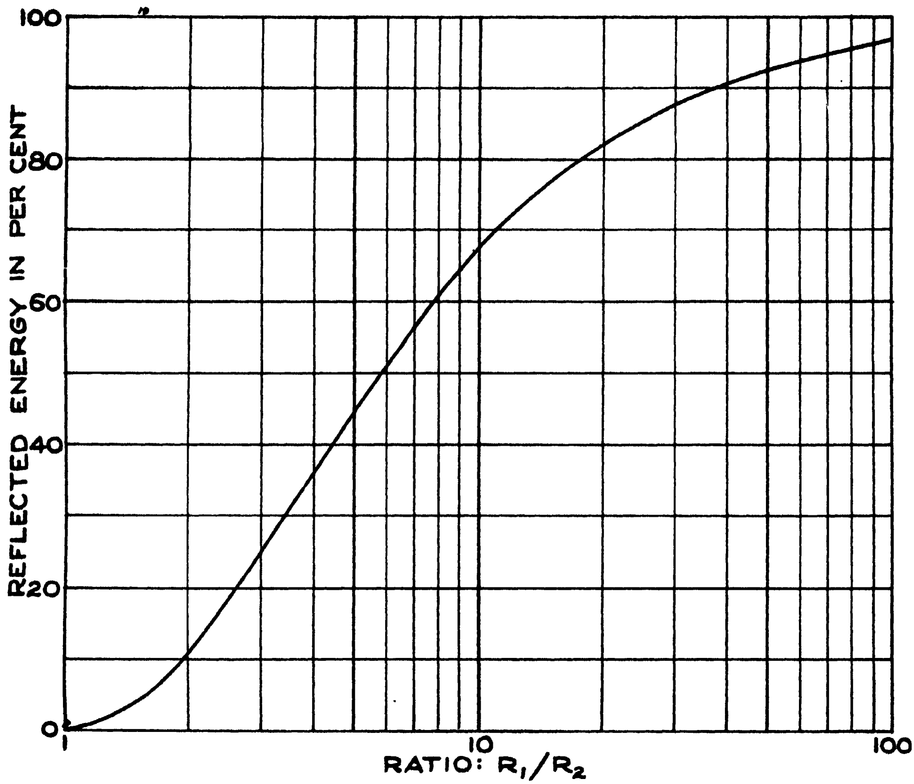


CHART NO. 10

Energy reflected when a plane sound wave is passing from one medium to another. R_1 = radiation resistance of one medium and R_2 = radiation resistance of other medium. (Radiation resistance is numerically equal to the product of the density of the medium in gms./cc. multiplied by the velocity of sound in the medium in cms./sec.)

SECTION 2

Attenuation of Sound and Vibrations

Chart 11 shows the attenuation of plane waves in air as a function of frequency.

Sample Problem

Find the loss due to attenuation in air of a 10,000 cycle signal which travels a distance of 1 mile.

Solution

From chart 11 find the loss at 10,000 cycles as 2.7 db./1,000 ft. The total loss in 1 mile equals:

$$\text{Loss} = \frac{2.7}{1,000} \times 5,280 = 14.3 \text{ db.}$$

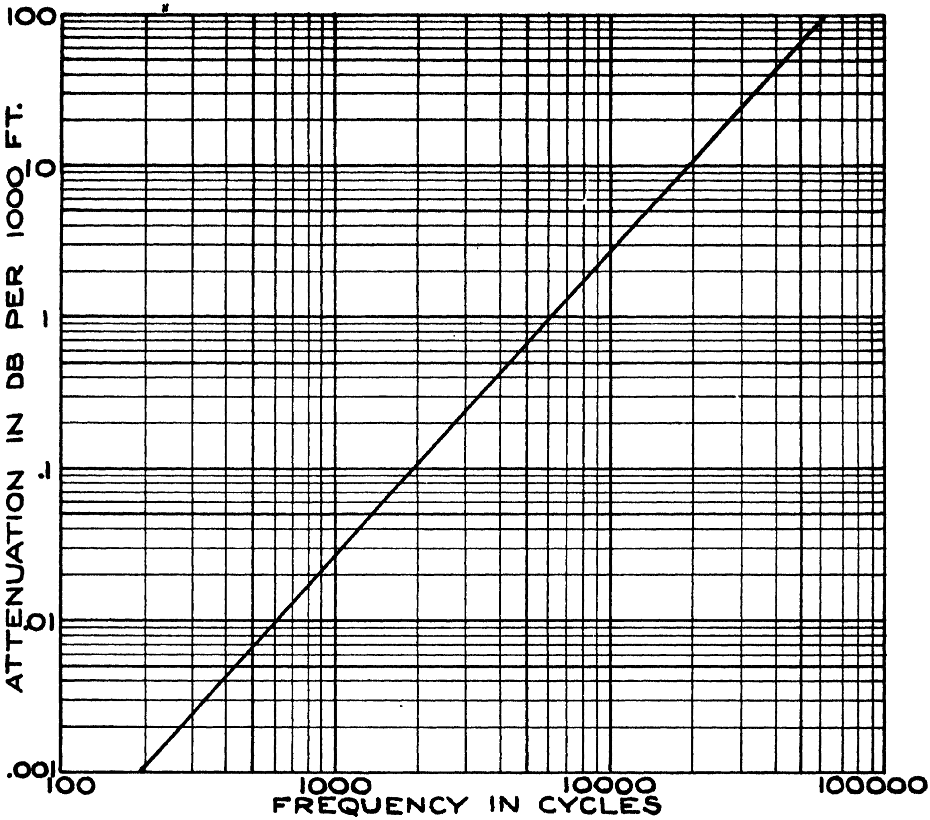


CHART NO. 11

Attenuation of plane sound waves in dry air at 20° C. and 760 mm. pressure.

Chart No. 12 shows the attenuation of sound in long, smooth, rigid conduits filled with dry air at 20° C. and 760 mm. pressure. The inside diameters of the conduits in inches are marked on the family of curves.

Sample Problem

Find the attenuation at 1,000 cycles in 10 ft. of 1 inch pipe.

Solution

From the chart, find the intersection of the abscissa = 1,000 cycles, with the curve marked 1 in. and read the attenuation as .2 db. per ft. The attenuation in 10 ft. of pipe is 10 × .2 = 2 db.

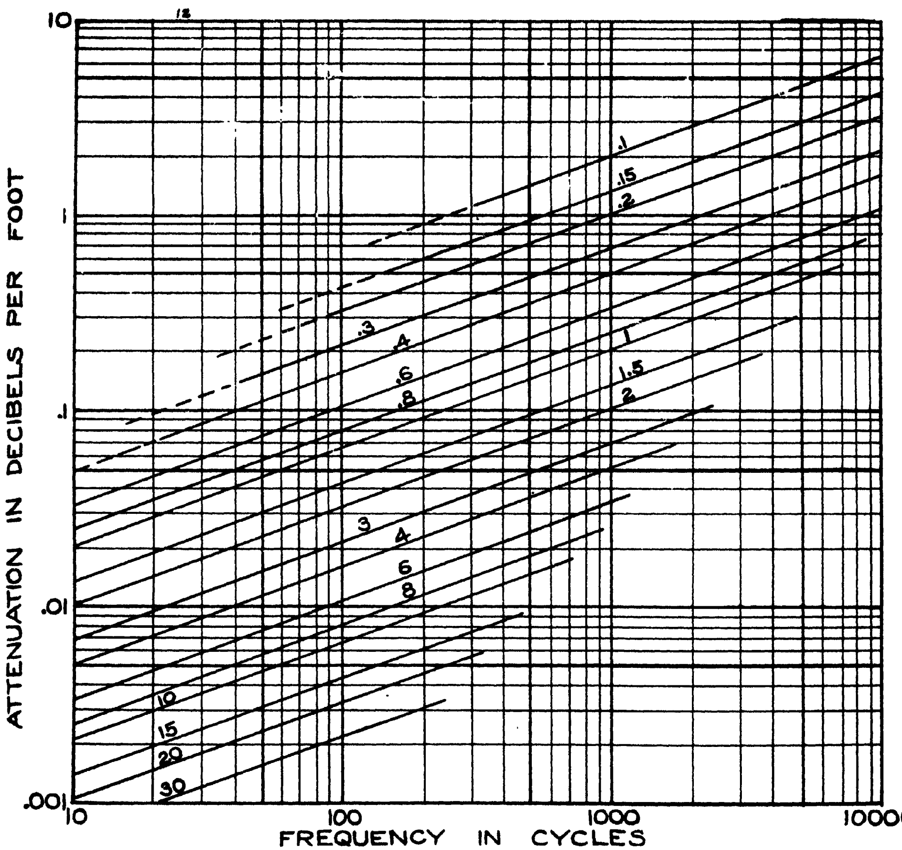


CHART NO. 12

Attenuation of sound in smooth, long, rigid conduits filled with dry air at 20° C. and 760 mm. pressure. The diameters of the conduits in inches are marked on the curves. For the dotted portion of the upper curves, the losses become higher than shown, due to the conduits' becoming effectively narrow tubes (see chart 13).

Chart No. 13 shows the attenuation of sound in long, smooth, rigid narrow tubes filled with dry air at 20° C. and 760 mm. pressure. The inside diameters of the tubes in inches are marked on the family of curves.

Sample Problem

Find the attenuation at 1,000 cycles in 10 ft. of tubing having a .01″ bore.

Solution

From the chart, find the intersection of the abscissa = 1,000 cycles with the curve marked .01 inch and read the attenuation as 45 db. per ft. The attenuation in 10 ft. of tubing = 10 × 45 = 450 db.

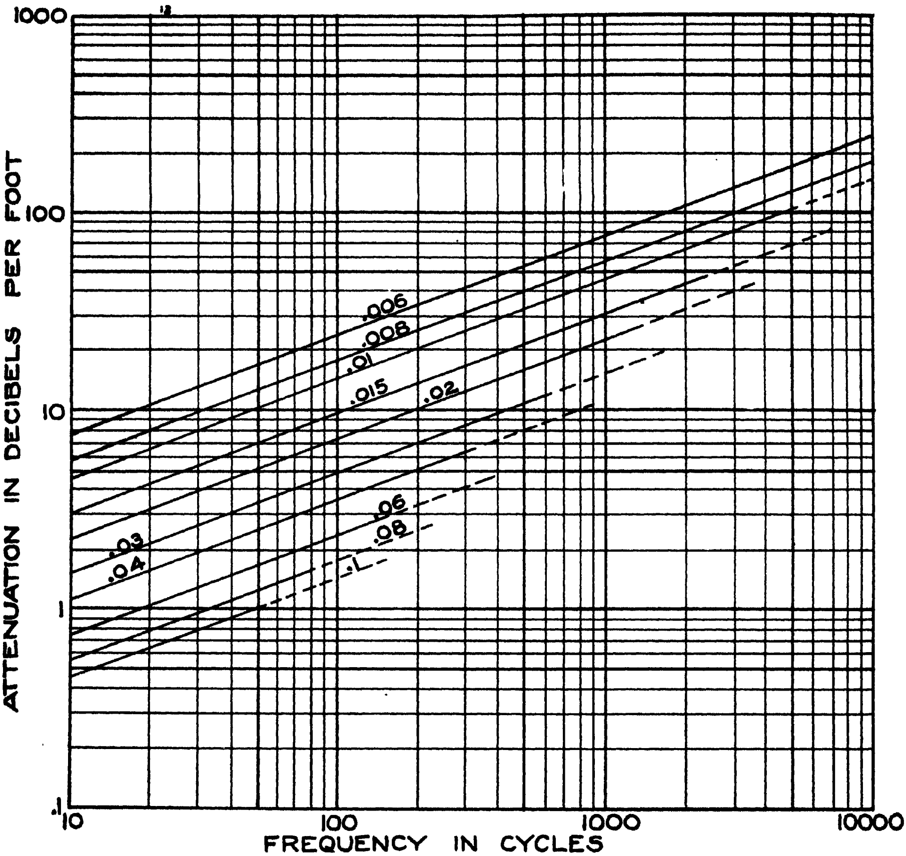


CHART NO. 13

Attenuation of sound in narrow tubes. The diameter of the bore in inches is marked on the curves. For the dotted portions of the curves, the losses become lower than shown due to the tubes' becoming effectively large (see chart 12).

Chart 14 shows the transmission loss through a thin rigid screen perforated with parallel slits whose width is small compared with the wavelength of sound being propagated through it.

The number on the curves indicate the ratio of the wavelength of sound being transmitted to the separation of the slits (S). The ratio S/W is the ratio of the slit separation to the slit width as shown on the insert drawing.

Sample Problem

Design a motion picture screen whose transmission loss at 10,000 cycles is no more than 2 db. and whose unperforated area is at least 90% of the total screen area.

Solution

From the conditions of the problem; namely, that the unperforated area = 90% of total area, the ratio of $S/W = 10$.

For $S/W = 10$, find the intersections with the ordinate 2 db. loss and read on the family of curves, the value 5^{-}. This value is the ratio of wavelength to slit separation. At 10,000 cycles, the wavelength is 1.4 inches (see chart 1) therefore:

$$\frac{1.4}{S} = 5, \text{ or } S = .28 \text{ inch separation between slits}$$

Since width of slits (W) = .1 S, W = .028 inch.

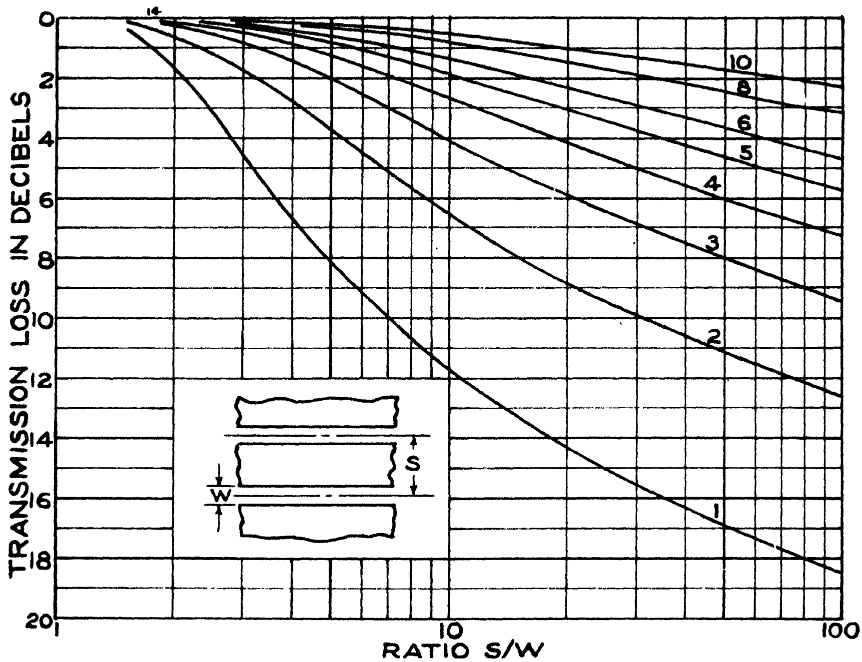


CHART NO. 14

Transmission loss through a thin rigid screen perforated with parallel slits whose width is small compared with the wavelength of sound. The numbers on the family of curves indicate the ratio of the wavelength of sound being transmitted through the screen to the separation of the slits (S).

Chart 15 shows the attenuation of sound through rigid walls whose thickness is small compared to the wavelength of sound and whose density is high compared to the density of air.

Sample Problem

Find the attenuation at 100 cycles through a 1 inch steel wall (40 lbs./sq. ft.) assuming the wall is so braced that it is absolutely rigid.

Solution

Frequency $\times$ weight per sq. ft. $= 100 \times 40 = 4{,}000$.

For the abscissa $= 4{,}000$, read the intersection on curve *B* which shows an attenuation of about 43 db.

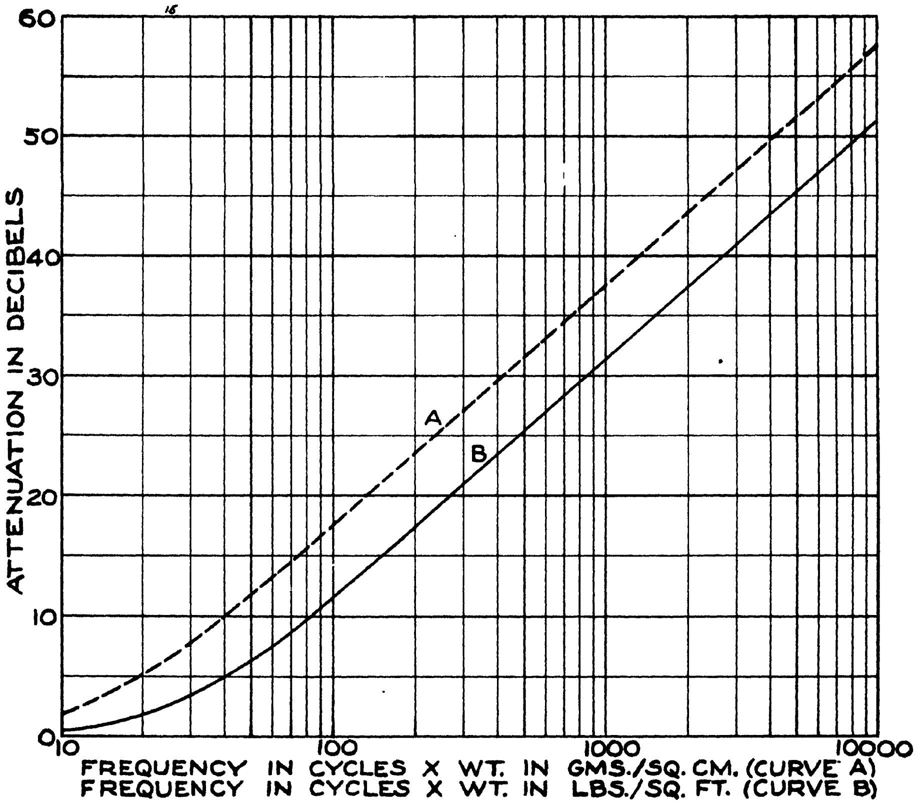


CHART NO. 15

Attentuation of sound through rigid walls of various weights per unit area. Wall thickness is small compared with wavelength of sound and density of wall is high compared with density of air.

Chart 16 shows the loss in force transmission from a vibrating body to a rigid floor when the body is separated from the floor by a spring having negligible damping. The resonance frequency referred to in the abscissa is that of the body in combination with the supporting spring. Negative valued ordinates represent an increase in the transmitted force due to the presence of the spring mounting. In other words, for vibration frequencies up to about 1.4 times the resonance frequency of the system the spring mounting actually increases the force transmitted to the floor.

Sample Problem

A motor has a vibrational frequency of 120 cycles and it is desired to spring mount the motor so that at least 30 db. attenuation of the force transmitted to the floor will result. Find the necessary resonance frequency of the motor and spring in order to fulfill this requirement.

Solution

For a transmission loss of 30 db. read from chart 16,

$$\frac{\text{Vibrational frequency}}{\text{Resonance frequency}} = 5.7$$

Since the vibrational frequency = 120 cycles,

$$\text{Resonance frequency} = \frac{120}{5.7} = 21 \text{ cycles.}$$

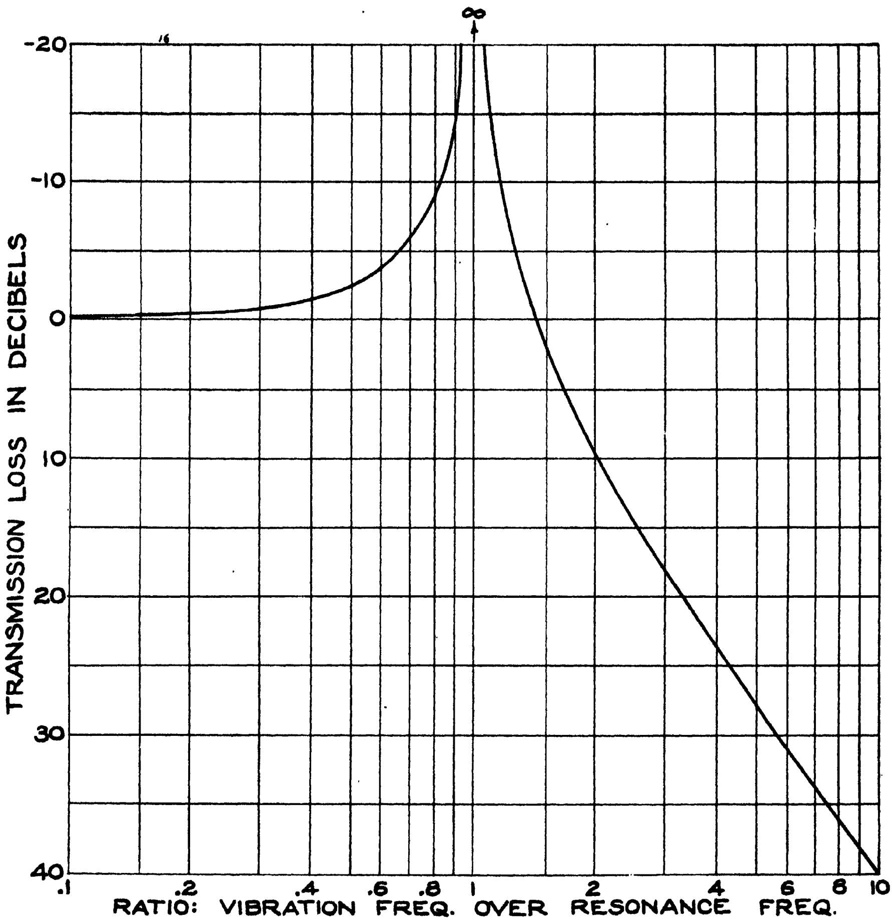


CHART NO. 16

Loss in force transmission from a vibrating body to a rigid floor when the body is separated from the floor by a spring having negligible damping. The resonance frequency referred to in the abscissa is that of the body in combination with the supporting spring. Note: The negative valued ordinates represent actual increases in transmitted forces due to the presence of the spring.

Chart 17 shows the loss in force transmission from a vibrating body to a rigid floor when the body is separated from the floor by a mechanical damping material having pure resistance.

Sample Problem

Find the magnitude of the mechanical resistance to introduce between a vibrating body having a mass of 1 kilogram in order to attenuate the force transmission by 30 db. Frequency of vibration = 120 cycles.

Solution

Mechanical reactance = $2\pi \times 120 \times 1{,}000 = 7.54 \times 10^5$ ohms.

For 30 db. loss, we find a necessary value of reactance to resistance equal to 32.

The necessary mechanical resistance is equal to

$$R_m = \frac{7.54 \times 10^5}{32} = 23{,}600 \text{ Mech. Ohms.}$$

NOTE.—1 Mech. ohm = 1 dyne sec./cm., or the resistance, across which the force of 1 dyne will produce a velocity of 1 cm./sec.

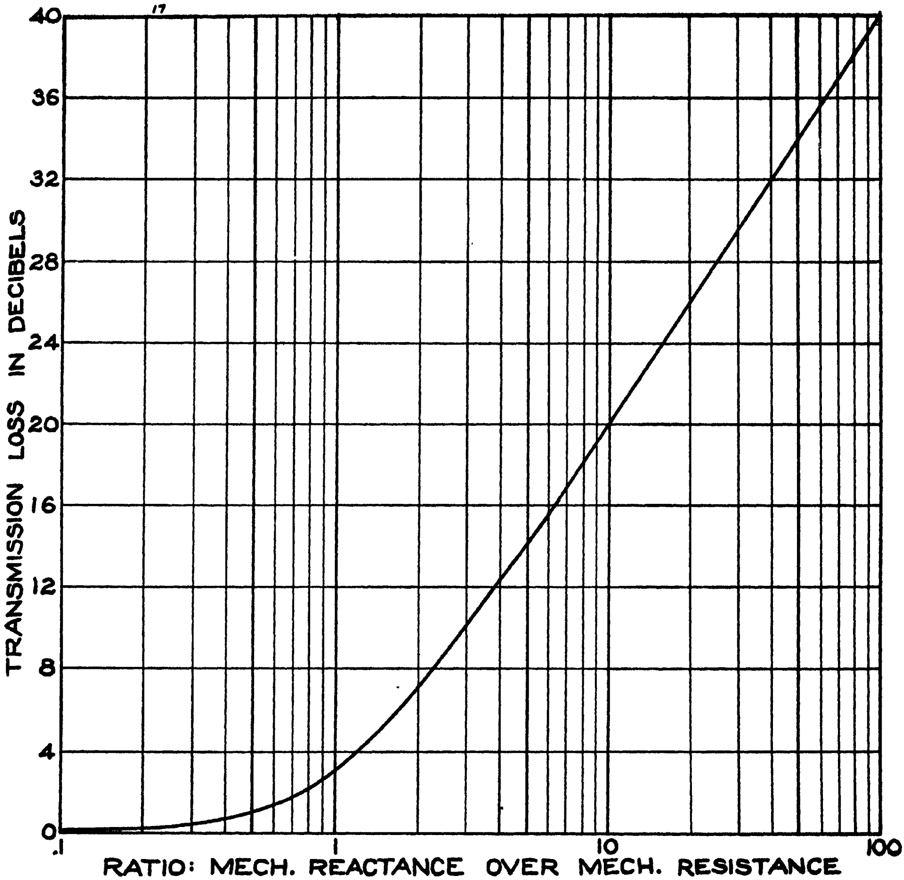


CHART NO. 17

Loss in force transmission from a vibrating body to a rigid floor when the body is separated from the floor by a mechanical damping material having pure resistance. The mechanical reactance $= 2\pi fm$, where f is the frequency of vibration and m the mass of the body in grams.

Chart 18 shows a group of curves which indicate the loss in transmission of an oscillatory force which originates in a vibrating mass which is separated from a rigid floor by a spring shunted with a mechanical resistance. The ratio X_M/R_M is the ratio of the mechanical reactance of the mass to the mechanical resistance in the support and K is the ratio X_M/X_S, where X_S is the mechanical reactance of the spring. Negative valued ordinates indicate increases in force transmission due to the mounting.

$$X_M = 2\pi fm \text{ Mech. ohms.}$$
$$X_S = S/2\pi f \text{ Mech. ohms.}$$

where f = frequency, m = mass in grams, S = stiffness of spring in dynes/cm.

Problem

A 100 gram mass has a vibrational frequency of 60 cycles and is mounted on a spring having a stiffness of 142,000 dynes/cm. which is shunted by a resistance of 1000 mechanical ohms. Find the loss in force transmission to the floor.

Solution

$$X_M = 2\pi \times 60 \times 100 = 37{,}700 \text{ mech. ohms}$$
$$X_S = 142{,}000/2\pi \times 60 = 377 \text{ mech. ohms}$$
$$K = X_M/X_S = 37{,}700/377 = 100$$
$$X_M/R_M = 37{,}700/1{,}000 = 37.7$$

For $X_M/R_M = 37.7$ and $K = 100$, the transmission loss as given by the curve is about 31 db.

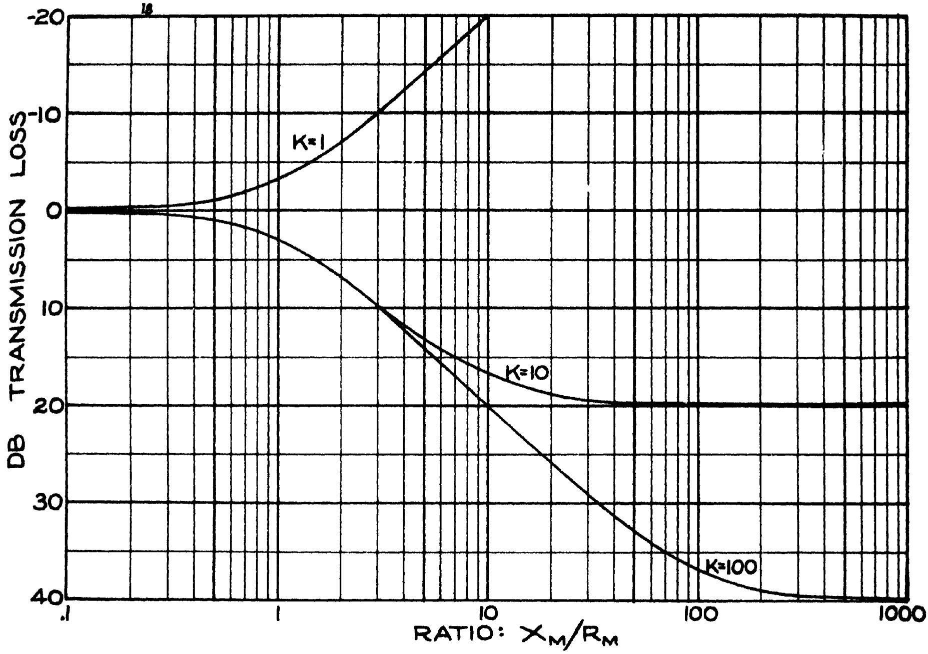


CHART NO. 18

Loss in transmission of an oscillatory force originating in a vibrating mass mounted over a rigid floor and separated therefrom by a spring shunted by mechanical damping of value R_M mechanical ohms. $X_M = 2\pi fm$; where f = frequency of vibration and m = mass of body in grams. $K = X_M/X_S$; where $X_S = S/2\pi f$ and S = stiffness of spring in dynes/cm. Note: Negative values of transmission loss indicate *increase* in force transmitted to floor due to mounting.

SECTION 3

Mechanical Vibrating Systems

Chart No. 19 shows the particle velocity, at all frequencies, of a resistance controlled mechanical system when acted on by a force of F dynes. The resistance R is expressed in mechanical ohms in which 1 mechanical ohm is the magnitude of resistance through which a force of 1 dyne produces a velocity of 1 cm. /sec.

Sample Problem

A force of 1,000 dynes causes a velocity of 10 cms. /sec. when acting on a mechanical circuit having pure resistance. Find the magnitude of the resistance.

Solution

For the ordinate equal to 10 cms. /sec., find the abscissa $F/R = 10$. Since $F = 1{,}000$ dynes, $R = \frac{1{,}000}{10} = 100$ mechanical ohms.

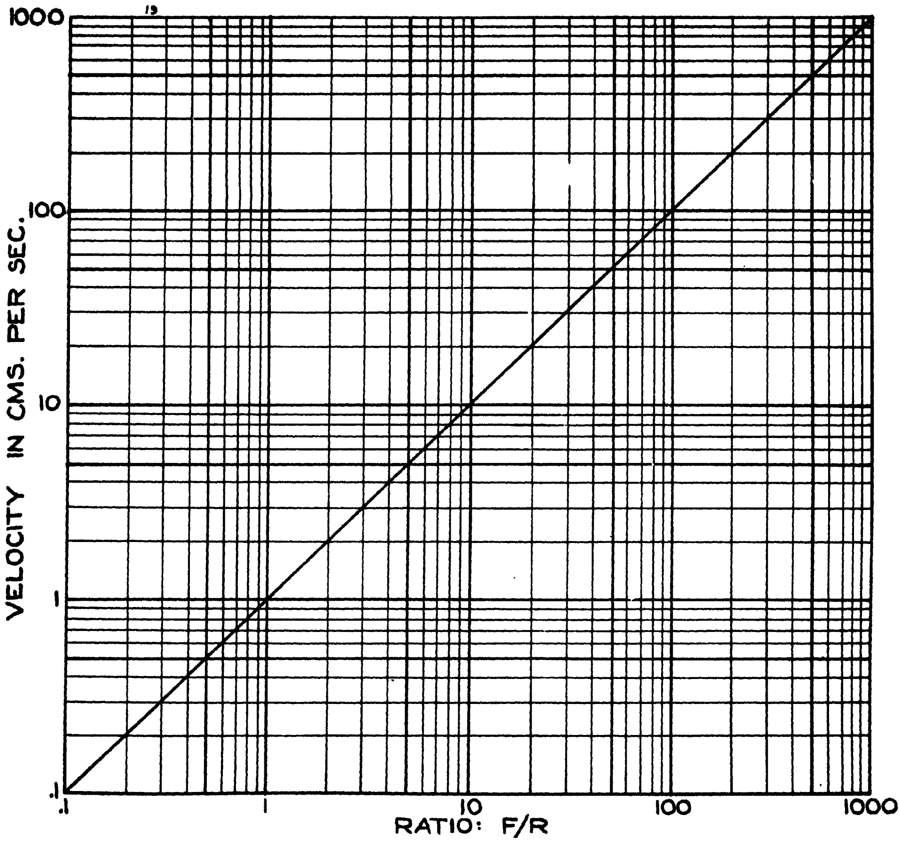


CHART NO. 19

Particle velocity, at all frequencies, of a resistance controlled mechanical system when acted on by a force of F dynes. R = mechanical resistance in mechanical ohms.

Chart No. 20 shows the amplitude of a resistance controlled mechanical system at various frequencies as a function of the driving force.

Sample Problem

Find the force required to cause a 1 mm. displacement from its normal position of a resistance controlled mechanical element having a resistance of 10,000 mechanical ohms and being operated at 1,000 cycles.

Solution

Along the ordinate equal to .1 cm. find the intersection with 1,000 cycles and read the value of $F/R = 630$.

Since $R = 10{,}000$.

$$F = 630 \times 10{,}000 = 6.3 \times 10^6 \text{ dynes.}$$

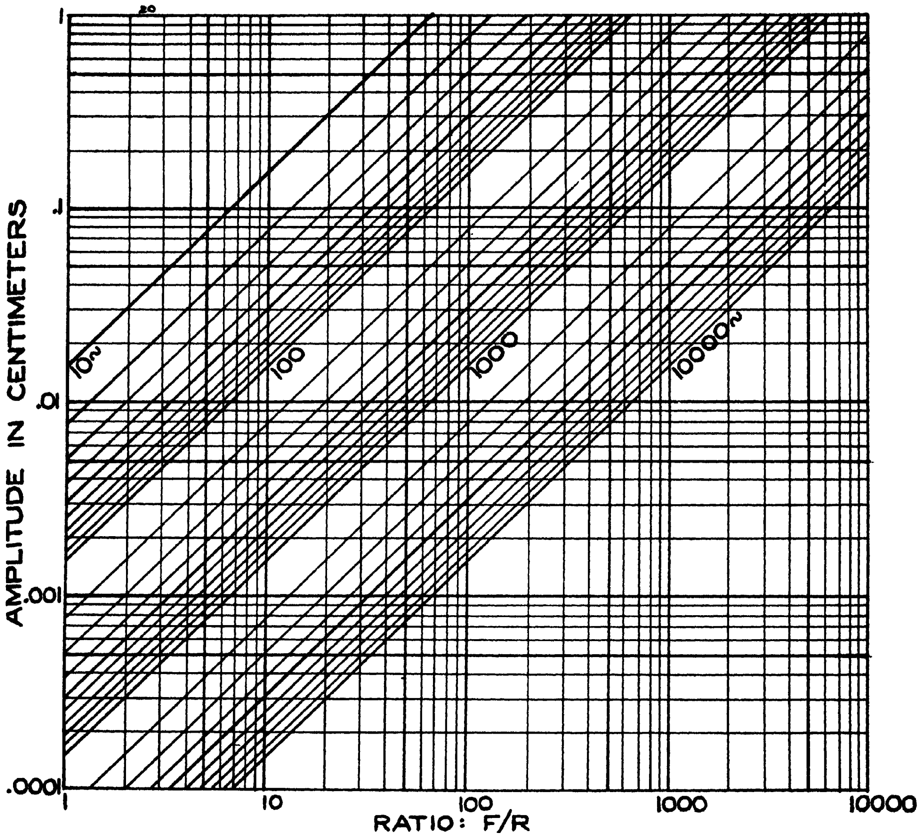


CHART NO. 20

Amplitude of a resistance controlled mechanical system when acted on by a force of *F* dynes at the various frequencies indicated by the family of curves. *R* = mechanical resistance in mechanical ohms.

Chart No. 21 shows the relation between the velocity of a mass controlled mechanical system and the force driving it at various operating frequencies.

Sample Problem

The vibrating portion of a mass controlled loud speaker has an effective mass of 8 grams. Find the driving force necessary to cause the diaphragm to have a velocity of 100 cms./sec. at 1,000 cycles.

Solution

At the intersection of the ordinate = 100 cms./sec. with the 1,000 cycle line read $F/m = 6.3 \times 10^5$.

The driving force to operate the diaphragm is,

$$F = 6.3 \times 10^5 \times 8 = 5.04 \times 10^6 \text{ dynes.}$$

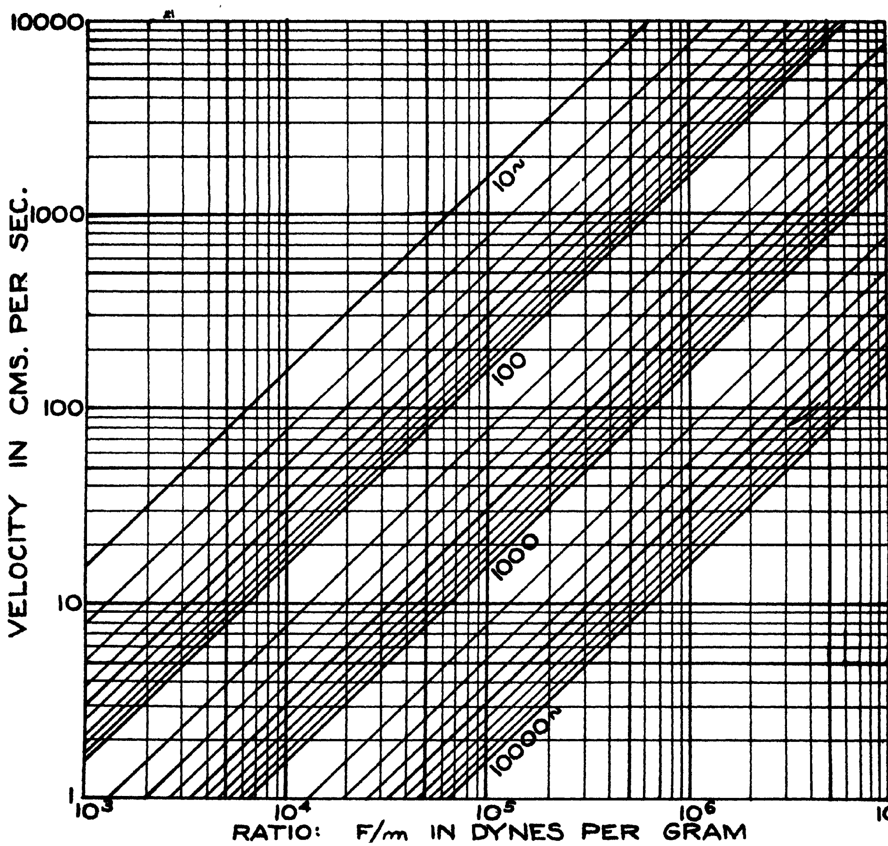


CHART NO. 21

Velocity of a mass controlled vibrating system at the various frequencies indicated by the family of curves. Note: Peak values of force will give peak velocity and r.m.s. force will show r.m.s. velocity.

Chart No. 22 shows the relation between the displacement of a mass controlled mechanical system and the driving force acting on the system at various frequencies.

Sample Problem

A force 10^5 dynes acts on a piston having a mass of 10 grams. Find the displacement of the piston from its position of rest at 100 cycles.

Solution

The ratio $F/m = 10^5/10 = 10^4$ dynes/gram.

For a value of $F/m = 10^4$, find the intersection with the 100 cycle line and read the displacement as .025 cm.

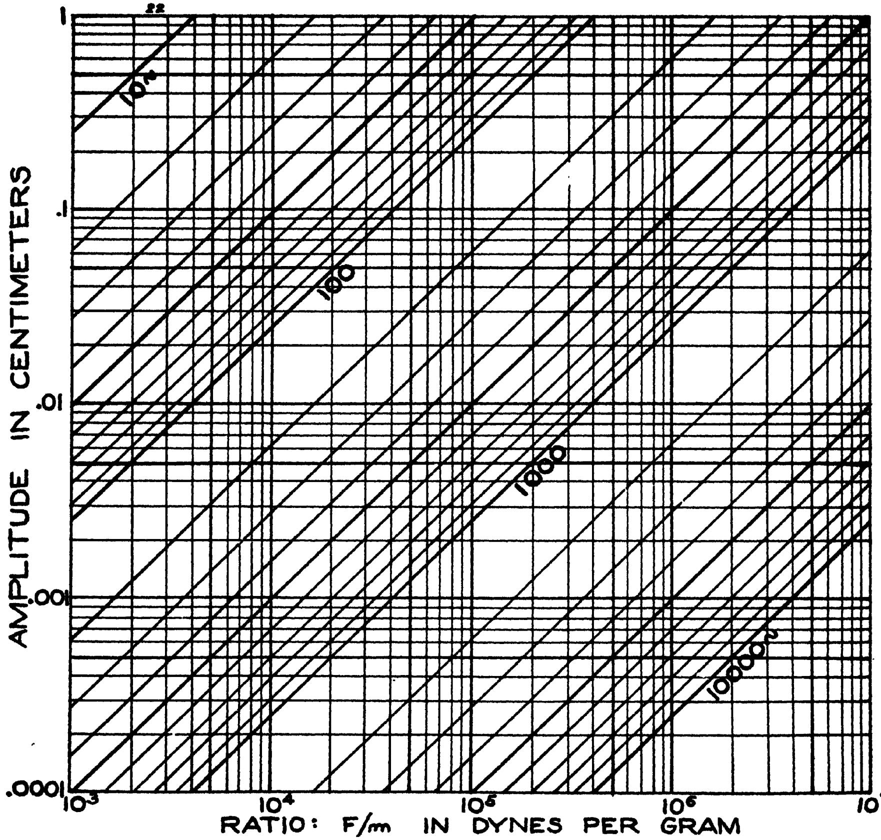


CHART NO. 22

Amplitude of a mass controlled vibrating system at the various frequencies indicated by the family of curves. Note: If peak or r.m.s. force is used, the amplitude indicated will be correspondingly peak or r.m.s.

Chart No. 23 shows the velocity of a stiffness controlled mechanical system as a function of frequency.

Sample Problem

Find the velocity at 1,000 cycles of the tip of a spring having a stiffness of 10^6 dynes per cm. and being driven by a force of 10,000 dynes.

Solution

The ratio $F/S = 10{,}000/10^6 = .01$

At the intersection of $F/S = .01$ with 1,000 cycles, read the velocity = 63 cms./sec.

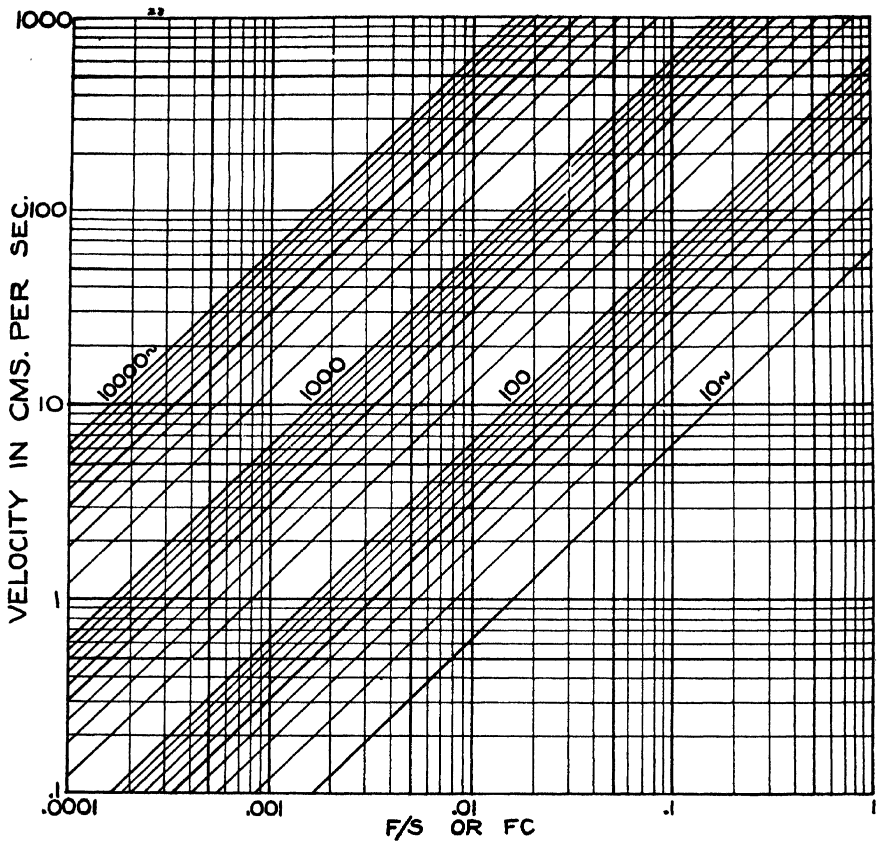


CHART NO. 23

Particle velocity of a stiffness controlled mechanical system when acted on by a force of F dynes at the various frequencies indicated by the family of curves. S = stiffness in dynes/cm.; C = compliance in cms./dyne.

Chart No. 24 shows the amplitude of a stiffness controlled mechanical system, at all frequencies, when acted on by a force of F dynes. The stiffness, S, is in dynes per cm.

Sample Problem

Find the force necessary to cause a 1 mm. displacement in a spring having a stiffness of 10^5 dynes per cm.

Solution

For the ordinate = .1 cm. find the value of $F/S = .1$. Since $S = 10^5$ dynes/cm. $F = .1 \times 10^5 = 10{,}000$ dynes.

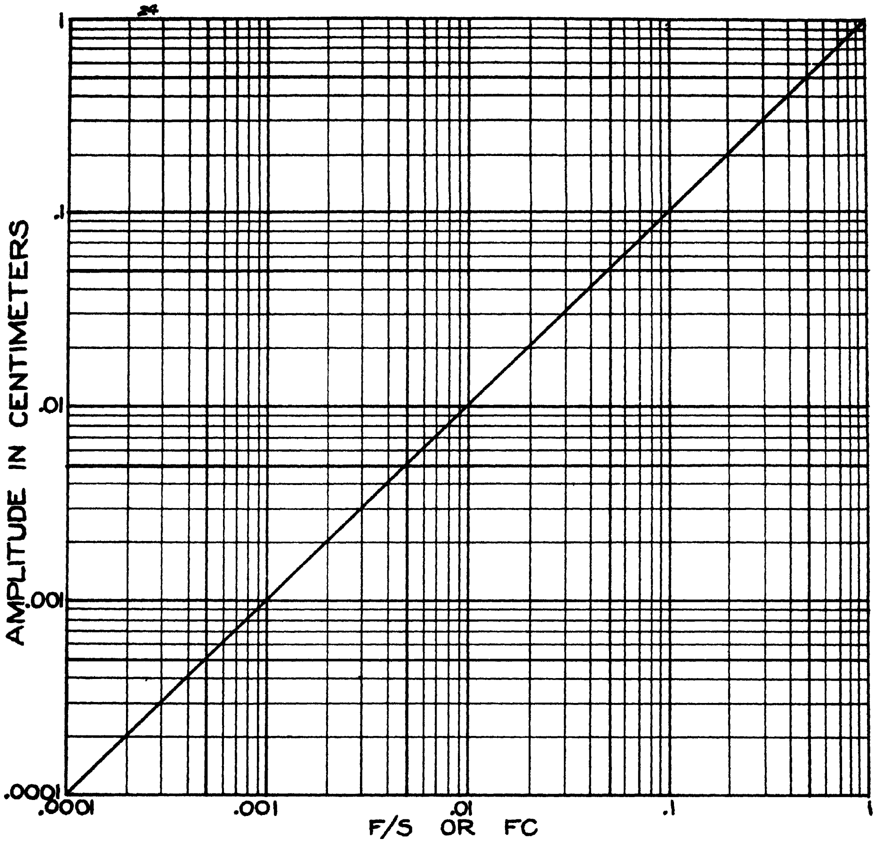


CHART NO. 24

Amplitude of a stiffness controlled mechanical system, at all frequencies, when acted on by a force of F dynes. S = stiffness in dynes/cm.; C = compliance in cms./dyne.

Chart 25 shows the mechanical reactance of a mass and a spring as a function of frequency.

Sample Problem

Find the reactance of a 5 gram mass at a frequency of 200 cycles. Also find the reactance of a spring having a compliance of 10^{-5} cm./dyne at 200 cycles.

Solution

The 5 gram mass at 200 cycles has a product $f \times m = 1{,}000$. At the left hand ordinate value = 1,000 read the reactance on curve A as 6300 mechanical ohms.

The spring at 200 cycles has a product $f \times c = 2 \times 10^{-3}$. At the right hand ordinate value 2×10^{-3} read the reactance on curve *B* as 80 mechanical ohms.

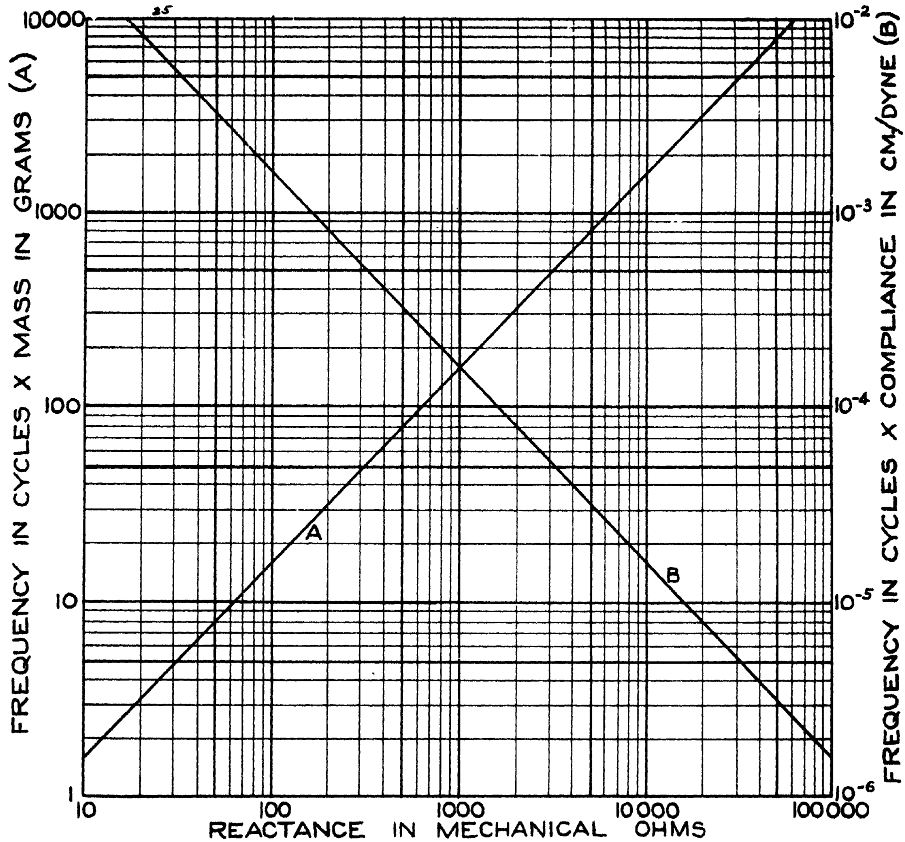


CHART NO. 25

Mechanical reactance of a mass and a spring as function of frequency.

Chart No. 26 is a conversion chart for obtaining the relation between stiffness in dynes/cm. or pounds/in. and the compliance in cms./dyne.

Sample Problem

It takes a force of 10 lbs. to deflect a spring 1/10 inch. Find its stiffness and compliance in c.g.s. units.

Solution

From the data it follows that the stiffness of the spring in the measured units is 100 lbs./in.

At the value of abscissa equal to 100 read the intersection on curve *A* on the left hand scale which gives the stiffness value $= 1.8 \times 10^7$ dynes/cm.

The intersection on the *B* curve which is read on the right hand scale gives the value of compliance $= 5.6 \times 10^{-8}$ cm./dyne.

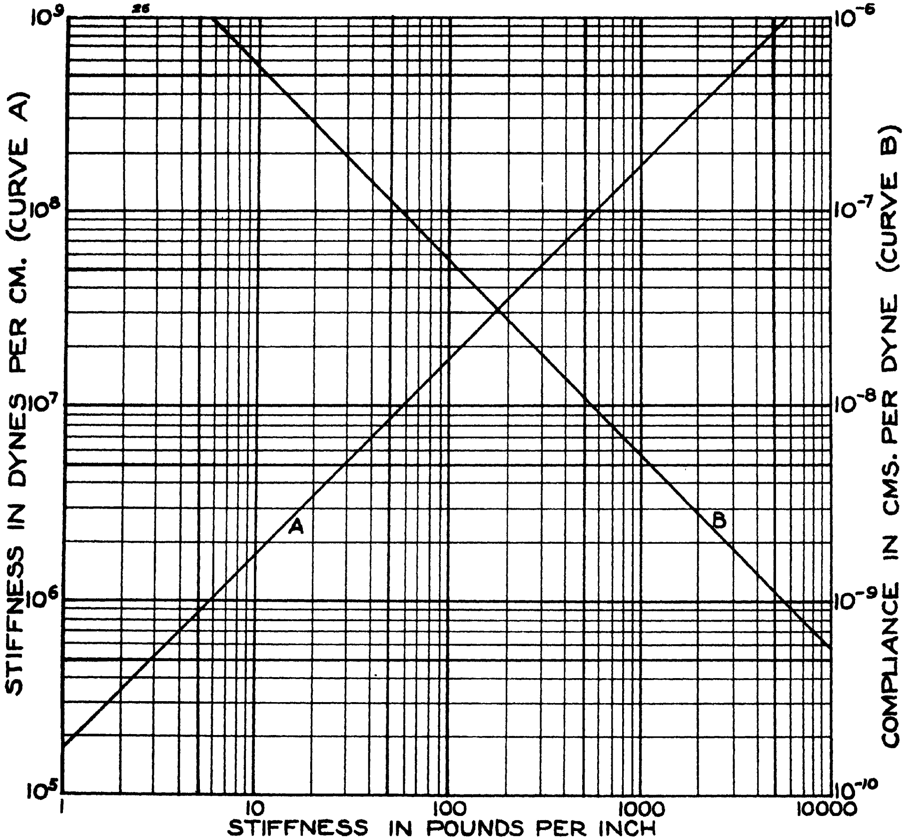


CHART NO. 26

Conversion chart for stiffness and compliance

Chart 27 shows the relations between mass, stiffness, and compliance, and the resonance frequency of a vibrating system.

Sample Problem

A mass of 2 grams resonates at a frequency of 100 cycles when mounted on a spring. Find the stiffness of the spring.

Solution

For the resonance frequency = 100 cycles find the intersection with the solid line which gives a value of stiffness/mass = 3.9×10^5. Since the mass is 2 grams, the stiffness of the spring is,

$$S = 3.9 \times 10^5 \times 2 = 7.8 \times 10^5 \text{ dynes/cm.}$$

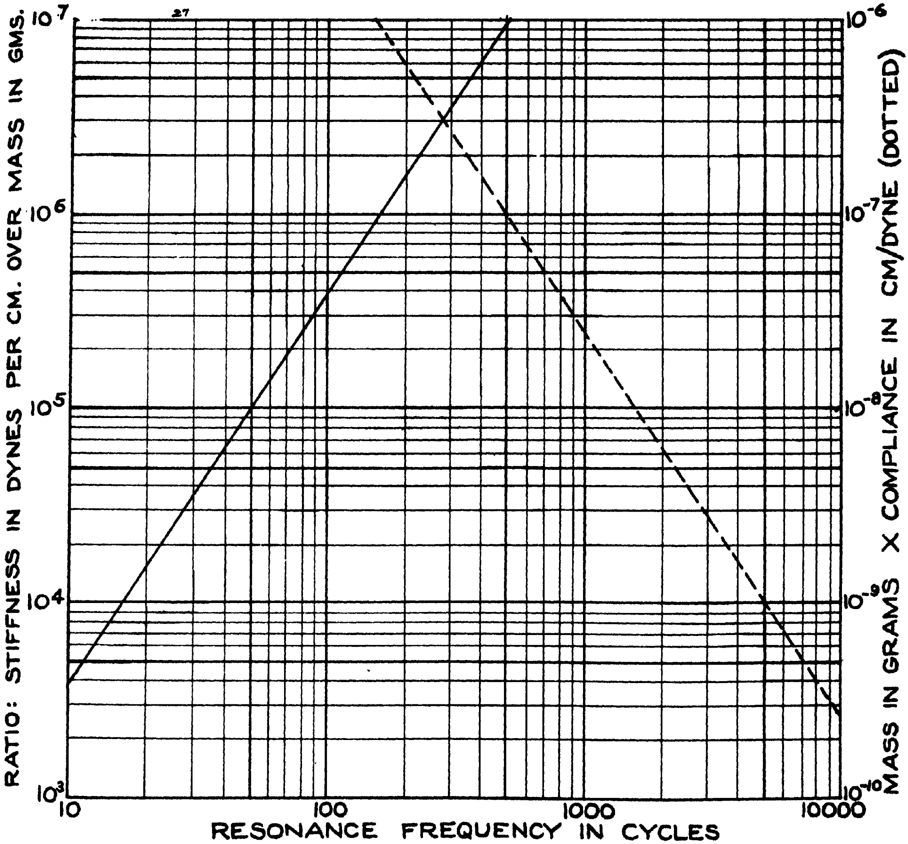


CHART NO. 27

Resonance frequency of a simple vibrating system consisting of a mass and spring in terms of the constants of the system.

Chart No. 28 shows the relation between compliance, grams, and resonance frequency of a simple vibrating system.

Sample Problem

Find the compliance of a spring on which a motor having a mass of 10,000 grams must be supported so that the resonance frequency is 2 cycles.

Solution

Mass $\times$ frequency of resonance = 10,000 $\times$ 2 = 20,-000.

For the abscissa = 20,000, the value of the ordinate is 1.25×10^{-6} which is the magnitude of the resonance frequency $\times$ compliance.

The compliance of the spring is equal to,

$$C = \frac{1.25 \times 10^{-6}}{2} = .625 \times 10^{-6} \text{ cm./dyne.}$$

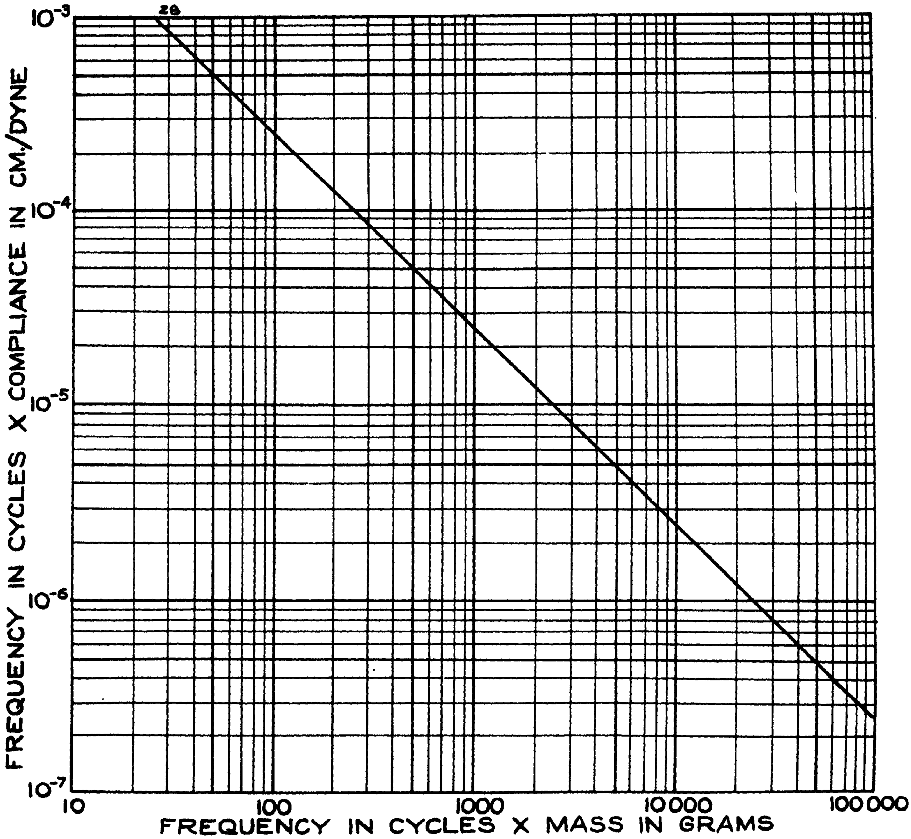


CHART NO. 28

Relations to be satisfied in a mechanical system consisting of a mass supported on a spring in order that the system will be in resonance.

Chart 29 shows the natural resonance frequency of a mass supported on a spring in terms of the static deflection of the spring due to the load. This chart is useful to give an indication of the resonance frequency of a simple vibrating system by only measuring the static deflection due to the mounted mass.

Sample Problem

A block of steel is mounted on a free spring causing a ½ inch deflection. Find the resonance frequency of the system.

Solution

At the ordinate value = .5 inch (left hand scale) read the intersection on curve *A* as 4.4 cycles resonance frequency.

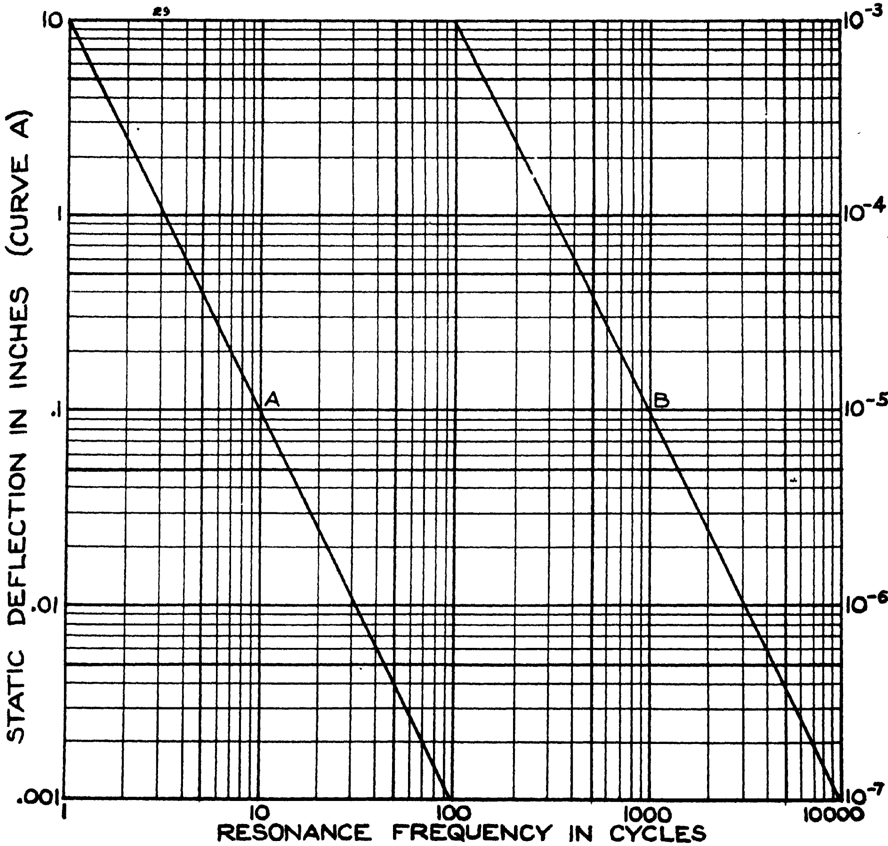


CHART NO. 29

Resonance frequency of a mechanical system consisting of a mass mounted on a spring in terms of the static deflection of the spring caused by the mass.

Chart 30 shows the natural frequencies in vacuo of unstretched aluminum discs clamped at their peripheries. The numbers on each curve indicate the diameter of the piston in inches.

Chart 31 shows the natural frequencies of clamped steel plates.

As can be seen from the two charts, the resonance frequencies of clamped circular steel discs are only very slightly higher than the same size aluminum discs. This follows because the ratio of Young's modulus to density is almost equal for both aluminum and steel.

The use of these two charts is obvious without the necessity of any sample problems.

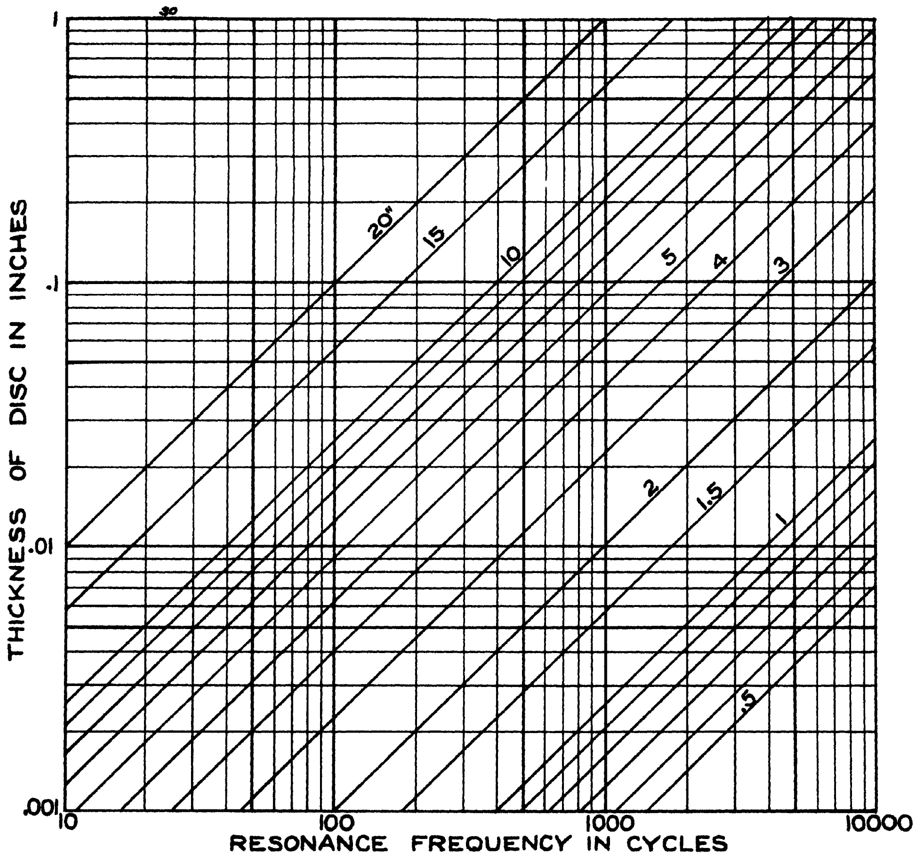


CHART NO. 30

Natural frequencies in vacuo of unstretched aluminum discs clamped at their peripheries for the various diameters in inches indicated by the family of curves. Note: The modulus of elasticity for the aluminum $= 7 \times 10^{11}$ dynes/cm.[2] For an aluminum alloy of modulus E, multiply resonance frequencies by $\sqrt{E/(7 \times 10^{11})}$.

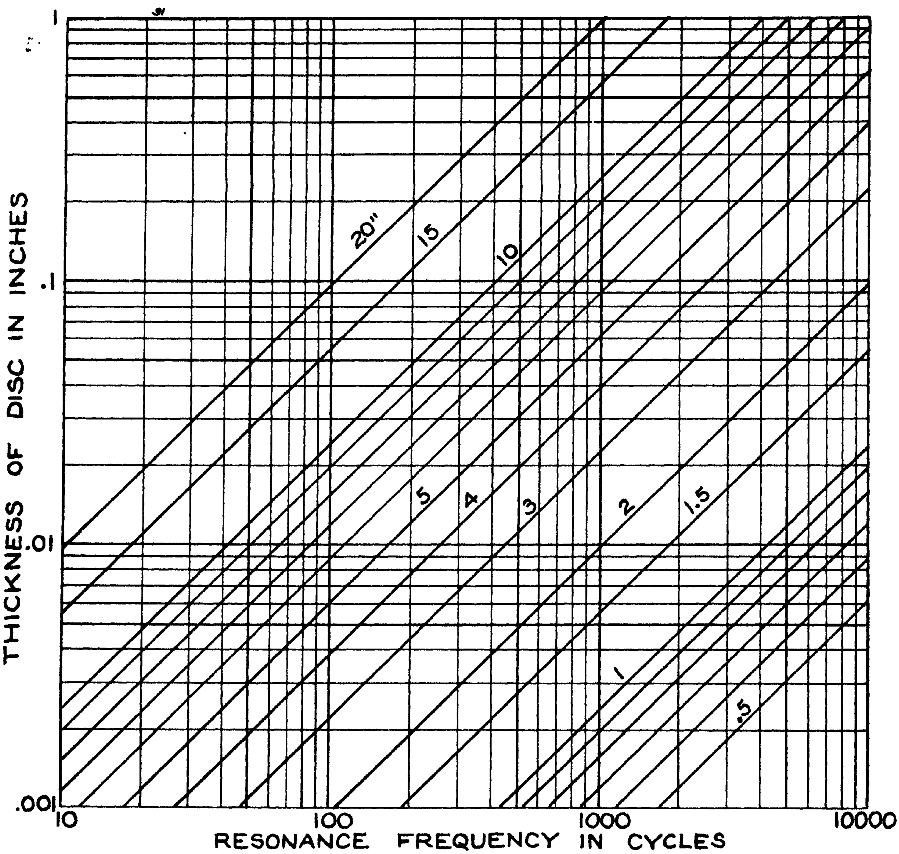


CHART NO. 31

Natural frequencies in vacuo of unstretched steel discs clamped at their peripheries for the various diameters in inches indicated by the family of curves. Note: The modulus of elasticity for the steel = 22×10^{11} dynes/cm.[2] For another steel of modulus E, multiply resonance frequencies by $\sqrt{E/(22 \times 10^{11}}$.

Chart 32 shows the resonance frequency of a stretched aluminum circular membrane as a function of the tension in the peripheral section of the membrane. The numbers on the family of curves represent the clamping diameters in inches.

Chart 33 shows the resonance frequencies for a family of stretched steel membranes.

Sample Problem

Find the necessary tension at the peripheral cross section of a 1½ inch diameter circular membrane if it is to be stretched to resonance at a frequency of 5,000 cycles.

A. Aluminum membrane.

B. Steel membrane.

Solution

A. On chart 32 find the intersection of the 5000 cycle abscissa with the curve labeled 1.5 inches and find the required tension = 25,000 lbs./sq. in.

B. Repeat the procedure on chart 33 and find the required tension for steel membrane = 71,000 lbs./sq. in.

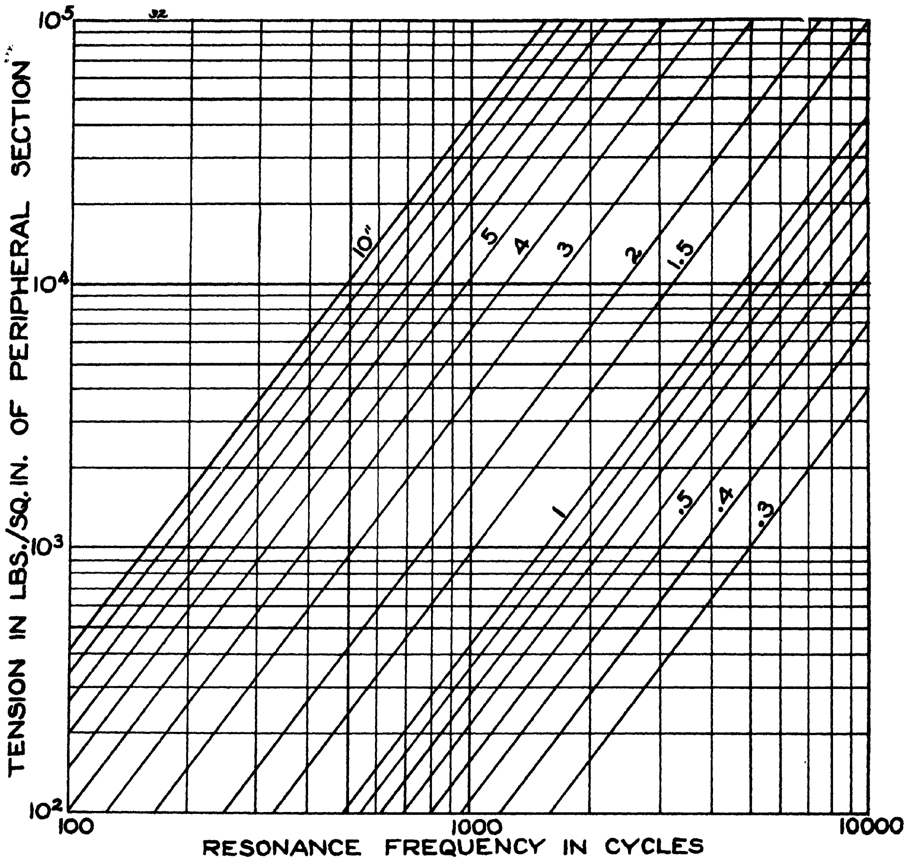


CHART NO. 32

Natural frequencies in vacuo of stretched circular aluminum membranes for the various diameters in inches indicated by the family of curves. Note: Specific gravity of aluminum was assumed equal to 2.67. For any other material of specific gravity S, multiply above frequencies by $\sqrt{2.67/S}$.

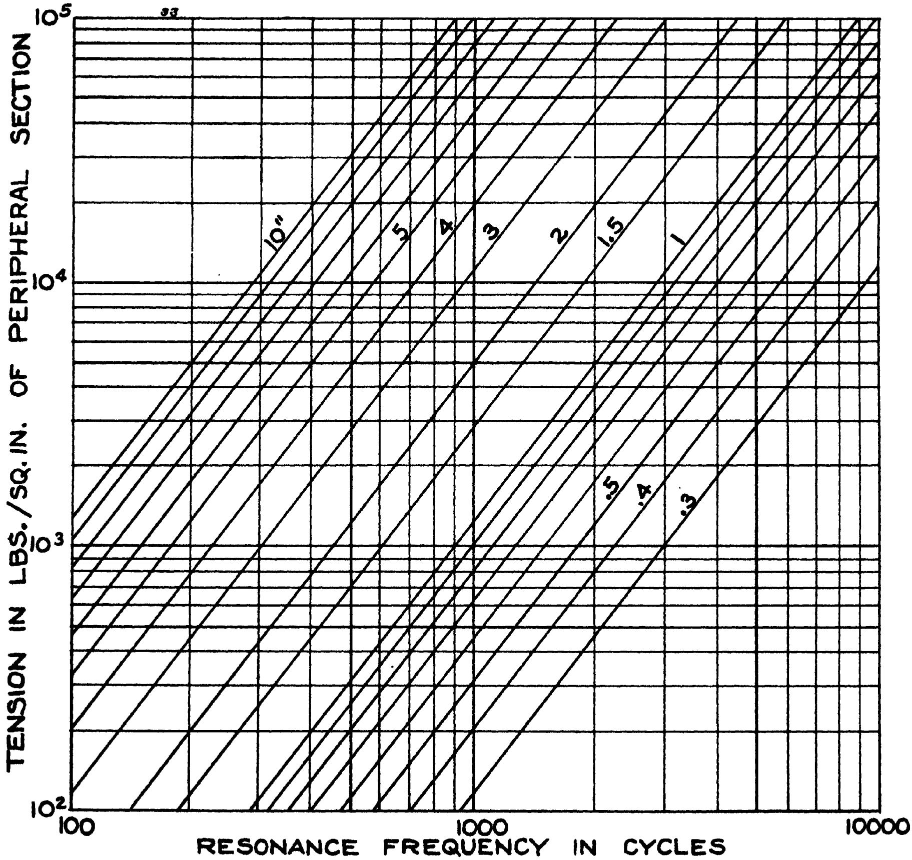


CHART NO. 33

Natural frequencies in vacuo of stretched circular steel membranes of the various diameters in inches indicated by the family of curves. Note: Specific gravity of steel was assumed equal to 7.8. For any other steel or alloy of specific gravity S, multiply above frequencies by $\sqrt{7.8/S}$.

Chart No. 34 shows the departure from sinusoidal motion of the end of a piston which is driven by crank and connecting rod as shown in the sketch drawn on the chart. The curve shows the per cent second harmonic amplitude which is generated in the piston when the crank is driven at uniform speed.

Sample Problem

A piston is to be used for a sound generator and is to be driven from a crank having a ¼ inch radius; find the minimum length of connecting rod which will be required if the second harmonic amplitude is not to exceed 2½%.

Solution

For 2½% second harmonic the ratio L/D which may be read from the chart is 10. Therefore, the length of the connecting rod, L, must be equal to 10 times the diameter of the crank pin circle, D. Since the problem states that the crank pin radius equals ¼ inch, making $D = \frac{1}{2}$ inch, then,

Minimum length of connecting rod $= 10 \times \frac{1}{2} = 5$ inches

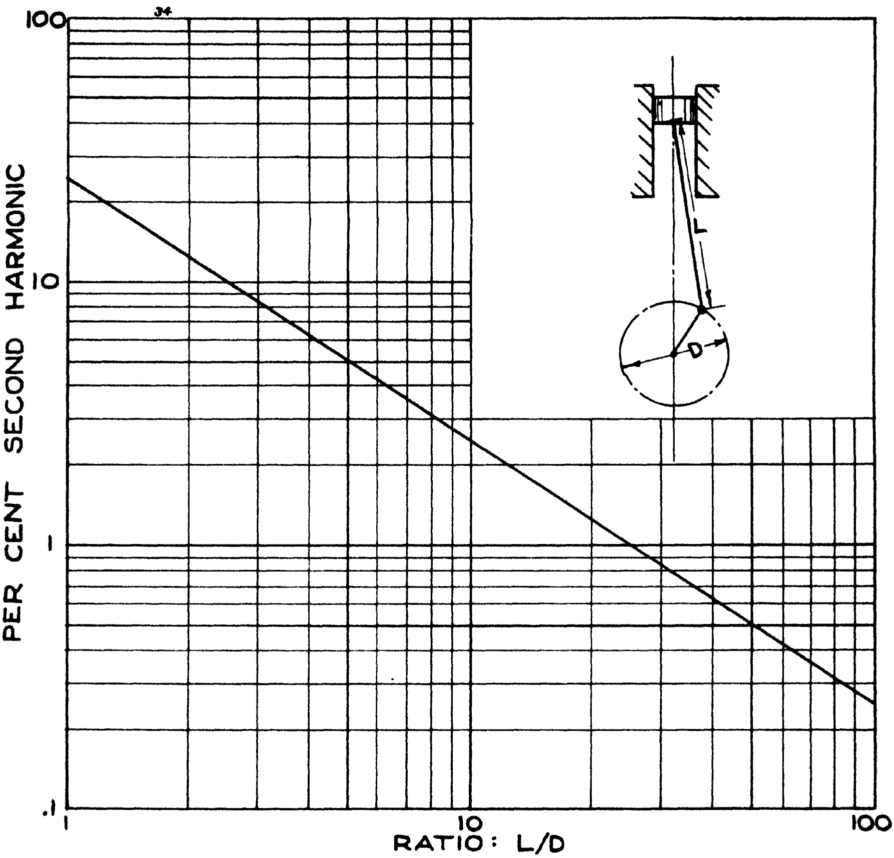


CHART NO. 34

Second harmonic generated in the motion of a piston which is driven by a connecting rod and crank running at constant speed.

SECTION 4

Acoustical Elements and Vibrating Systems

Chart No. 35 shows the acoustic resistance of small tubes as a function of the tube dimensions. The conditions that must be fulfilled in the use of the chart are:

1. Tube diameter small compared to length.
2. Length small compared to the wavelength of sound.

Sample Problem

The walls of a cylinder are 2 cms. thick and a hole 1 mm. diameter is drilled in the wall to present an acoustic resistance to the piston which is vibrating in the cylinder. Find the magnitude of the resistance for the frequency range over which the tube may be considered small.

Solution

For a tube diameter equal to 1 mm., read opposite the abscissa = .1 cms. and find a value of specific resistance = 7.5 acoustic ohms.

Total acoustic resistance of hole is given by,

$$R_A = 7.5 \times \frac{2}{.1} = 150 \text{ acoustic ohms.}$$

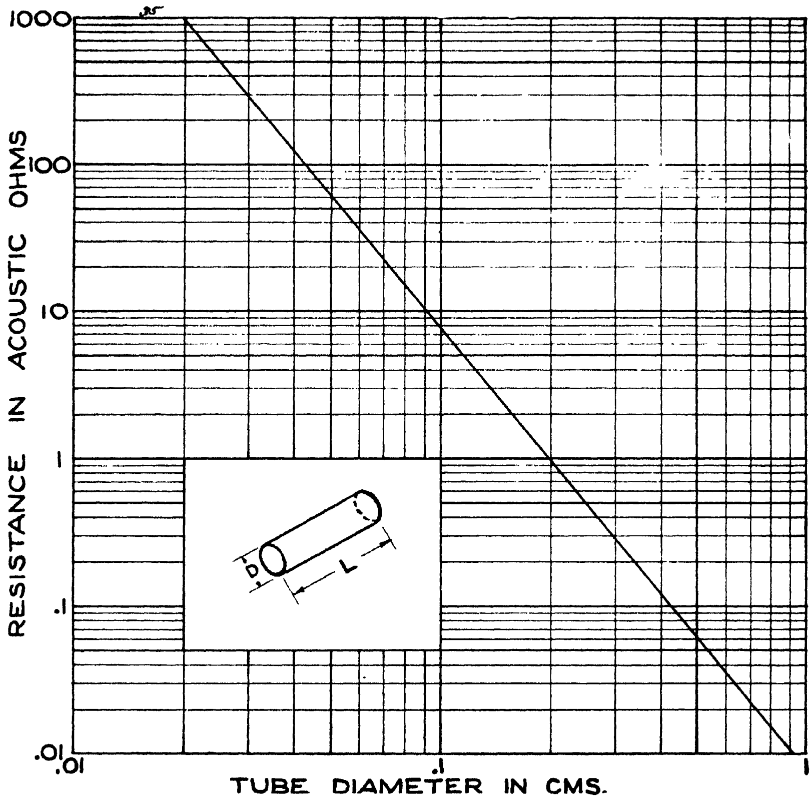


CHART NO. 35

Specific acoustic resistance of a small tube whose diameter is small compared with its length and whose length is small compared with the wavelength of sound. Note: To obtain total resistance of tube, multiply specific resistance by the ratio L/D shown in sketch.

Chart No. 36 shows the relation between the acoustic reactance of a small tube as a function of frequency and the tube's dimensions.

Sample Problem

Find the acoustic reactance of the hole described in the previous problem (chart 35) at a frequency of 100 cycles. The tube dimensions as given in the previous problem were $L = 2$ cms. $D = 1$ mm.

Solution

At the intersection of the abscissa = .1 cm. with the 100 cycle line, find the specific acoustic reactance = 13 acoustic ohms. The total reactance of the tube is

$$X_A = 13 \times \frac{2}{.1} = 260 \text{ acoustic ohms.}$$

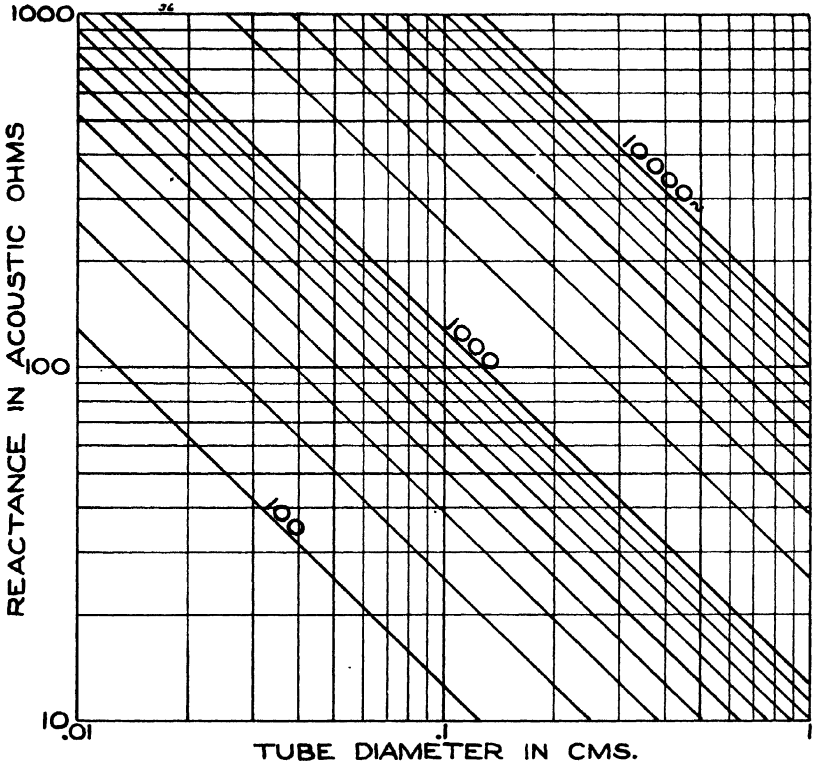


CHART NO. 36

Specific acoustic reactance of a small tube whose diameter is small compared with its length and whose length is small compared with the wavelength of sound. Note: To obtain total reactance of tube, multiply specific reactance by the ratio L/D shown in sketch on chart No. 35.

Chart 37 shows the acoustic reactance at various frequencies of tubes whose lengths are small compared to the wave length of sound.

Sample Problem

Find the acoustic reactance at 100 cycles of a tube whose effective length is 10 cms. and whose cross sectional area is 2 sq. cms.

NOTE.—See chart 38 for the determination of effective length from the physical length.

Solution

The ratio of tube length to area $= 10/2 = 5$.

For an abscissa value equal to 5 read the intersection with the 100 cycle line as 3.8 acoustic ohms.

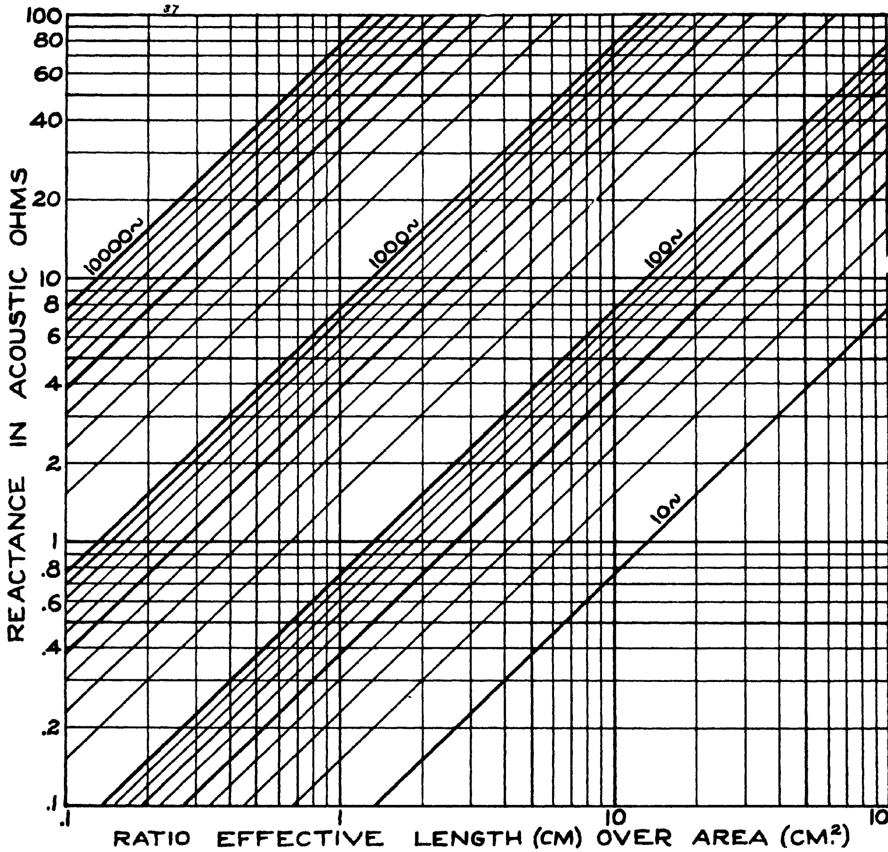


CHART NO. 37

Acoustic reactance of tubes used as inertance elements in acoustic circuits for the various audio frequencies marked on the family of curves. To be used as an inertance element, the tube length must be small compared with the wavelength of sound at the frequency of operation. For relation between effective length and physical length, see chart 38.

Chart 38 shows the increase in apparent length of a tube which is open on both ends as a function of the ratio of length over diameter of tube. For tubes closed on one end, the apparent increase in length is one half the value shown on the chart.

Sample Problem

Find the effective length of a tube which is 2 inches long and 2 inches diameter:

A. When both ends are open.

B. When one end is closed.

Solution

For a ratio $L/D = 1$, read the apparent increase in length as 80%. The apparent length of the tube is:

A. Apparent length $= 2 + .8 \times 2 = 3.6$ inches.

B. Apparent length $= 2 + \dfrac{.8 \times 2}{2} = 2.8$ inches.

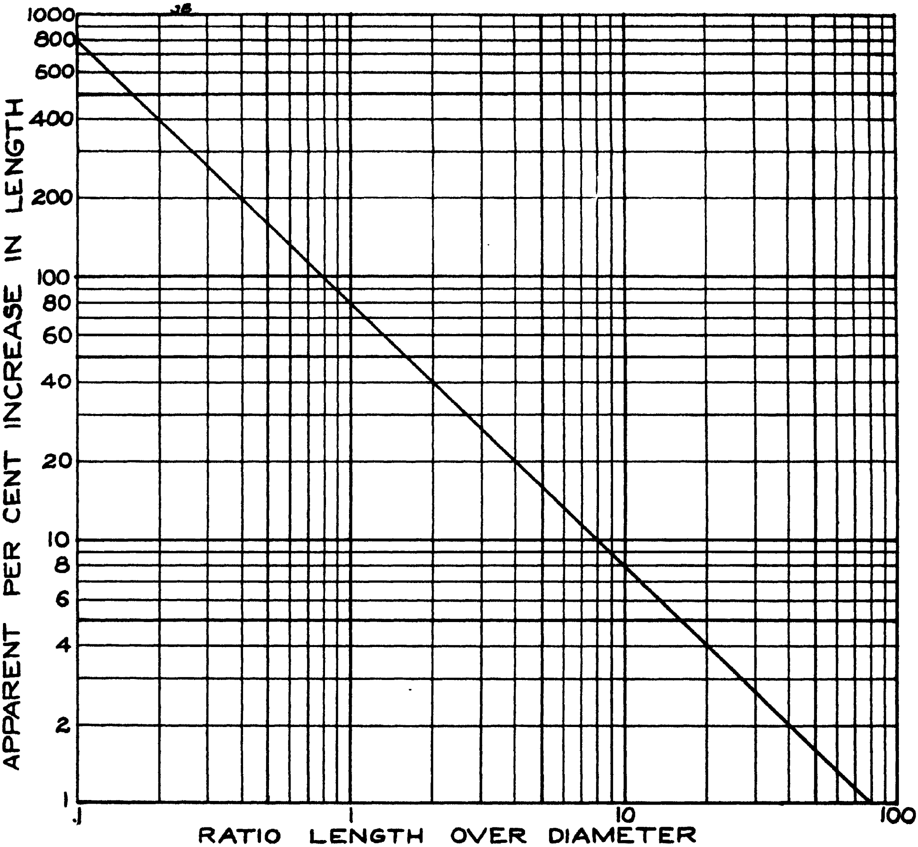


CHART NO. 38

Increase in apparent length of an open tube due to "end effect." Curve shows the percentage increase in physical length as a function of the ratio of length over diameter of the tube. The effective length of a tube is its physical length plus the percentage increase shown on the chart.

Chart 39 shows the relation between the acoustic resistance of a narrow slit and its dimensions. A narrow slit is defined as one whose dimension W is small compared to B and B small compared to the wave length of sound being transmitted through the slit.

Sample Problem

Two plates 3 cms. × 2 cms. are separated by a distance of ½ mm. Find the acoustic resistance when the axis of the sound wave propagation is along the 2 cm. dimension.

Solution

In terms of the sketch on the chart, the following slit dimensions occur in this problem:

$$W = .05 \text{ cm.}; A = 3 \text{ cm.}; B = 2 \text{ cm.}$$

For $W = .05$ along the abscissa, read the specific resistance as 18 acoustic ohms on the chart.

The total resistance of the slit is equal to

$$R_A = 18 \times 2/3 = 12 \text{ acoustic ohms.}$$

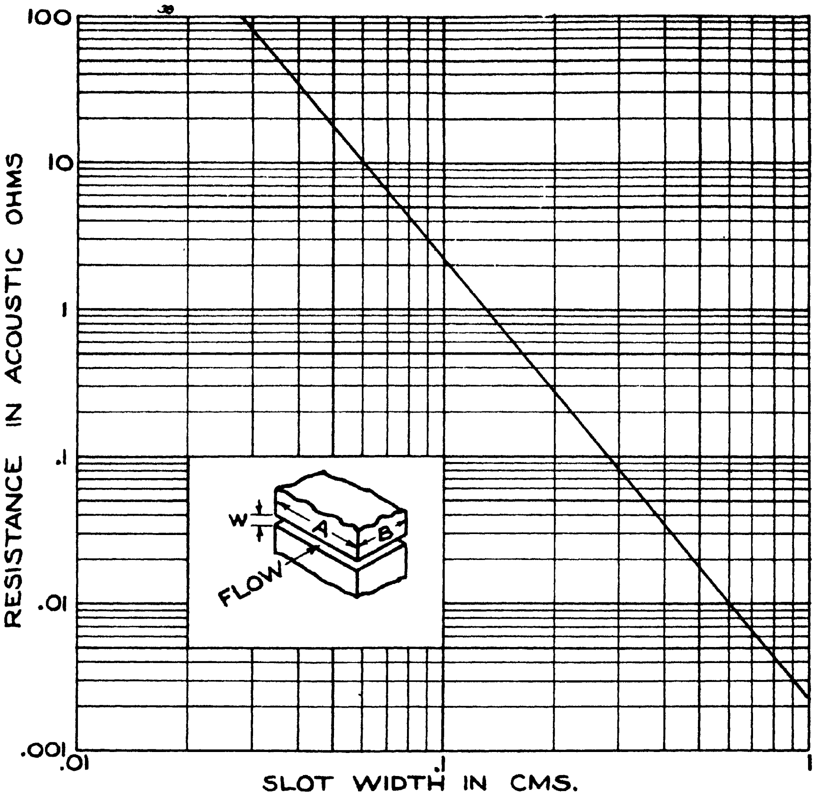


CHART NO. 39

Specific acoustic resistance of a narrow slit (dimensions small compared with wavelength of sound) formed by two rigid parallel plates separated by a width *W*. Note: To obtain total resistance of slit, multiply the specific resistance by the ratio *B*/*A* shown in the sketch.

Chart 40 shows the relation between the acoustic reactance of a small slit as a function of frequency and the slit's dimensions.

Sample Problem

Find the acoustic reactance of the slit described in the previous problem (chart 39) at a frequency of 100 cycles. The slit dimensions as given in the previous problem are:

$$W = .05 \text{ cm.}; A = 3 \text{ cm.}; B = 2 \text{ cm.}$$

Solution

At the intersection of the abscissa = .05 cm. with the 100 cycle line, find the specific acoustic reactance = 18 acoustic ohms. The total reactance of the slit is

$$X_A = 18 \times 2/3 = 12 \text{ acoustic ohms.}$$

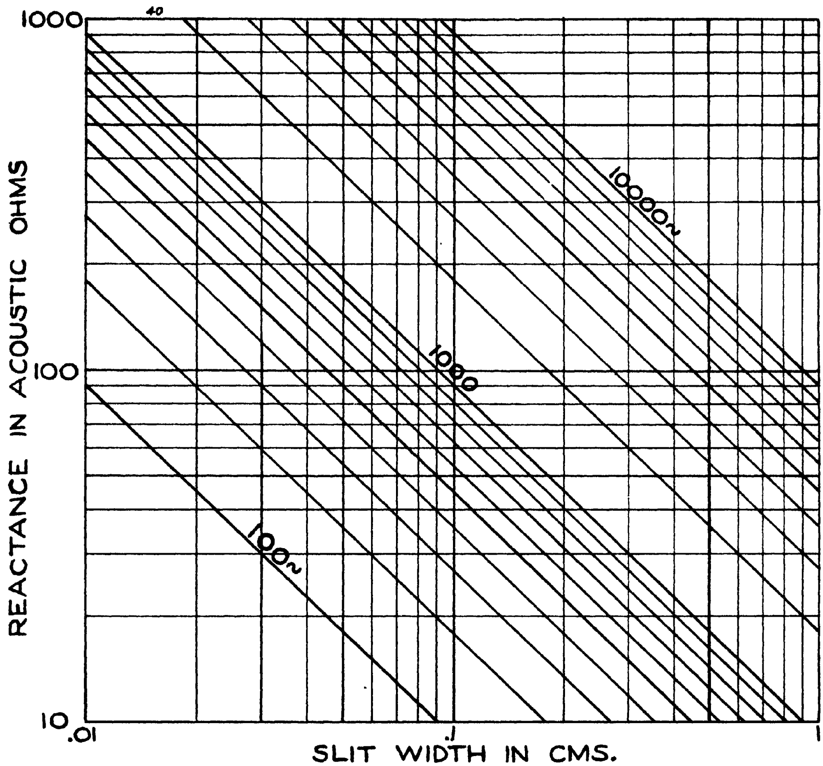


CHART NO. 40

Specific acoustic reactance of a narrow slit (dimensions small compared with wavelength of sound) formed by two rigid parallel plates at the various frequencies shown by the family of curves. Note: To obtain total reactance of slit, multiply the specific reactance by the ratio *B/A* shown in the sketch on chart 39.

Chart 41 shows the reactance of a circular orifice mounted in an infinite wall whose thickness is small compared to the orifice diameter. The diameter of the orifice is also small compared to the wavelength of sound being transmitted.

Sample Problem

Find the acoustic reactance at 1,000 cycles of a 1/4 inch diameter hole which is drilled in a thin plate.

Solution

At the value of the abscissa = 1,000 cycles read the intersection on the curve marked inches which gives a value (on the left hand ordinate scale) of diameter × reactance = 3.

Since the diameter of the hole = .25 inches, the reactance is equal to

$$X_A = 3/.25 = 12 \text{ acoustic ohms.}$$

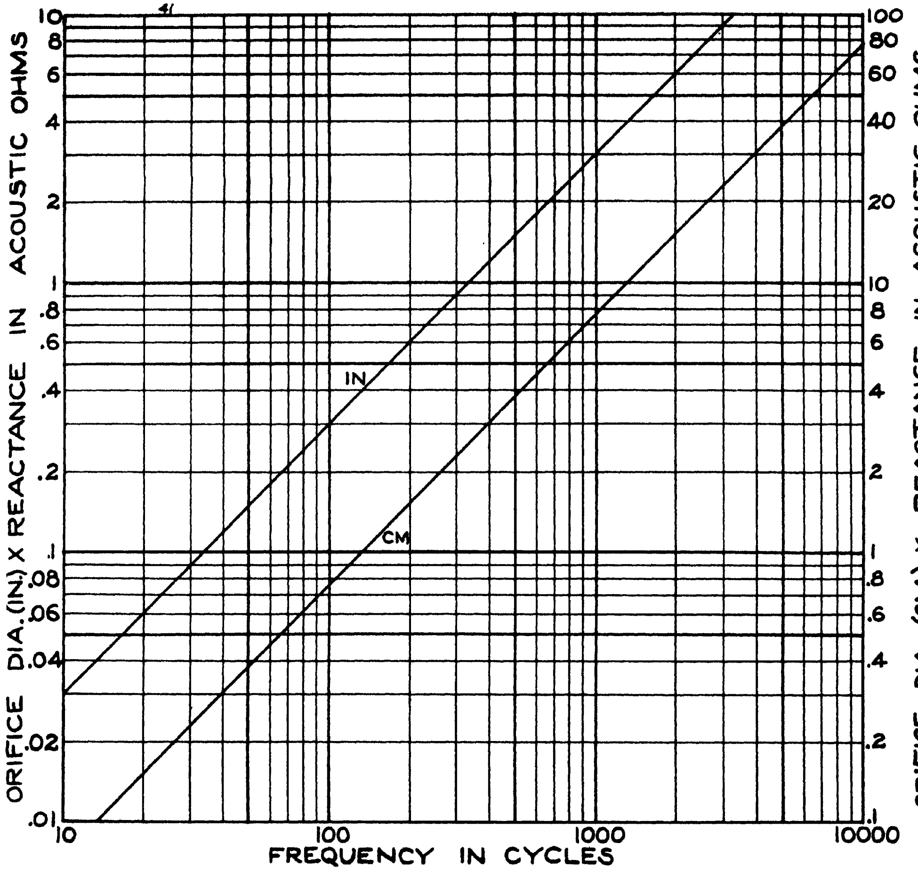


CHART NO. 41

Acoustic reactance of a circular orifice mounted in a wall whose thickness is small compared with diameter of orifice.

Chart 42 shows the acoustic capacitance of an enclosed volume when the volume is expressed in cms.[3] or ins.[3] It is assumed that the linear dimensions of the volume are small compared with the wave length of sound at the frequency concerned.

Sample Problem

Find the acoustic capacitance of an enclosure having a volume equal to 1,000 cubic inches.

Solution

Along the upper abscissa scale marked in cubic inches, find the value 1,000 and read down to the intersection on the curve marked "IN" and find the ordinate value equal to an acoustic capacitance = .012 acoustic farad.

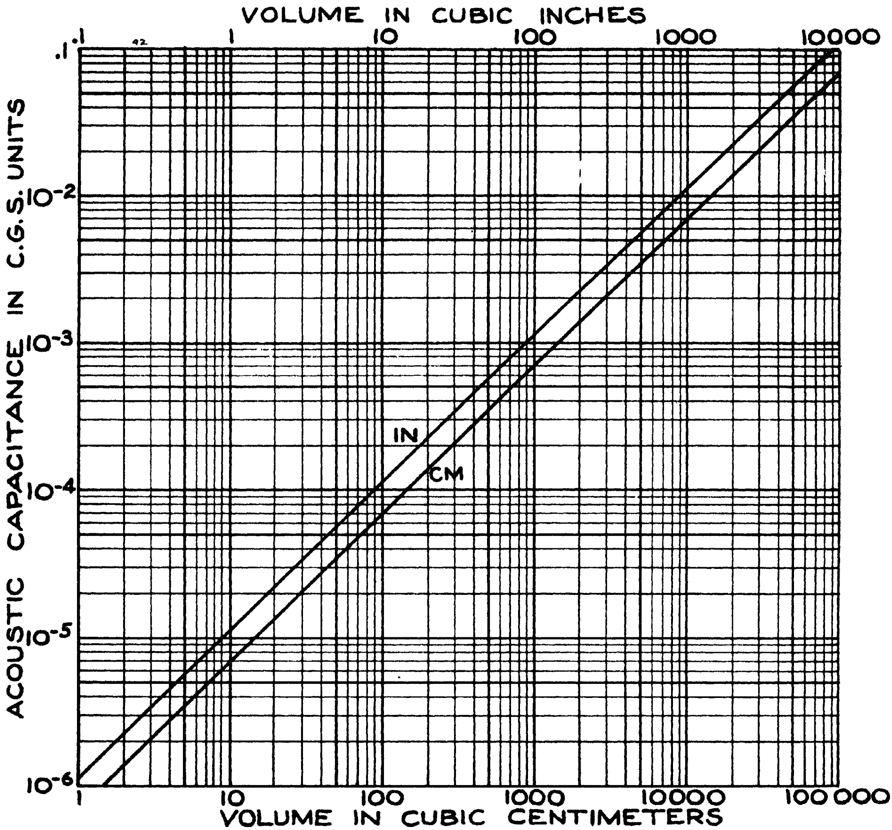


CHART NO. 42

Acoustic capacitance of enclosed volumes of air at 20° C. and 760 mm. pressure. Note: Maximum linear dimension of enclosure is assumed small compared with the wavelength of sound at the frequency of operation.

Chart 43 shows the relation between frequency and the acoustic reactance of enclosed volumes. Two curves are shown, one for volumes expressed in cu. ins. and another for volumes in cu. cms.

Sample Problem

Find the acoustic reactance of a cubical enclosure measuring 10 inches on a side at a frequency of 100 cycles.

Solution

Volume of enclosure = 1,000 cu. ins.

At a value of frequency = 100 cycles, read up to the intersection with the curve marked "IN" and read on the left hand ordinate scale the value of volume × reactance = 140.

$$\text{Reactance} = \frac{140}{1{,}000} = .14 \text{ acoustic ohm.}$$

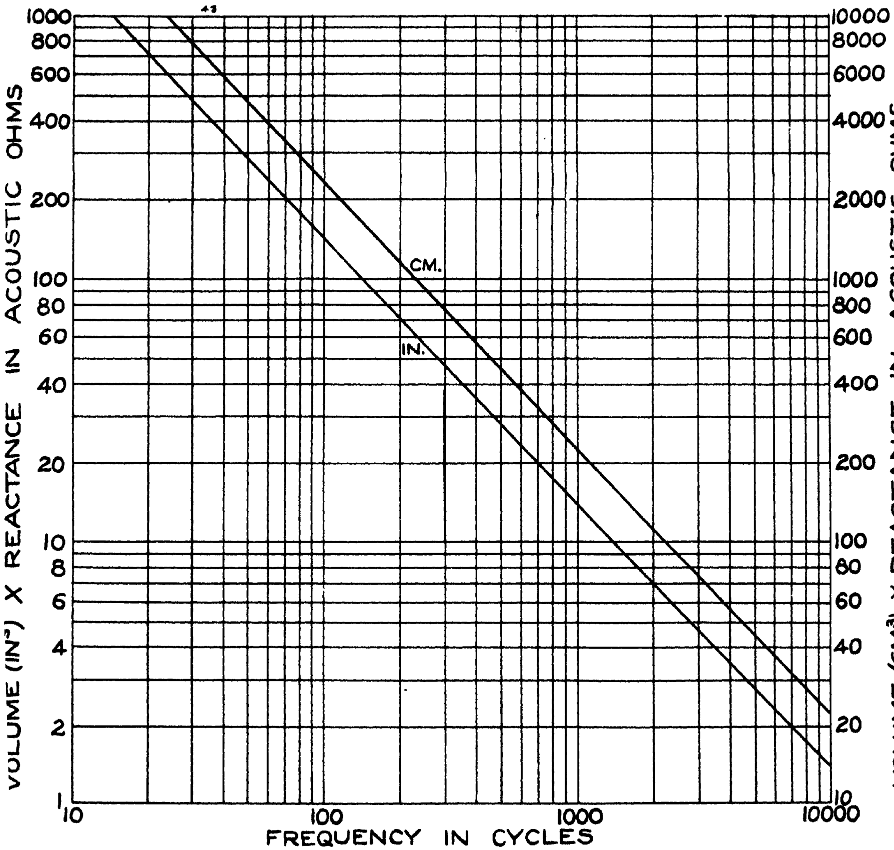


CHART NO. 43

Acoustic reactance of an enclosed volume whose maximum linear dimension is small compared with the wavelength of sound at the frequency of operation.

Chart 44 shows the acoustic reactance of an enclosed volume as a function of frequency. The relations are shown for the volumes expressed in cu. ins. or cu. cms. NOTE.—the maximum linear dimension of the enclosure must be small compared to the wavelength.

Sample Problem

Find the acoustic reactance at 500 cycles of an enclosed volume equal to 100 cu. ins.

Solution

The product of frequency $\times$ volume in cu. ins. is $500 \times 100 = 5 \times 10^4$.

At the intersection of the lower abscissa $= 5 \times 10^4$ with the curve marked "IN," read the ordinate as .27 acoustic ohm.

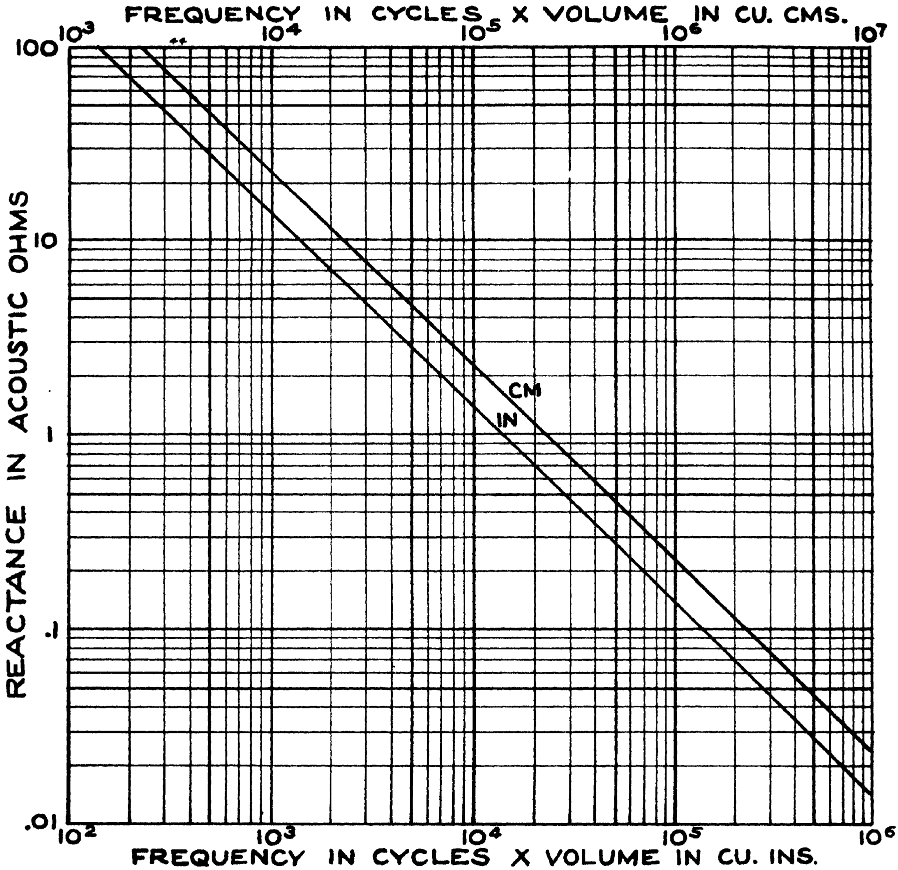


CHART NO. 44

Acoustic reactance of enclosed volumes at various frequencies. Note: Maximum linear dimension of volume is assumed small compared with the wavelength of sound at the frequency of operation.

Chart 45 shows the relation between inertance and acoustic reactance for the various frequencies marked on the family of curves.

Sample Problem

Find the acoustic reactance at 100 cycles of an inertance equal to .01 c.g.s. units (acoustic henry).

Solution

At the intersection of the abscissa = .01 with the 100 cycle line, find the ordinate equal to 6.3 acoustic ohms.

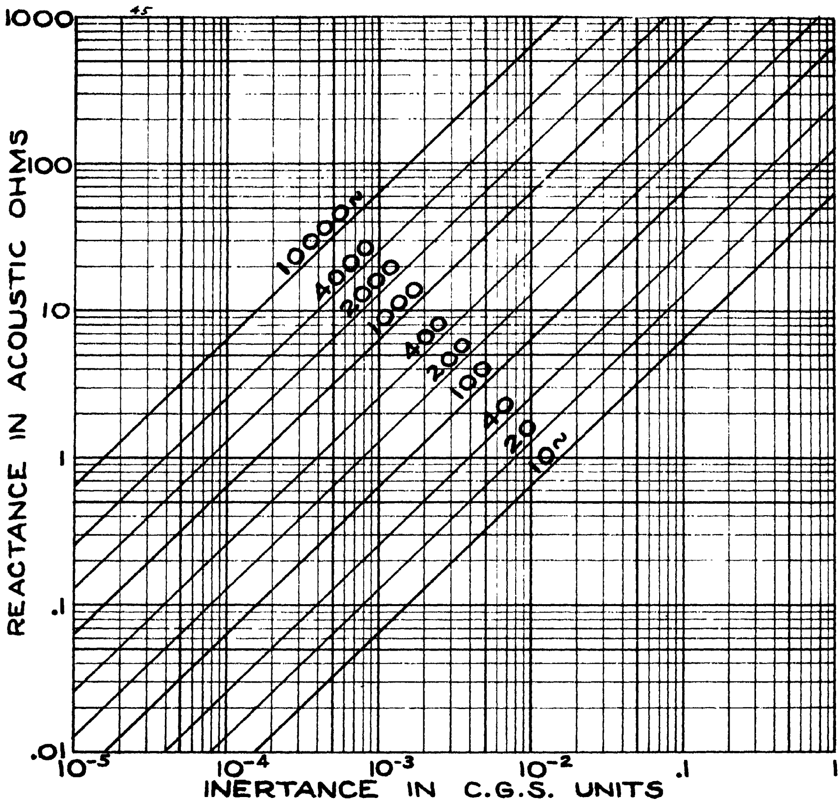


CHART NO. 45

Inertance versus acoustic reactance at the various frequencies marked on the family of curves.

Chart 46 shows the relation between acoustic capacitance and acoustic reactance for the various frequencies shown by the family of curves.

Sample Problem

Find the acoustic reactance at 100 cycles of an acoustic capacitance equal to .001 c.g.s. units (acoustic farad).

Solution

At the abscissa = 10^{-3}, find the intersection with the 100 cycle line and read the ordinate as 1.6 acoustic ohms.

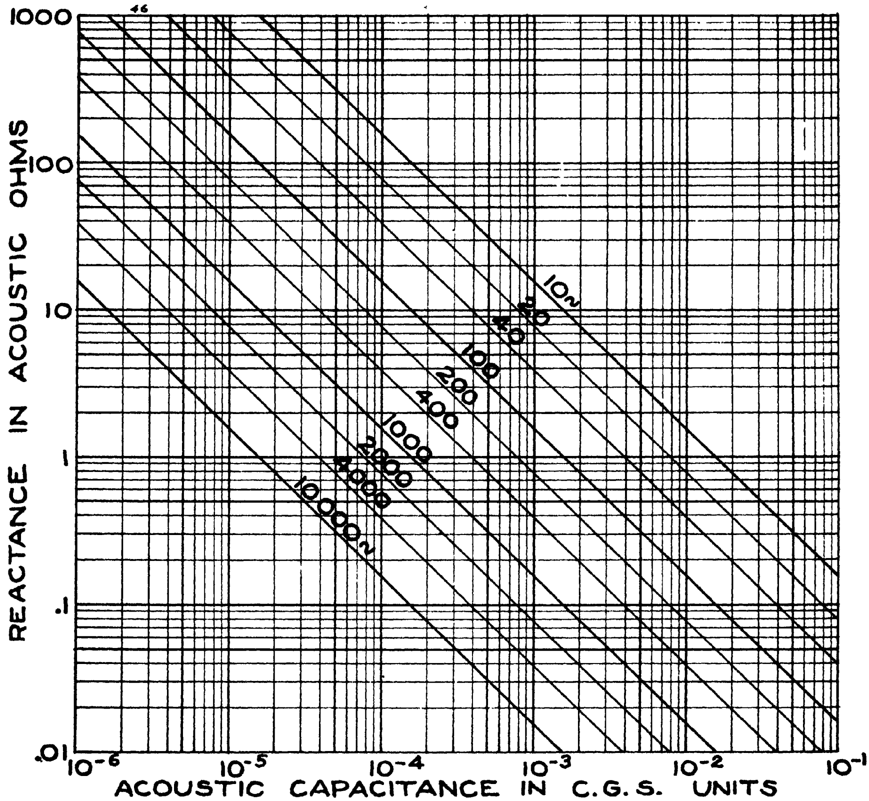


CHART NO. 46

Acoustic capacitance versus acoustic reactance at the various frequencies marked on the family of curves.

Chart 47 shows the necessary volume of enclosure to resonate with various inertances at the various frequencies marked on the family of curves.

Sample Problem

Find the volume of enclosure to be coupled to an inertance of 10^{-4} c.g.s. units (acoustic henry) so that the system will be in resonance at 100 cycles.

Solution

For the abscissa equal to 10^{-4}, find the intersection with the 100 cycle line and read the ordinate equal to 2,200 cu. ins.

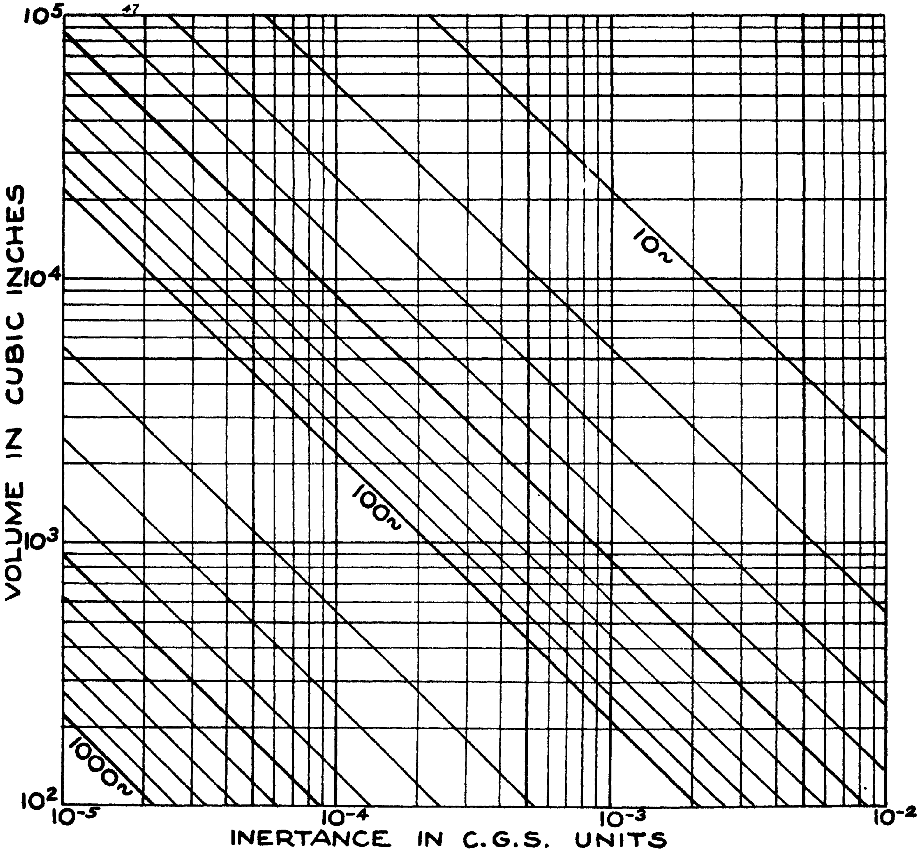


CHART NO. 47

Volume of enclosure required to resonate with various inertances at the various frequencies indicated by the family of curves.

Chart 48 shows the resonance frequency of an enclosed volume coupled to the atmosphere through a circular orifice whose diameter is large compared to the wall thickness. NOTE.—The largest linear dimension of the enclosure is small compared to the wavelength.

Sample Problem

Find the size hole to drill into the face of 10 inch cube so that a Helmholtz resonator will result that will be tuned to a frequency of 100 cycles.

Solution

At the abscissa equal to 100 cycles, find the intersection with the curve marked "IN" and read the ordinate on the left and find,

$$\frac{\text{Vol. in cu. ins.}}{\text{Orifice diam. in ins.}} = 470$$

$$\text{Diameter of hole} = \frac{\text{Vol.}}{470} = \frac{1{,}000}{470} = 2.14 \text{ inches}$$

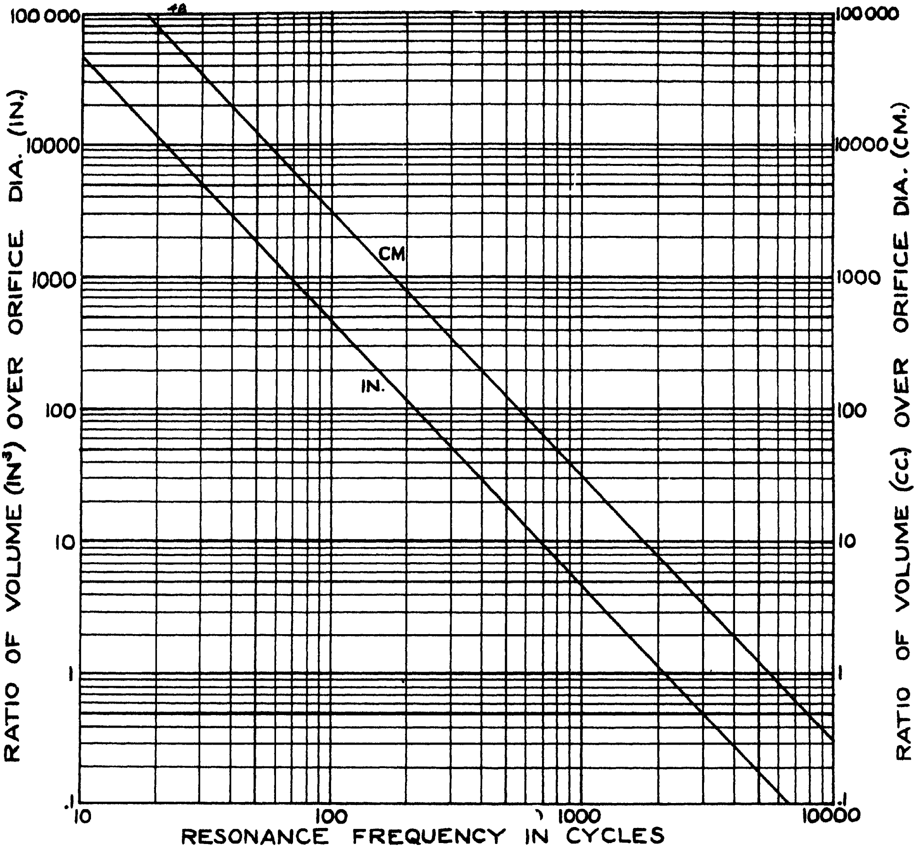


CHART NO. 48

Resonance frequency of an enclosed volume coupled to the atmosphere through a circular orifice whose diameter is large compared with the wall thickness. (The largest linear dimension of the enclosure is assumed small compared with the wavelength of sound at the frequency of operation.)

Chart 49 shows the pressure amplification (P_1/P_0) inside a Helmholtz resonator consisting of an enclosed volume coupled to the atmosphere through an orifice mounted in an infinite baffle. The values marked on the family of curves show the resonance frequency of the resonator and the ordinates show the volume of the resonator enclosure. The solid curves are accurate because the linear dimensions of the enclosure (assumed cubical) are smaller than $1/10$ the wavelength of sound at resonance. The dotted portions are approximate because the dimensions of the enclosure become larger and there is some phase variation through the region represented by the dotted curves.

Sample Problem

It is desired to build a resonator to work at 100 cycles and a pressure amplification of at least 100 times is required. Find the maximum volume of enclosure that can be used.

Solution

At the intersection of the 100 cycle curve with the abscissa $P_1/P_0 = 100$, find the volume = 10,000 cubic centimeters, which is the answer to the problem.

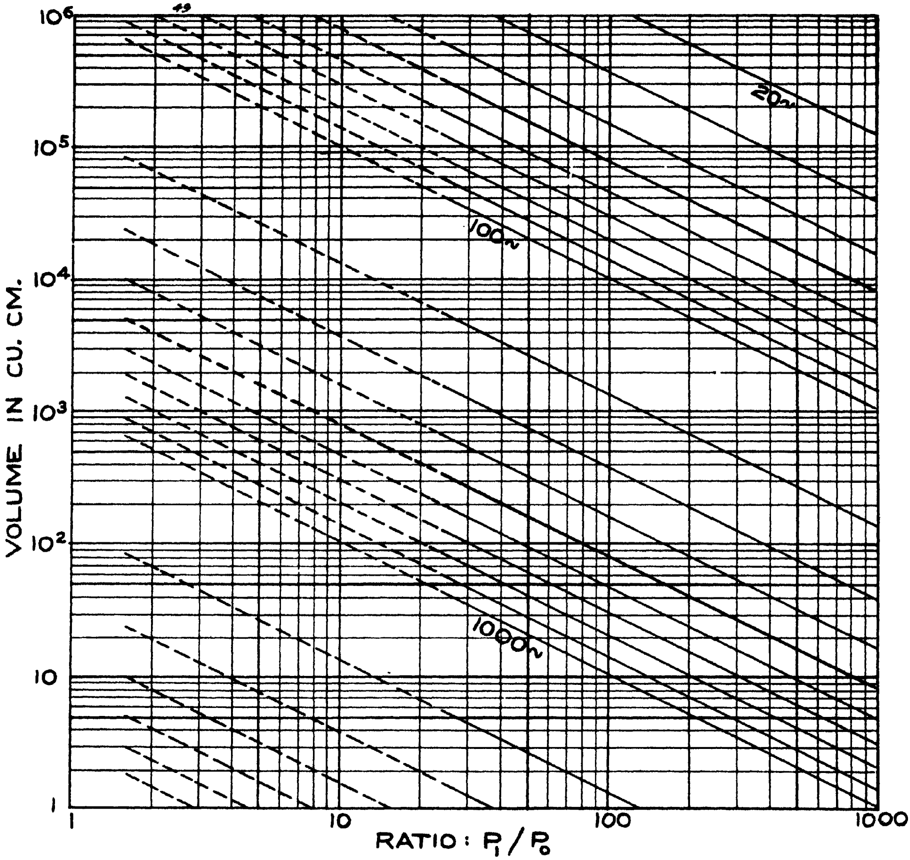


CHART NO. 49

Ratio of the pressure developed inside a Helmholtz resonator (P_1) to the free space pressure in the sound wave (P_0) as a function of the resonator volume at the various resonance frequencies indicated by the family of curves. Internal losses in the resonator have been assumed zero and the resonator opening has been assumed mounted in an infinite baffle. If no baffle is used, multiply pressure ratios by 2. The solid curves represent conditions in which the resonator volume is smaller than that of a cube whose side equals 1/10 of the wavelength of sound. The dotted portion stops at the left for volumes whose side of equivalent cube equals 1/4 wavelength.

Chart No. 50 shows the fundamental resonance of a tube closed on one end and open on the other. Three curves are shown on the chart so that the resonance frequencies may be found directly whether the tube length is expressed in feet, inches, or centimeters. The length of the tube is the effective length, which is the physical length plus the end correction. The end correction may be found on chart 38.

Sample Problem

Find the fundamental resonance of a pipe closed on one end and whose effective length is 5 ft.

Solution

On the left hand scale of the chart find the ordinate = 5 ft. and read the intersection with the curve marked "FT.," giving the fundamental resonance frequency = 55 cycles.

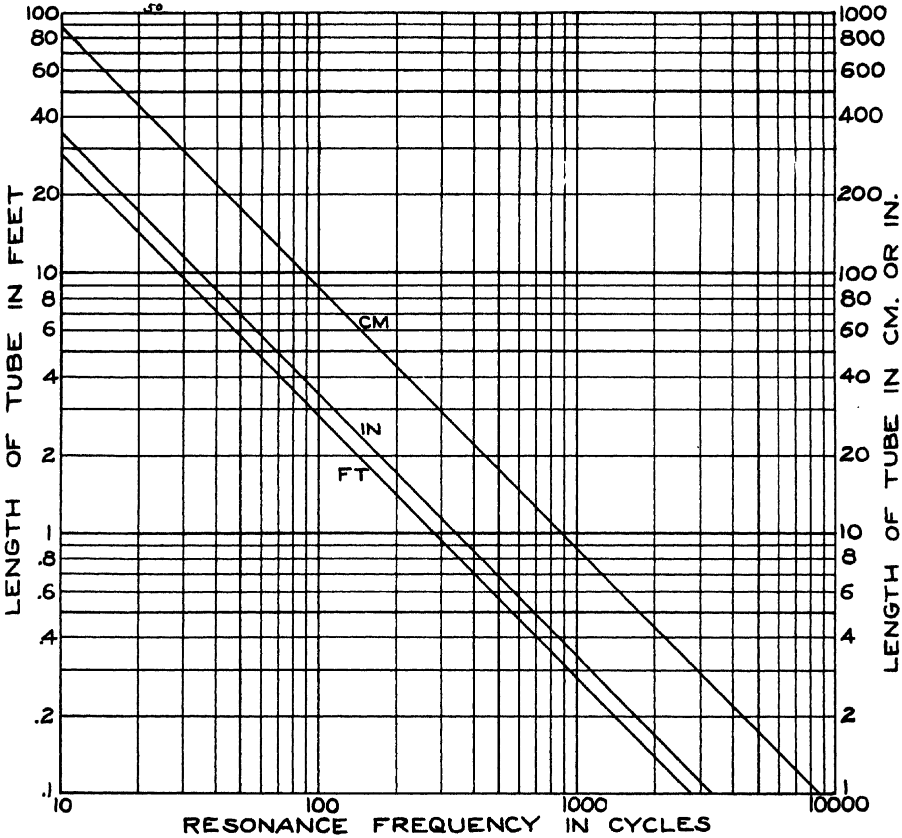


CHART NO. 50

Fundamental resonance frequency versus length for a tube closed on one end. Additional frequencies of resonance will occur at odd multiples of the values shown on the curves. The curves are computed for tubes whose lengths are large compared with the diameter. For shorter tubes, the length on the chart represents "effective length" (see chart No. 38).

Chart No. 51 shows the fundamental resonance of a tube open on both ends. Three curves are shown on the chart so that the resonance frequencies may be found directly whether the tube length is expressed in feet, inches, or centimeters. The length of the tube is the effective length, which is the physical length plus the end correction. The end correction may be found on chart 38.

Sample Problem

Find the fundamental resonance of a pipe open on both ends and whose effective length is 5 ft.

Solution

On the left hand scale of the chart find the ordinate = 5 ft. and read the intersection with the curve marked "FT.," giving the fundamental resonance frequency = 110 cycles.

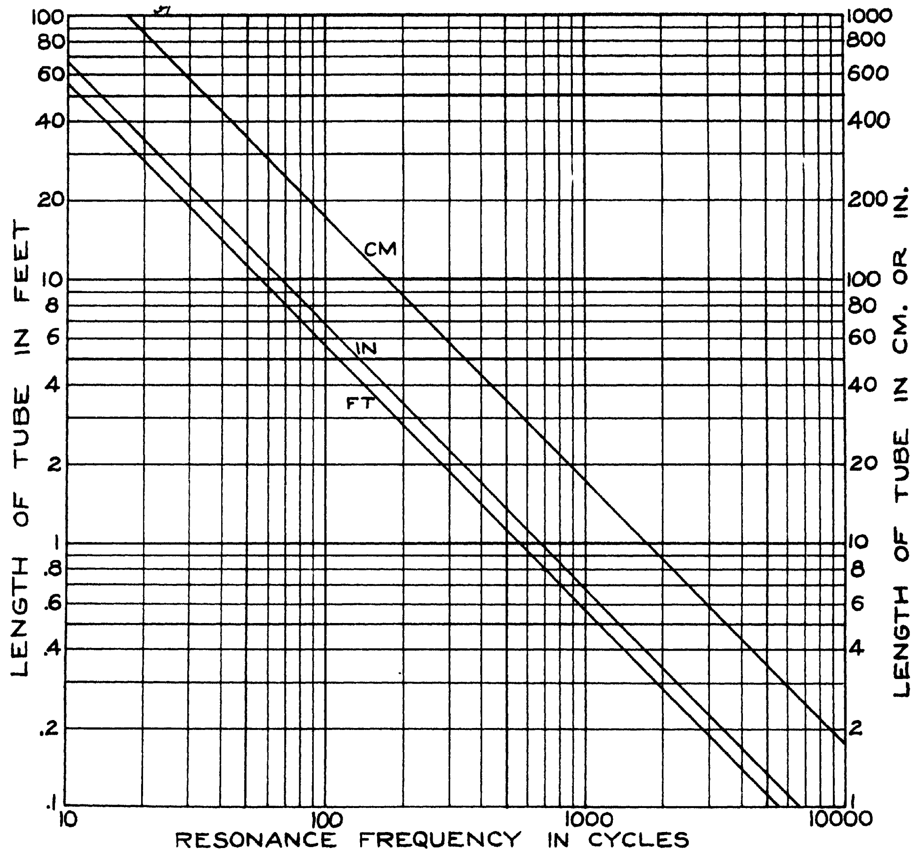


CHART NO. 51

Fundamental resonance frequency versus length for a tube open on both ends. Additional frequencies of resonance will occur at odd and even multiples of the values shown on the curves. The curves are computed for tubes whose lengths are large compared with the diameter. For shorter tubes, the length on the chart represents "effective length" (see chart No. 38).

SECTION 5

Radiation of Sound from Pistons (Direct Radiator Loud Speakers)

CHART 52. Radiation resistance of a vibrating piston mounted in an infinite baffle vs. piston diameter over wavelength.

CHART 53. Radiation resistance of a vibrating piston set in an infinite baffle vs. frequency.

CHART 54. Radiation resistance of a vibrating piston set in an infinite baffle vs. piston diameter.

CHART 55. Air load at low frequencies on a vibrating piston set in an infinite baffle vs. piston diameter.

CHART 56. Reduction of air load at high frequencies on vibrating pistons vs. piston diameter over wavelength.

CHART 57. Ratio of radiation reactance to resistance on a vibrating piston set in an infinite baffle vs. piston diameter over wavelength.

CHART 58. Inertance of pistons vs. piston mass and piston diameter.

CHART 59. Resonance frequencies of pistons coupled to enclosed air chambers.

CHART 60. Relative acoustic power output of a mass controlled piston mounted in an infinite baffle and driven by a constant force vs. piston diameter over wavelength.

CHART 61. Acoustic watts output of vibrating pistons mounted in an infinite baffle vs. peak amplitude and piston diameter.

CHART 62. Sound pressure at various distances from a piston source radiating into semi-infinite space vs. peak amplitude, piston diameter and frequency.

CHART 63. Sound pressure at various distances from a small source radiating into semi-infinite space vs. acoustic power output of the source.

CHART 64. Peak amplitude necessary for a vibrating piston to radiate one acoustic watt vs. piston diameter and frequency.

Chart 52 shows the radiation resistance per unit area of a circular piston mounted in an infinite baffle and radiating sound into free space at 20 deg. C. and 760 mm. pressure. The abscissa is the ratio of piston diameter over wavelength of sound.

To obtain the radiation resistance in mechanical ohms multiply the value on the chart by the area of the surface in sq. cms. To obtain the resistance in acoustic ohms, divide the value on the chart by the area of the surface in sq. cms.

Sample Problem

Find the radiation resistance on one side of a circular piston 8 ins. diameter, mounted in an infinite baffle and operating at 100 cycles.

Solution

From chart 1, the wavelength at 100 cycles = 135″. The ratio of diameter to wavelength for the problem = $8/135$ = .0593. For the value of abscissa = .0593 find the radiation resistance equal to about .7 ohm per sq. cm. of piston area. Area of 8″ piston = 320 sq. cms., therefore, the radiation resistance on oneside of the vibrating piston is

$$R_M = .7 \times 320 = 224 \text{ mechanical ohms.}$$

or $$R_A = .7/320 = .00219 \text{ acoustic ohms.}$$

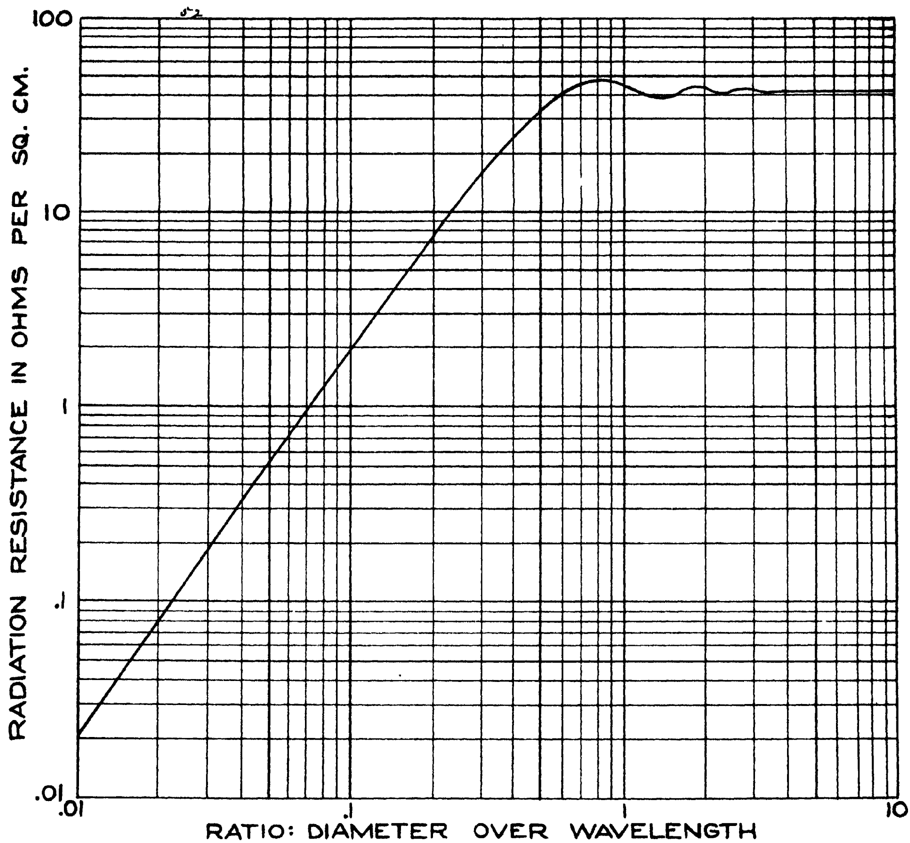


CHART NO. 52

Radiation resistance in air per unit area of a circular piston mounted in an infinite baffle as a function of piston diameter and wavelength of sound being radiated. (To obtain total radiation resistance of piston in mechanical ohms multiply total radiating surface by the value on curve. To obtain radiation resistance in acoustic ohms divide value on curve by the total radiating surface of piston.)

Chart 53 shows the radiation resistance in acoustic ohms acting on one side of a circular piston which is mounted in an infinite baffle and radiating sound into free space at 20 deg. C. and 760 mm. pressure. The chart holds for piston diameters less than one half wavelength of sound being radiated.

Note that the acoustic resistance is independent of the size of the piston in the region where its diameter is less than one half wavelength. The acoustic resistance merely depends on frequency. (See chart 54 for the relation which holds for the region where the piston diameter is greater than one half wavelength.)

Sample Problem

Find the acoustic resistance at 100 cycles and 1,000 cycles on one side of a circular piston mounted in an infinite baffle and radiating low frequencies (diam. less than ½ wavelength of sound).

Solution

At 100 cycles, find the acoustic resistance from the chart = .0022 acoustic ohm.

At 1000 cycles the radiation resistance = .22 acoustic ohm.

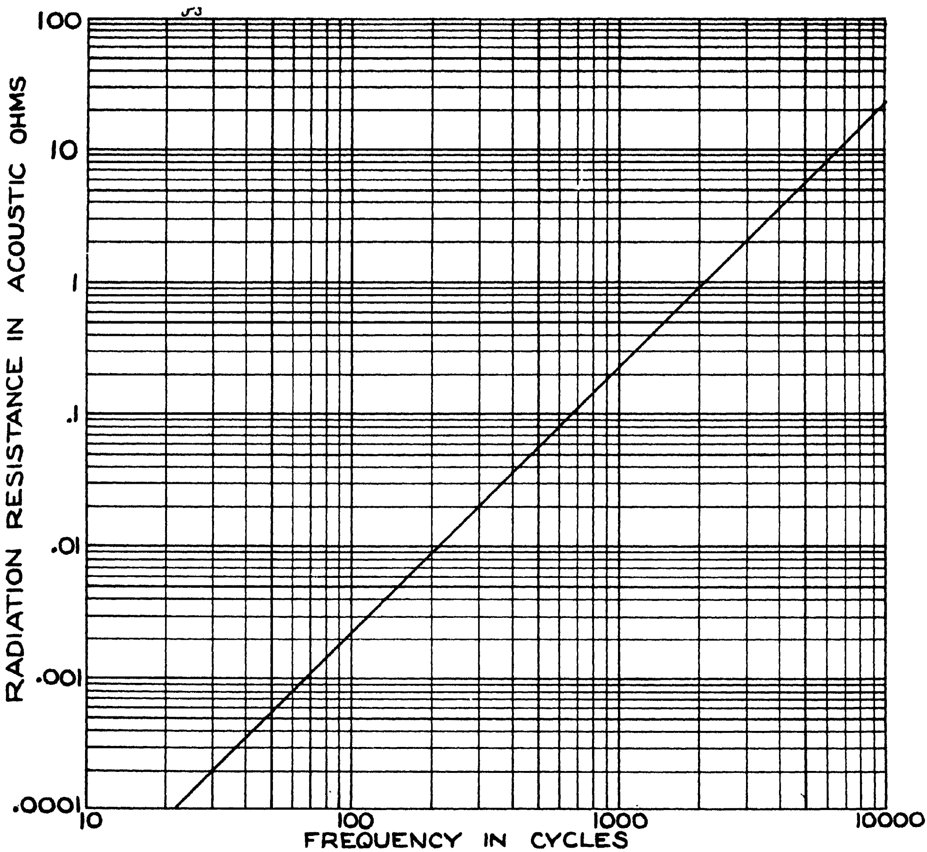


CHART NO. 53

Radiation resistance versus frequency on one side of a circular piston mounted in an infinite baffle in air. Diameter of piston is less than ½ wavelength of sound being radiated.

Chart 54 shows the radiation resistance in acoustic ohms acting on one side of a circular piston which is mounted in an infinite baffle and radiating sound into free space at 20 deg. C. and 760 mm. pressure. The chart holds for piston diameters greater than one half the wave length of sound being radiated.

Note that the acoustic resistance is independent of frequency in the region where its diameter is greater than one half wavelength. The acoustic resistance depends merely on the piston diameter. (See chart 53 for the relation which holds in the range where the piston diameter is less than one half wavelength.)

Sample Problem

Find the radiation resistance on one side of a 10 inch diameter piston operating at high frequencies such that the piston diameter is less than one half the wavelength of sound.

Solution

For a piston diameter = 10 inches, read the ordinate = .08 acoustic ohm which is the acoustic resistance due to radiation of sound on one side of the piston.

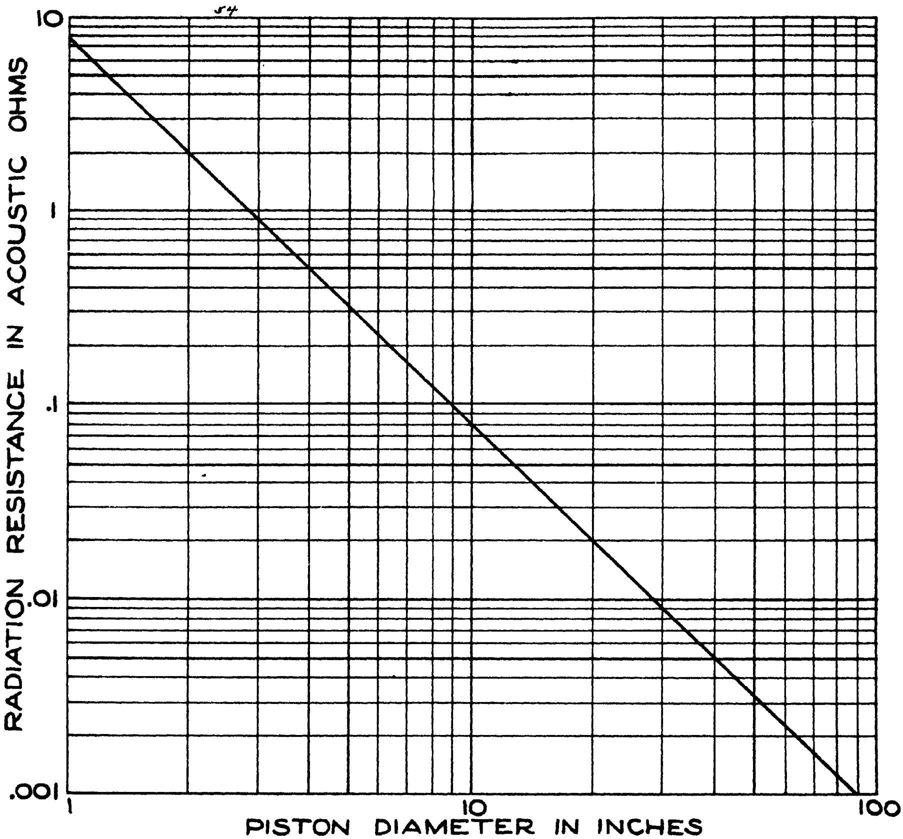


CHART NO. 54

Radiation resistance on one side of a circular piston mounted in an infinite baffle in air versus piston diameter at high frequencies. (Piston diameter is greater than ½ wavelength of sound.)

Chart 55 shows the load contributed to the mass of a piston due to the inertia of the air which must be set into motion by the vibrating piston. The air load shown in the chart has been computed for low frequencies (piston diameter less than .2 wavelength of sound). The piston is mounted in an infinite baffle and is radiating freely from both sides. If only one side of the piston is radiating into free space (the opposite side terminated into an infinite pipe, for example) the air load is one half the value shown on the curve.

Note that the air load is independent of frequency so long as the piston diameter is less than .2 wavelength at the frequency being radiated. (See chart 56 for the amount of reduction in air load at the higher frequencies.)

Sample Problem

Find the total air load on both sides of a circular piston, 8 inches diameter, operating at low frequencies. (Piston diameter is less than .2 wavelength of sound.)

Solution

Diameter of piston = 8 ins. = 20.3 cms.

For diameter = 20.3 cms. find the value of air load from the chart = 6.6 grams.

(If only one side of the diaphragm were radiating into free space, the air load would have been 3.3 grams.)

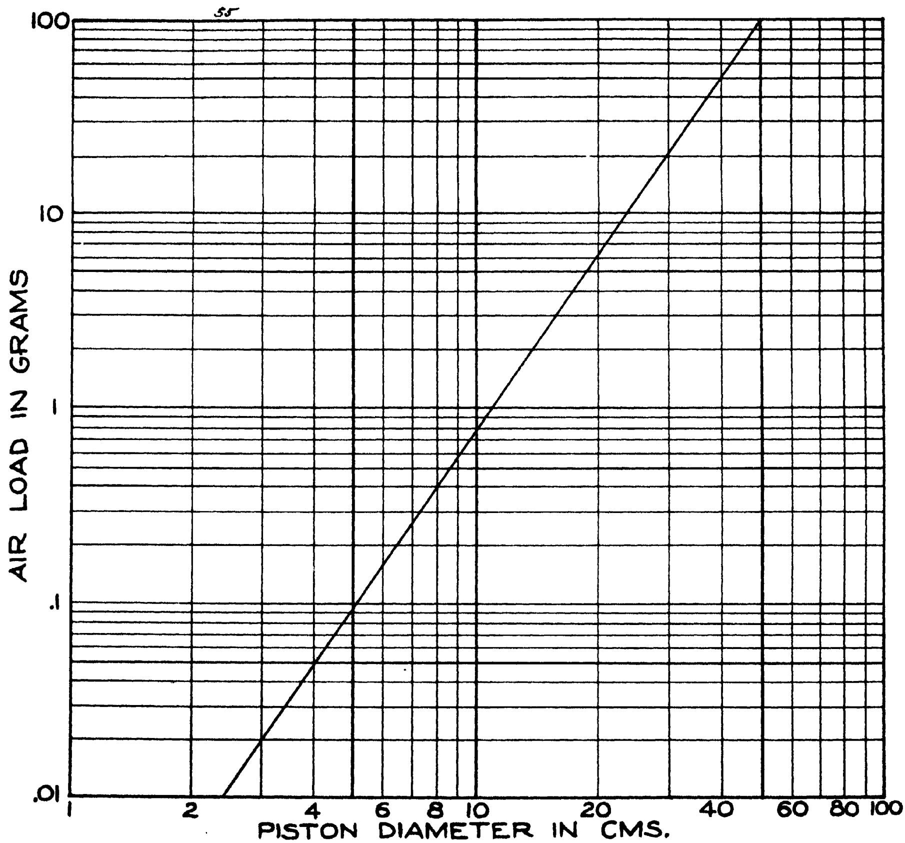


CHART NO. 55

Total mass contributed by the inertia of the air on a vibrating piston set in an infinite baffle (both sides of piston radiating). If one side of piston is enclosed so that only one surface radiates from the infinite baffle, divide ordinates by 2. The above data apply only at low frequencies (diameter of piston less than ⅔₀ the wavelength of sound). For higher frequencies multiply ordinates by the factor shown on chart No. 56.

Chart 56 shows the relative air load on a vibrating piston as the frequency is increased. At low frequencies (D/λ less than .2) the air load in grams on various size pistons are given on chart 55. As the frequency increases (D/λ increases) the value of air load shown on chart 55 is to be multiplied by the factor obtained on this chart.

Sample Problem

Find the air load on the 8 inch piston given in the problem illustrating the use of chart 55 if the piston frequency is raised to 3,400 cycles.

Solution

From the problem given with chart 55, the air load on both sides of the 8 inch piston at low frequencies = 6.6 grams.

From chart 1, the wavelength for 3,400 cycles = 4 inches; therefore, $D/\lambda = 8/4 = 2$.

For $D/\lambda = 2$, find the reduction factor from this chart = .019.

The air load on the piston at 3,400 cycles is $6.6 \times .019 = .125$ gram.

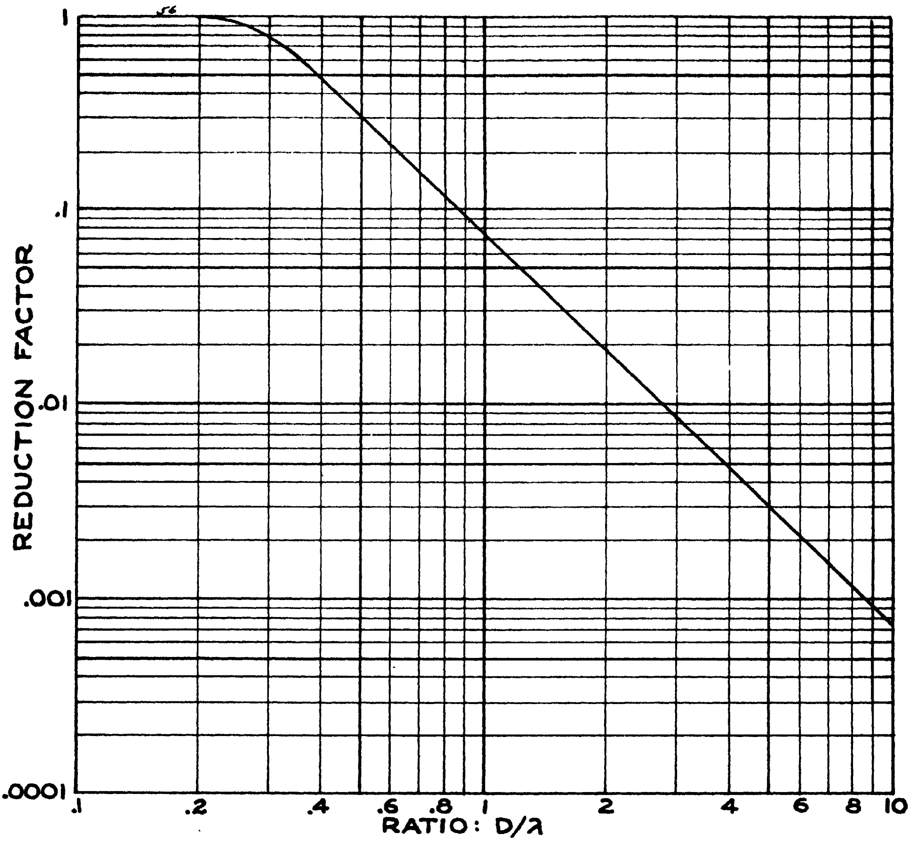


CHART NO. 56

Reduction in the air load on a vibrating piston at increasing frequencies. D = diameter of piston and λ = wavelength of sound in the same units. Note: An average smooth curve has been drawn rather than attempting to show the small variations in the function.

Chart 57 shows the ratio of acoustic or mechanical reactance to resistance (X/R) due to the air load on a circular piston or orifice which is mounted in an infinite baffle and is radiating sound into free space from either one or both sides of the piston or orifice. NOTE.—The mass of the piston is assumed negligible compared to the mass contributed by the air load. If such is not the case (see charts 55 and 56 for the mass due to air load) the values of X/R obtained from the chart should be multiplied by the ratio of $\frac{\text{piston mass} + \text{air load mass}}{\text{air load mass}}$.

Sample Problem

Find the ratio X/R of the impedance components due to radiation from a circular orifice having a 2.7″ diameter and mounted in an infinite baffle. Frequency of radiation = 100 cycles.

Solution

From chart 1 the wavelength at 100 cycles = 135″.

The ratio $\frac{D}{\lambda}$ for the orifice $= \frac{2.7}{135} = .02$.

For the abscissa = .02, find the ratio X/R from the curve = 27. This indicates that the radiation impedance on a small circular hole is mostly reactive at the low frequencies.

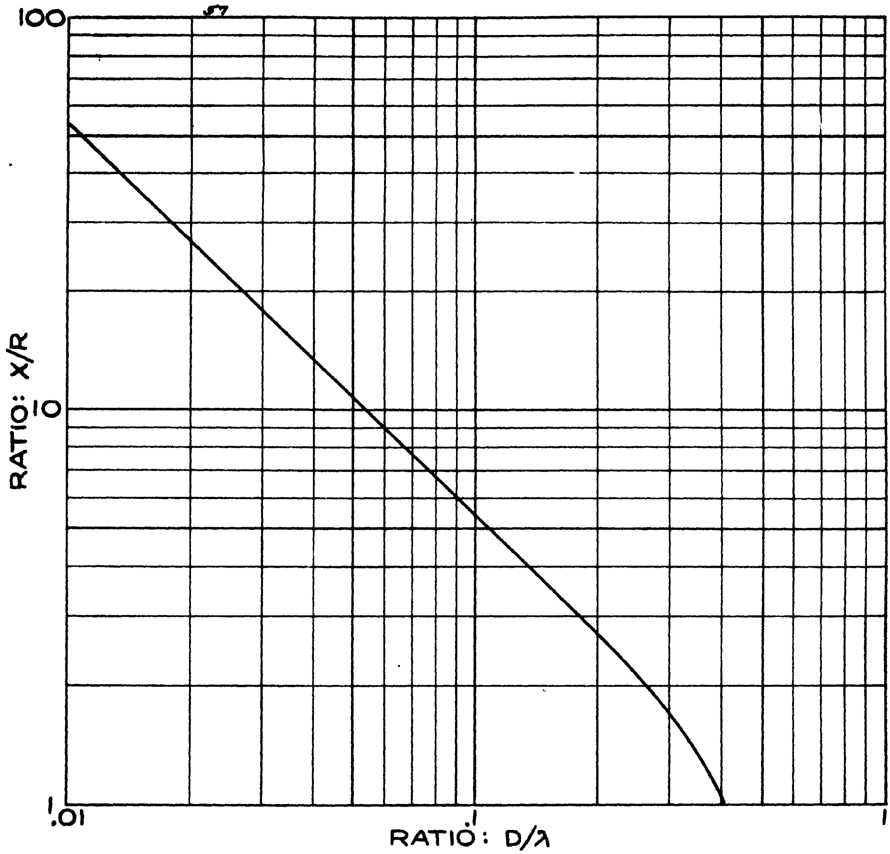


CHART NO. 57

Ratio of mechanical or acoustic reactance (X) to resistance (R) due to radiation on one side of a piston or orifice mounted in an infinite baffle. D = piston or orifice diameter. λ = wavelength of sound.

Chart 58 shows the inertance of vibrating circular pistons as a function of the piston mass and piston diameter. The numbers on the family of curves indicate the piston diameter in inches and the abscissa is the effective piston mass in grams. NOTE.—The effective mass of the piston is the actual mass of the piston plus the mass of air which it carries along as it vibrates. The mass component due to the air load may be obtained from charts 55 and 56.

The inertance is that quantity which when multiplied by $2\pi \times$ frequency gives the magnitude of the positive reactance of the vibrating piston in acoustic ohms.

Sample Problem

Find the acoustic reactance at 100 cycles of a freely suspended piston (negligible stiffness at the point of suspension) which is mounted in an infinite baffle. Piston diameter = 5 inches and its effective mass is 3 grams.

Solution

At the intersection of the abscissa = 3 grams with the curve marked 5 inches, read the inertance = 1.9×10^{-4} c.g.s. units. At 100 cycles, the acoustic reactance of the vibrating piston is,

$$X_A = 2\pi \times 100 \times 1.9 \times 10^{-4} = .12 \text{ acoustic ohms.}$$

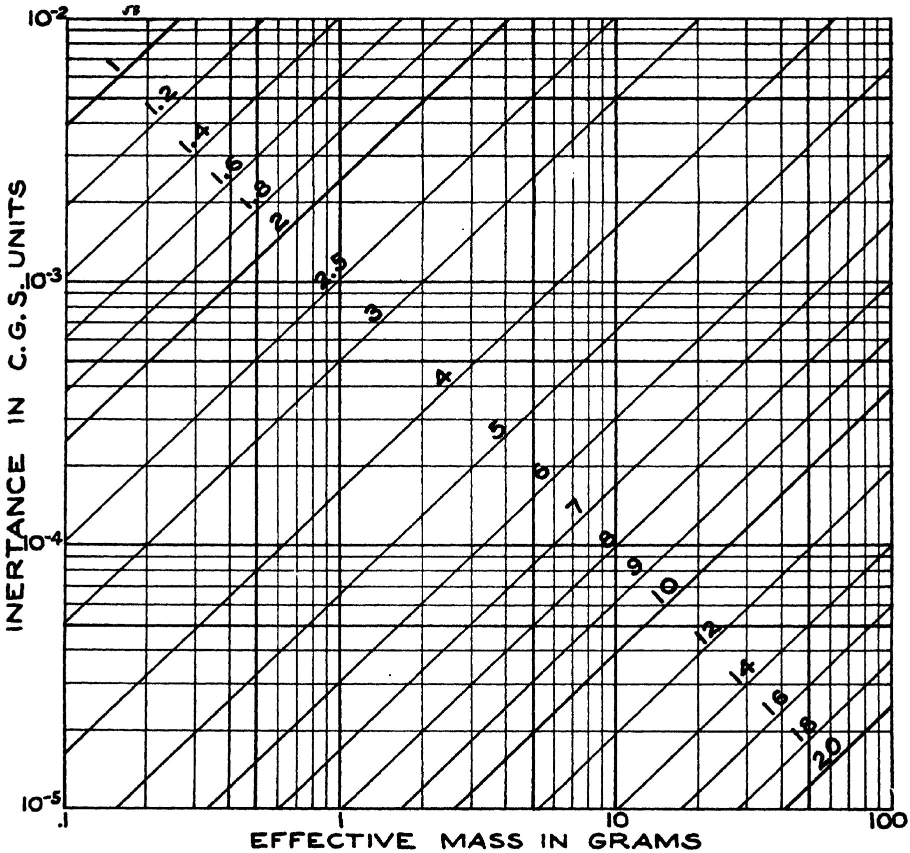


CHART NO. 58

Inertance versus mass of vibrating circular pistons of the various diameters in inches shown by the family of curves.

Chart 59 shows the volume of enclosure required behind a vibrating piston in order to resonate the system at 100 cycles. The effective piston mass is plotted as the abscissa and the numbers on the family of curves indicate the diameter of the piston in inches. The effective piston mass = mass of piston + air load (see chart 55 for determination of air load). The stiffness of the piston mounting is assumed negligible compared to the stiffness of the enclosed volume of air. To find the volume that will resonate at another frequency, f, multiply the ordinates by $10^4/f^2$. The maximum linear dimension of the enclosure should not exceed ¼ wavelength at the desired frequency of resonance in order to insure approximately constant phase of the sound pressure throughout the enclosure.

Sample Problem

Find the volume of enclosure required behind a 8″ piston having an effective mass of 20 grams in order to resonate the system at 200 cycles.

Solution

At the intersection of the abscissa = 20 grams with the curve marked 8 inches, find the required volume to resonate at 100 cycles = 1,150 cu. ins. At 200 cycles, the volume required is

$$V = 1{,}150 \times \frac{10^4}{(200)^2} = 290 \text{ cu. in.}$$

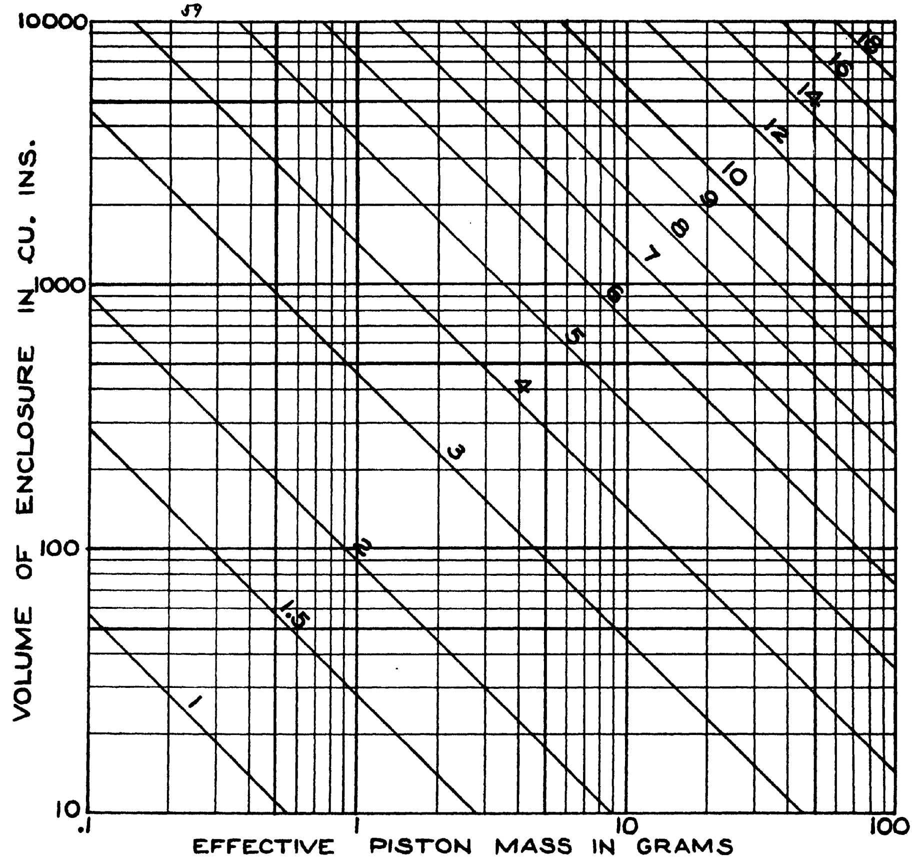


CHART NO. 59

Volume of enclosure required behind a vibrating piston, of an effective mass shown by the abscissa, to resonate at a frequency of 100 cycles. Piston diameter in inches is marked on each curve. Note: To find volume that will resonate at any other frequency, f, multiply the ordinates by $10^4/f^2$.

Chart 60 shows the relative acoustic power output of a mass controlled circular piston set in an infinite baffle and driven with a constant force. The abscissa is the ratio of piston diameter to the wavelength of sound being generated.

Sample Problem

An 8 inch diameter piston which is predominantly mass reactance over its frequency range is driven by a constant mechanical force. If its power output at low frequencies = 2 watts, find the power output at 3,440 cycles.

Solution

At 3,440 cycles the wavelength of sound (see chart 1) = 4 inches; therefore, $D/\lambda = 8/4 = 2$.

For $D/\lambda = 2$, find the relative acoustic power output = .052.

The acoustic power output at 3,440 cycles equals $.052 \times 2 = .104$ acoustic watt.

Note that in a mass controlled vibrating system driven by a constant force the radiated power falls off rather fast when the piston diameter becomes greater than one half wavelength of sound being generated.

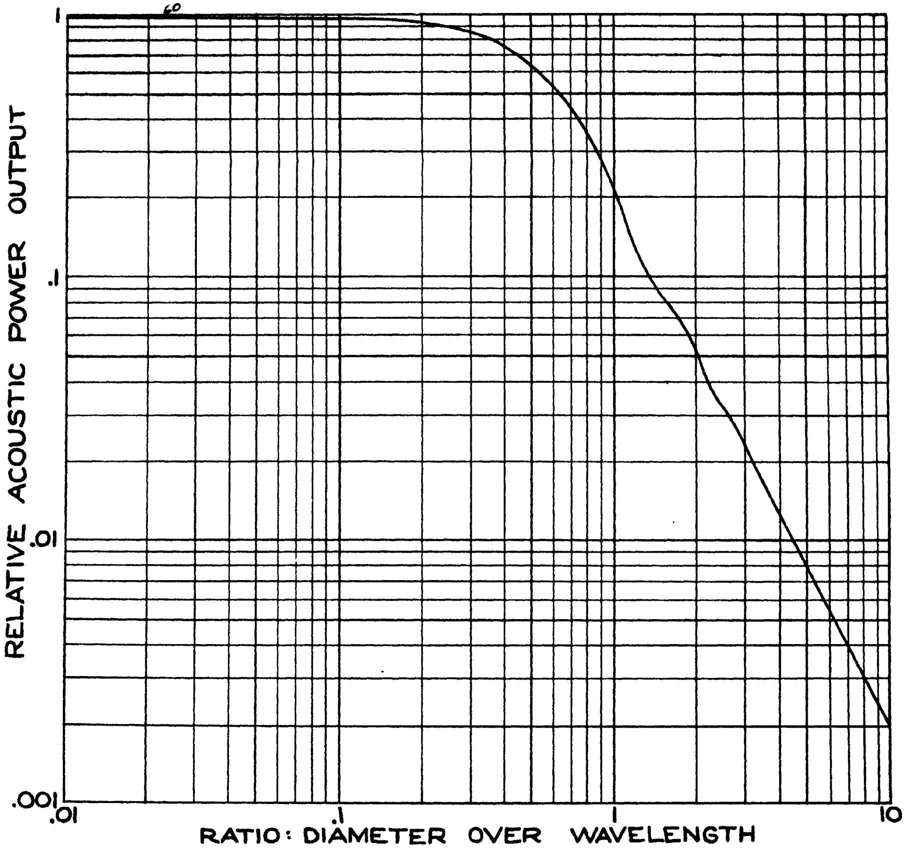


CHART NO. 60

Relative acoustic power output of a mass controlled circular piston set in an infinite baffle and driven with a constant force as a function of piston diameter and wavelength of sound being radiated.

Chart 61 shows the root mean square acoustic power in watts radiated from one side of a circular piston mounted in an infinite baffle as a function of the peak amplitude of vibration. The numbers on the family of curves indicate the product of the piston diameter in inches times the frequency of vibration in cycles. NOTE.—The curves hold for all ratios of piston diameter to wavelength of sound being radiated.

Sample Problem

Find the necessary piston diameter to radiate 5 acoustic watts of power from one side of the piston at 200 cycles if the maximum allowable peak travel of the piston from its normal position of rest = .1 inch. The piston is mounted in an infinite baffle.

Solution

At the intersection of the abscissa = .1 inch with the ordinate = 5 acoustic watts, find the product of piston diameter times frequency = 1,600. Since the frequency = 200 cycles, piston diameter = $\frac{1{,}600}{200} = 8$ inches.

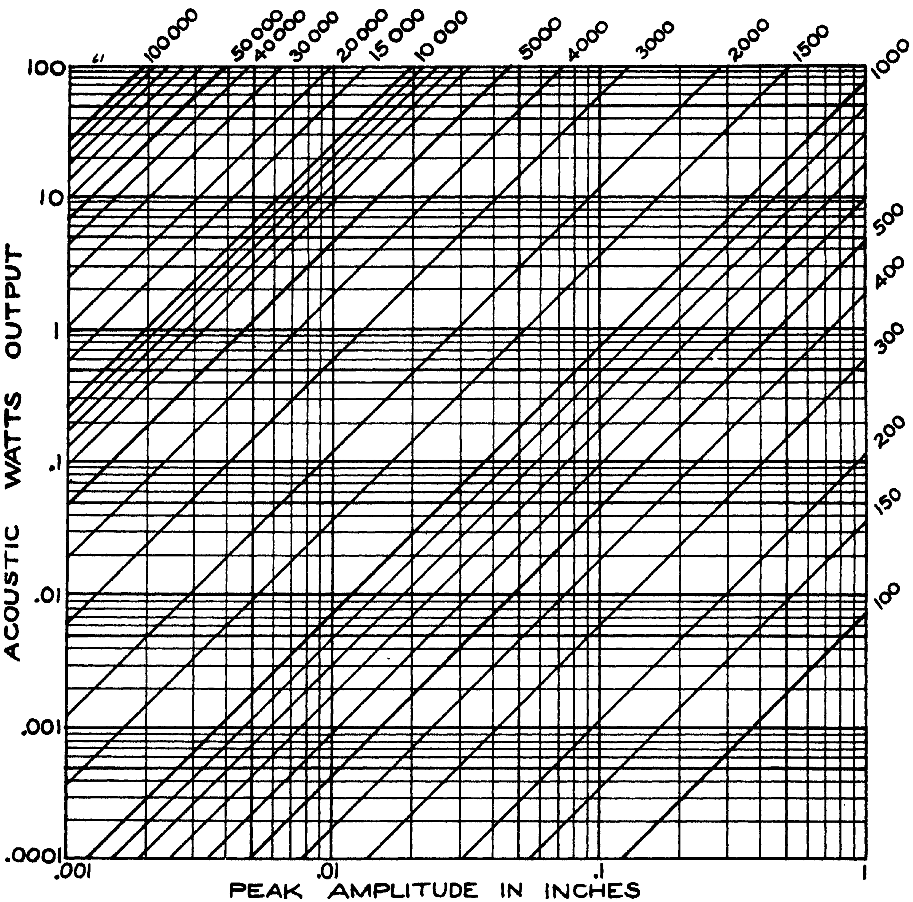


CHART NO. 61

Acoustic watts output in air as a function of the peak amplitude (from position of rest) of various pistons radiating into semi-infinite space. The number on each curve indicates the product of the piston diameter in inches by the frequency of vibration in cycles per second.

Chart 62 shows the r.m.s. sound pressure developed in air at various distances from a small source of sound radiating into semi-infinite space. The curves apply for piston diameters less than ¼ wavelength of the sound being radiated. The numbers on the family of curves indicate the product of the piston diameter in inches by the frequency of vibration in cycles.

Sample Problem

Find the sound pressure at a distance of 20 ft. from an 8 inch piston mounted in an infinite baffle and vibrating through a peak amplitude of .050″ at 100 cycles.

Solution

For an 8 inch piston at 100 cycles, the product of diameter $\times$ frequency = 800. At the intersection of the abscissa = .050″ with the curve labeled 800 read the ordinate (sound pressure $\times$ distance in ft.) = 71. At a distance of 20 ft., the sound pressure is equal to,

$$p = \frac{71}{20} = 3.6 \text{ dynes/cm.}^2$$

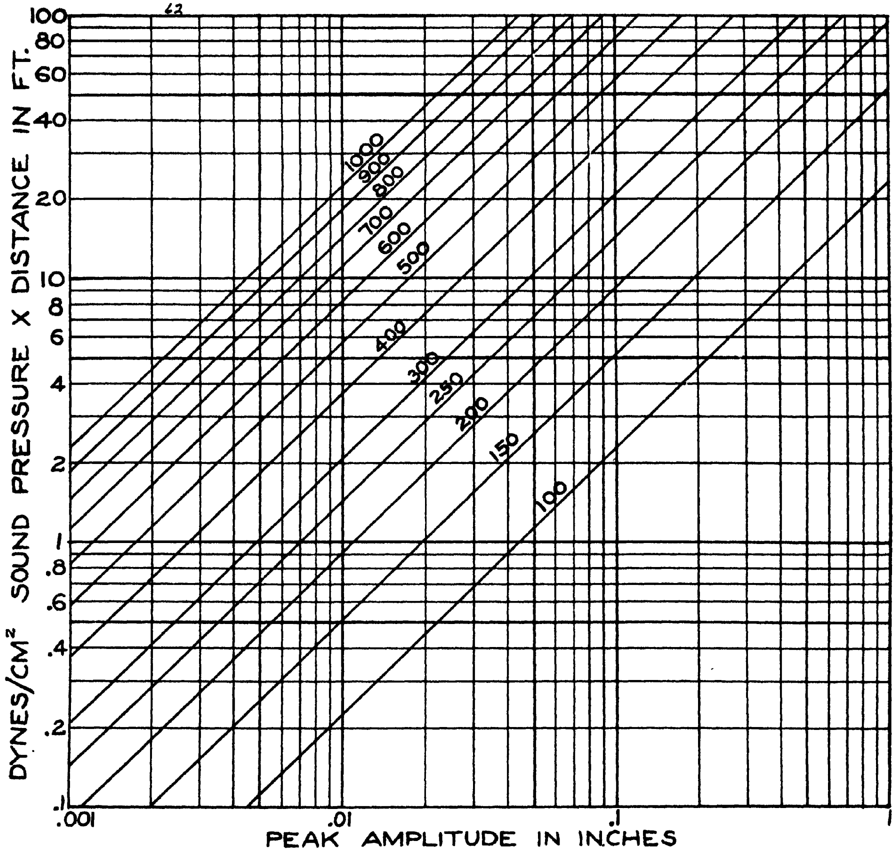


CHART NO. 62

Sound pressure developed in air at various distances from a small piston source radiating into semi-infinite space as a function of the peak amplitude of the piston. The number on each curve represents the product of the piston diameter in inches by the frequency of vibration in cycles per second.

Chart 63 shows the sound pressure at various distances from a small sound source as a function of acoustic power radiated from the source. The numbers on the curves indicate the distances from the source in feet. The source is assumed to be radiating into a semi-infinite medium (one side of an infinite baffle) and its size is small enough compared to the wavelength so that the directional radiation is independent of the angle off the normal axis of the sound source. (This condition will be approximately satisfied if the diameter of the source is not greater than $2/10$ the wavelength of sound being radiated.) If the sound source is larger, the pressure on the axis is increased over the value shown on this chart by the factor shown on chart 69.

Sample Problem

Find the acoustic power output required from a small sound source in order to generate a sound pressure of 10 dynes per sq. cm. at a distance of 10 feet from an infinite baffle in which the source is mounted.

Solution

At the intersection of the ordinate = 10 dynes/cm.^{2}, with the curve marked 10 ft., find the acoustic power required on the abscissa = .14 watts.

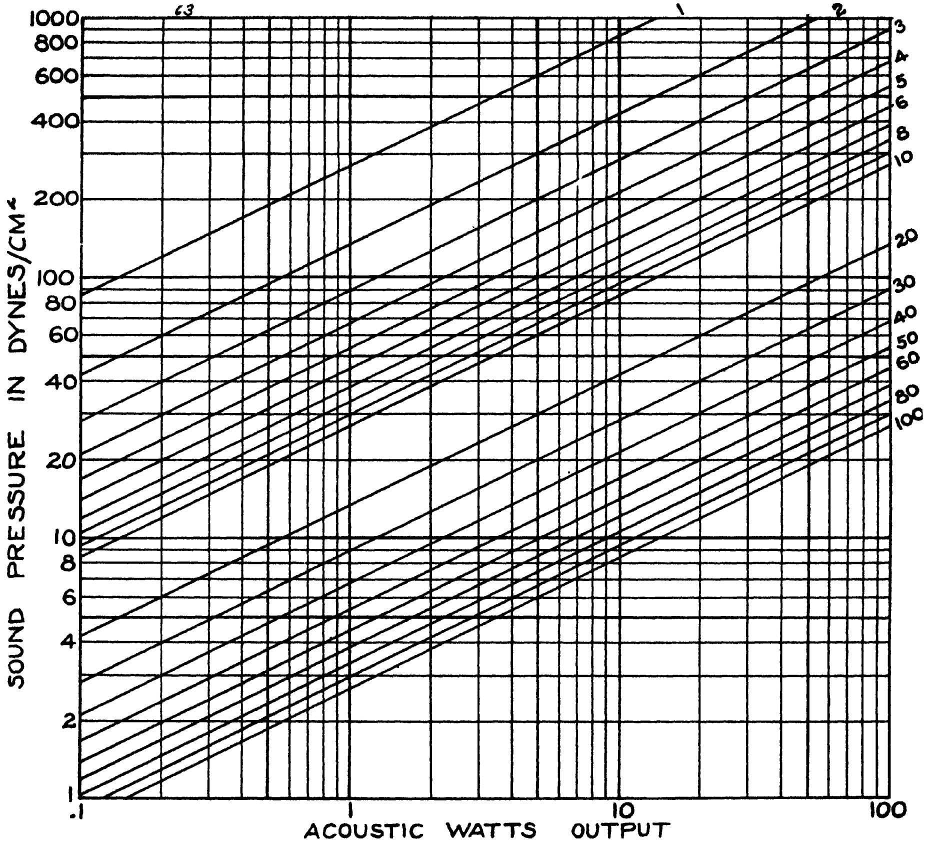


CHART NO. 63

Sound pressure at various distances from a small source which is radiating into semi-infinite space as a function of the power output of the source. The number on each curve indicates the distance from the source in feet.

Chart 64 shows the necessary peak amplitude (from position of rest) required of a circular piston mounted in an infinite baffle, to radiate one acoustic watt (root mean square) of sound from one of its surfaces. The peak amplitudes in inches are marked on the family of curves. For any other value of acoustic power output, P, multiply the amplitude obtained from the chart by $\sqrt{P}$.

Sample Problem

Find the peak amplitude necessary for a 10 inch piston mounted in an infinite baffle in order for it to radiate 2 acoustic watts from one of its sides at a frequency of 200 cycles.

Solution

At the intersection of the abscissa = 200 cycles with the ordinate piston diameter = 10 inches, find the necessary peak amplitude = .029 inch to radiate 1 acoustic watt. To radiate 2 watts, the peak amplitude required is equal to,

$$A = .029\sqrt{2} = .041 \text{ inch}$$

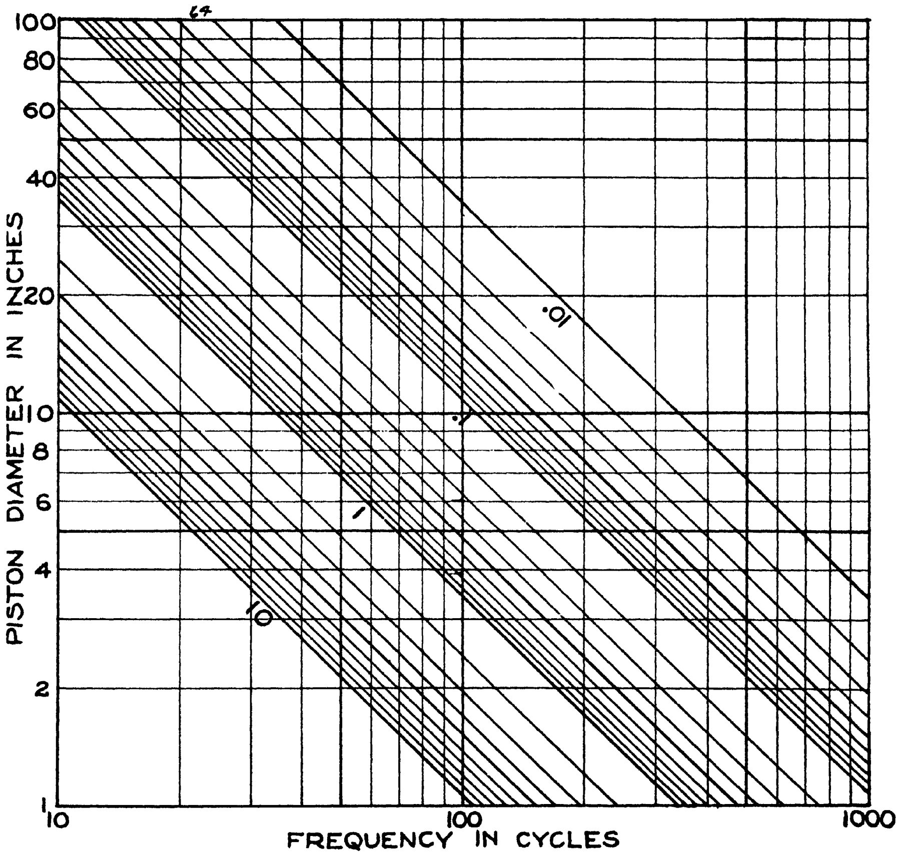


CHART NO. 64

Necessary peak amplitude of a piston, mounted in an infinite baffle, to radiate one acoustic watt of sound power at various frequencies (one side of piston radiating). Peak amplitudes in inches are marked on the family of curves. For any other value of acoustic power output, P, multiply peak amplitude by $\sqrt{P}$.

SECTION 6

Directional Radiation Characteristics

Chart 65 shows the directional radiation characteristics of circular pistons mounted in an infinite baffle for the various ratios of piston diameter to wavelength of sound being radiated marked on the family of curves.

Sample Problem

Find the loss in response between the normal axis of a piston and an axis 45° off the normal, when the piston diameter = ¾ wavelength of sound being radiated.

Solution

On the curve marked .75 read the intersection with the angle 45° and find the response equals 68% of the response on the normal axis. This shows a loss of 32% at 45° as compared to the pressure response "head on."

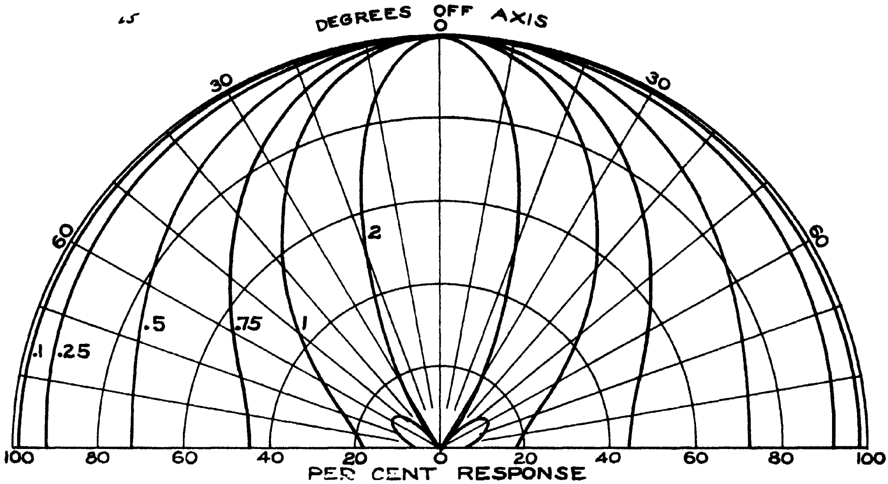


CHART NO. 65

Directional radiation characteristics of circular piston mounted in an infinite baffle for the various ratios of piston diameter to wavelength of generated sound marked on the curves.

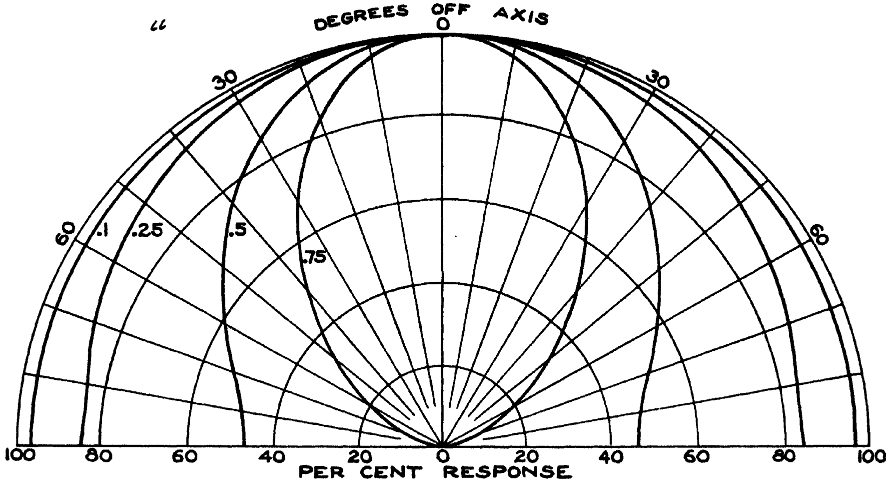
Chart 66 shows the directional radiation characteristics of circular rings mounted in an infinite baffle for the various ratios of ring diameter to wavelength of sound being radiated by the ring. The width of the ring is assumed small compared to its diameter.

Sample Problem

Find the loss in response between the normal axis of a ring mounted in an infinite baffle and an axis 45° off the normal, when the piston diameter = ¾ wavelength of sound being radiated.

Solution

On the curve marked .75 read the intersection with the angle 45° and find the response = 40% of the response on the normal axis. This shows a loss of 60% at 45° as compared to the "head on" response. (Compare this loss with a loss of 32% in the case of the piston having the same diameter on chart 65, which indicates how much sharper the radiation from a ring is as compared to a piston.)



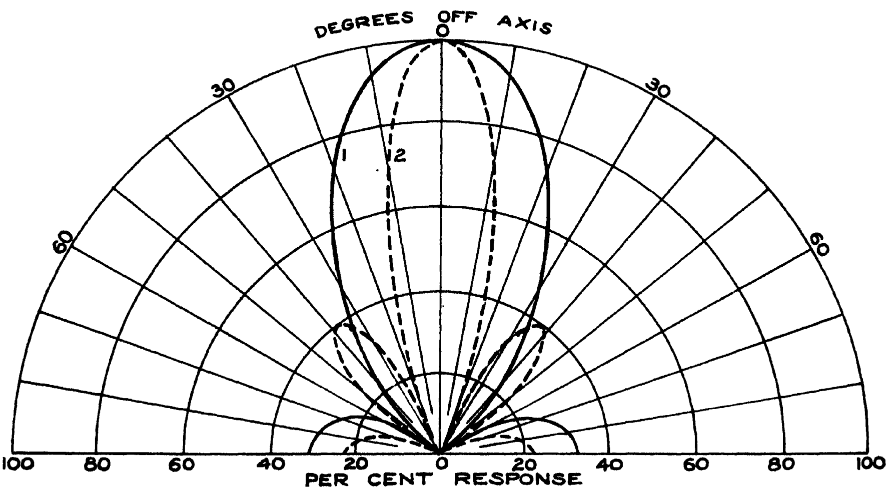


CHART NO. 66

Directional radiation characteristics of a thin circular ring mounted in an infinite baffle for the various ratios of ring diameter to wavelength of generated sound marked on the curves.

Chart 67 shows the directional radiation characteristics of circular pistons mounted in an infinite baffle. The abscissa shows the ratio of piston diameter over wavelength and the ordinates are the degrees off the normal axis of the piston. The family of curves marked in db. show the relation between piston size and the angle off the normal axis for the sound to be attenuated 20, 10, 6 and 3 db. from the sound on the normal axis. (See chart 68 for a similar set of data applying to rings.)

Sample Problems

Find the size of piston necessary to radiate 1400 cycles in the form of a beam such that the response is attenuated 10 db. at an angle of 10° off the normal axis of the radiator.

Solution

For the ordinate marked 10°, find the intersection with the curve labeled 10 db. and read the abscissa as piston diameter over wavelength = 5. From chart 1 find wavelength for 1,400 cycles = 10 inches. Therefore, the necessary piston diameter is equal to $5 \times 10 = 50$ inches.

NOTE.—See problem on chart 68 to compare the required ring diameter for the same sharpness of beam.

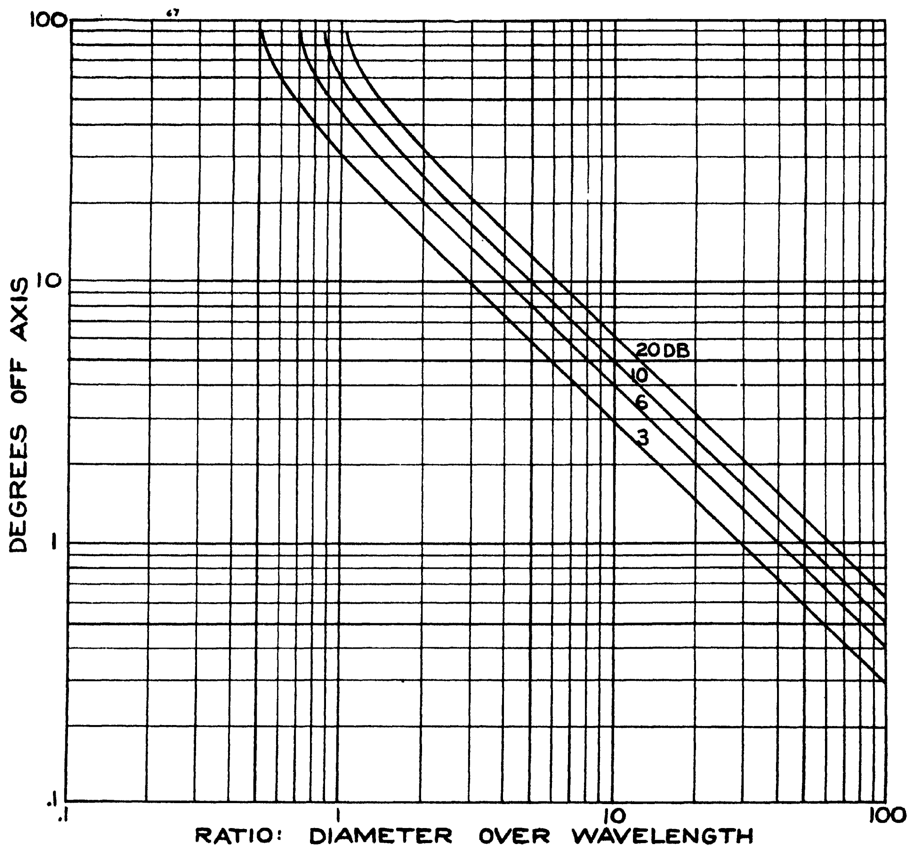


CHART NO. 67

Directional radiation characteristic of a circular piston mounted in an infinite baffle. Showing the degrees off the normal axis at which the attenuation is 3, 6, 10, and 20 db. (as marked on curves) as a function of the ratio of the piston diameter over wavelength of the generated sound wave.

Chart 68 shows the directional radiation characteristics of circular rings mounted in an infinite baffle. The rings are narrow compared to the diameter. The abscissa shows the ratio of ring diameter over wavelength and the ordinates are the degrees off the normal axis of the ring. The family of curves marked in db. show the relation between ring diameter and angle off the normal axis for the sound to be attenuated 20, 10, 6 and 3 db. from the sound on the normal axis. (See chart 67 for similar data applying to pistons.)

Sample Problem

Find the size of thin ring necessary to radiate 1,400 cycles in the form of a beam such that the response is attenuated 10 db. at an angle of 10° off the normal axis of the radiator.

Solution

From the ordinate marked 10°, find the intersection with the curve labeled 10 db and read the abscissa as ring diameter over wavelength = 3.3. From chart 1, find the wavelength at 1,400 cycles = 10 inches. Therefore, the necessary ring diameter is equal to $3.3 \times 10 = 33$ inches

Note.—Compare this with the problem on chart 67 which shows the size piston necessary to meet the same requirements.

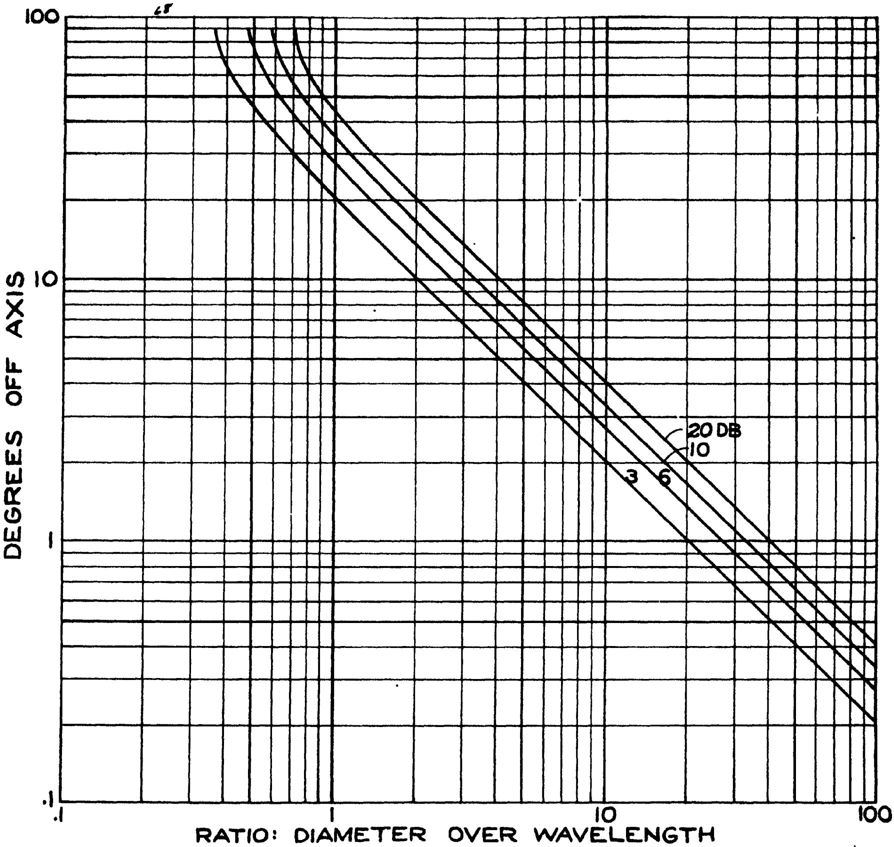


CHART NO. 68

Directional radiation characteristic of a thin circular ring mounted in an infinite baffle. Showing the degrees off the normal axis at which the attenuation is 3, 6, 10, and 20 db. (as marked on curves) as a function of the ratio of ring diameter over wavelength of the generated sound wave.

Chart 69 shows the relative increase in sound pressure on the normal axis of a piston (solid curve) or a thin ring (dotted curve) mounted in an infinite baffle, as a function of piston or ring diameter over wavelength of sound being radiated. As the diameter increases, the acoustic power radiated is kept constant (in other words, the increase in pressure on the normal axis is due solely to the sharpening up of the radiated beam.)

Sample Problem

Find the necessary piston and thin ring diameters which are necessary at 1,400 cycles in order to double the pressure on the normal axis as compared to the pressure obtained from a non directional source mounted in an infinite baffle and radiating the same acoustic power.

Solution

At the intersection of the ordinate = 2 with the dotted line, find ring diameter over wavelength = .65; and at the intersection with the solid line, find piston diameter over wavelength = .94. At 1,400 cycles (from chart 1) find wavelength = 10 inches. Therefore the necessary piston diameter to double the pressure on the normal axis = .94 × 10 = 9.4 inches. Necessary ring diameter to double the pressure = .65 × 10 = 6.5 inches.

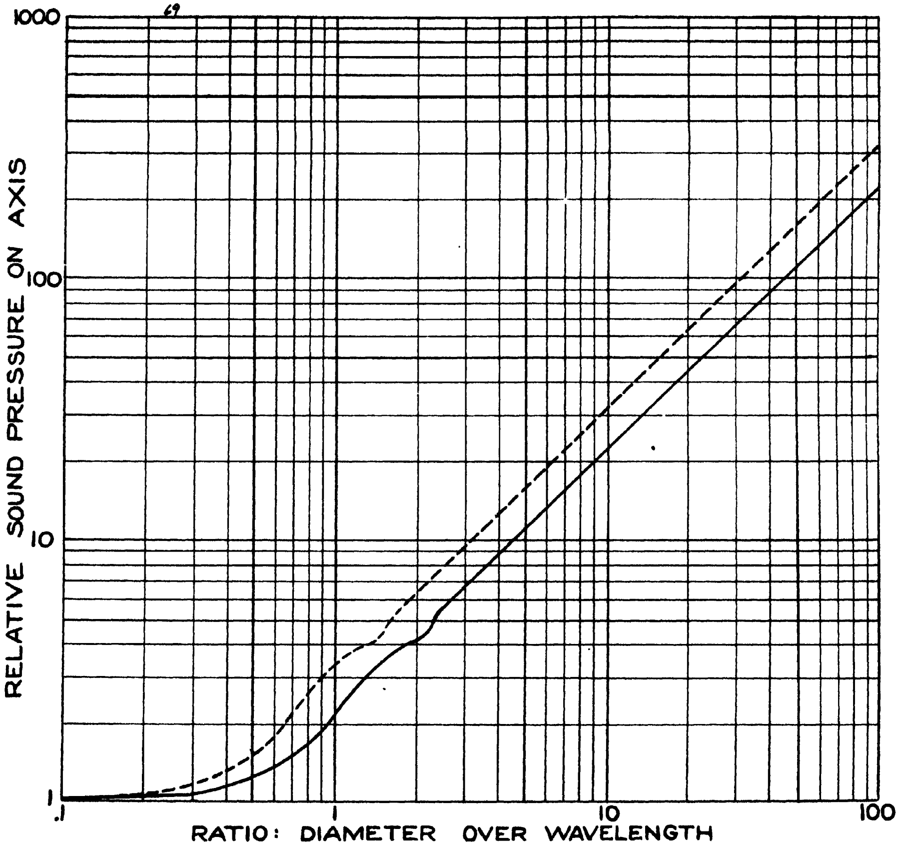


CHART NO. 69

Increase in sound pressure on the normal axis of a piston mounted in an infinite baffle as a function of the ratio of the piston diameter over wavelength of generated sound. (Dotted curve is the pressure increase for a thin ring. The dotted curve was obtained by a series of approximations because the mathematical computations became much more involved than in the case of the piston.)

SECTION 7

Reverberation and Sound Reproduction

CHART 70. Optimum reverberation time in auditoriums vs. frequency and room size.

CHART 71. Total absorption units vs. reverberation time and size of auditorium.

CHART 72. Acoustic watts and sound pressure produced vs. volume of auditorium and reverberation time.

CHART 73. Acoustic watts required per 1000 sq. ft. of open area vs. sound pressure over area.

CHART 74. Relation between intensity level, sound pressure, loudness level, and frequency.

Chart 70 shows the relations between the optimum reverberation time as a function of size of room and frequency. The upper chart shows the optimum reverberation at 500 cycles as a function of room size and the lower chart shows the relative reverberation time as a function of frequency (500 cycle value reference being unity).

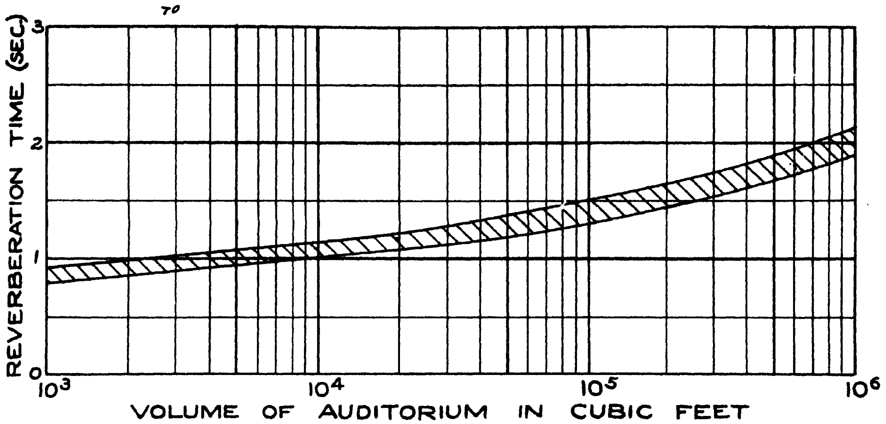
Sample Problem

Find the optimum reverberation times in a room whose volume is 10^5 cu. ft. at 70 cycles and 150 cycles.

Solution

From the upper chart, we find the optimum reverberation time at 500 cycles for a room volume of 10^5 cu. ft. to be about 1.4 seconds.

From the lower chart we find the increase in reverberation time at 70 cycles and 150 cycles to be 2 and 1½ respectively. The optimum reverberation time at 70 cycles is $2 \times 1.4 = 2.8$ seconds and at 150 cycles, the optimum is $1.5 \times 1.4 = 2.1$ seconds.



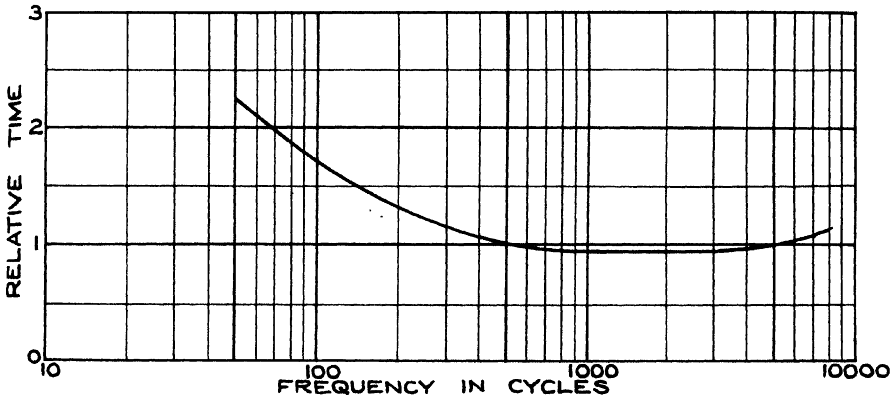


CHART NO. 70

Upper curve: Optimum reverberation time in auditoriums of various sizes at 500 cycles. Lower curve: Relative reverberation time as a function of frequency.

Chart 71 shows the total absorption units in sq. ft. of open window required to produce the various reverberation times marked on the family of curves for auditoriums of various sizes. The dotted lines were computed from the Sabine formula and the solid lines were computed from the more accurate Eyring formula assuming a cubical room.

Sample Problem

Find the necessary absorption units required to produce a reverberation time of 1½ seconds in an auditorium 25 × 40 × 100 ft. in dimensions.

Solution

Volume of auditorium = 25 × 40 × 100 = 10^5 cu. ft. At the abscissa value = 10^5 find the intersection with the curve marked 1.5 seconds and read the following ordinates:

A. From dotted curve, total absorption = 3,300 units (sq. ft.).

B. From solid curve, total absorption = 2,900 units (sq. ft.).

The (*B*) value above is the more accurate of the two values and is the best answer to the problem.

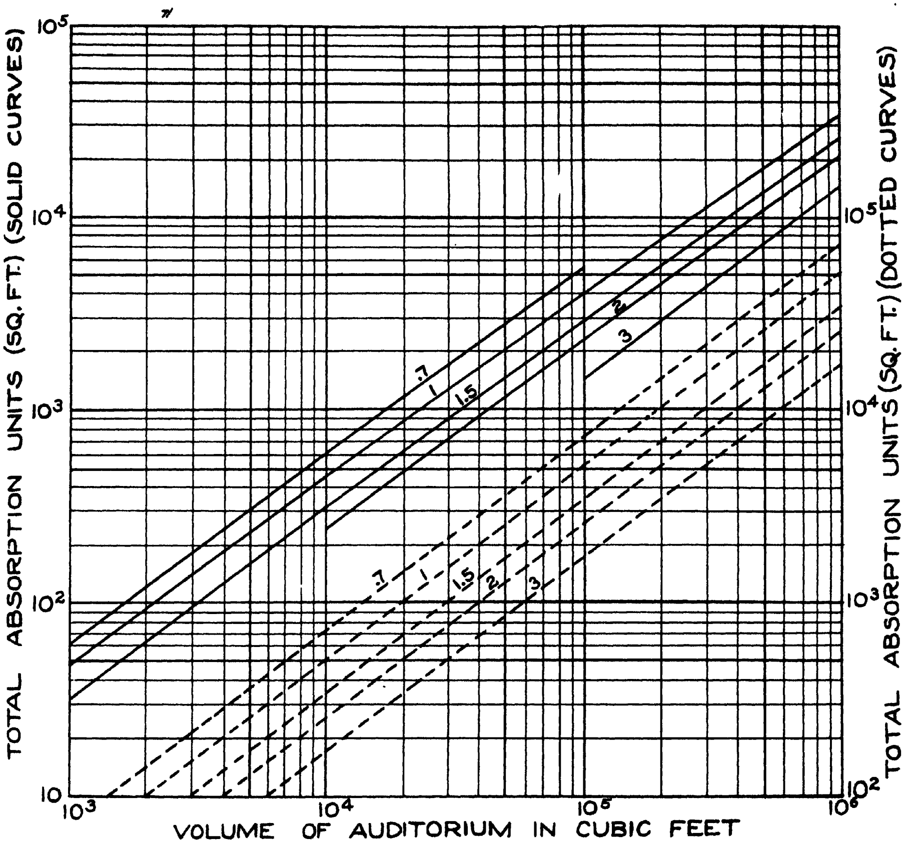


CHART NO. 71

Total absorption in sq. ft. of open window required to produce the various reverberation times marked on the curves for different sizes of auditoriums. The dotted curves were computed from Sabine's formula and the solid curves from the more accurate Eyring formula assuming a cubical room. (Note that the Sabine formula gives absorption values which are too high especially for the larger rooms.)

Chart 72 shows the acoustic power required to maintain a sound pressure of 100 dynes/cm.^{2} in rooms of various sizes and for various reverberation times shown on the family of curves. For any value of sound pressure p, other than 100, the acoustic power should be multiplied by $(p/100)^2$.

Sample Problem

Find the acoustic power required to produce sound pressures of 50 dynes/cm.^{2} in an auditorium having a volume of one million cu. ft. and a reverberation time of 2 seconds.

Solution

From the chart, we find the abscissa = 10^6 cu. ft. and read the intersection with the curve marked 2 seconds, which gives an ordinate value = 140 acoustic watts. This is the power to produce 100 dynes/cm.^{2} The power required to produce 50 dynes/cm.^{2} is

$$P = \left(\frac{50}{100}\right)^2 \times 140 = 35 \text{ acoustic watts.}$$

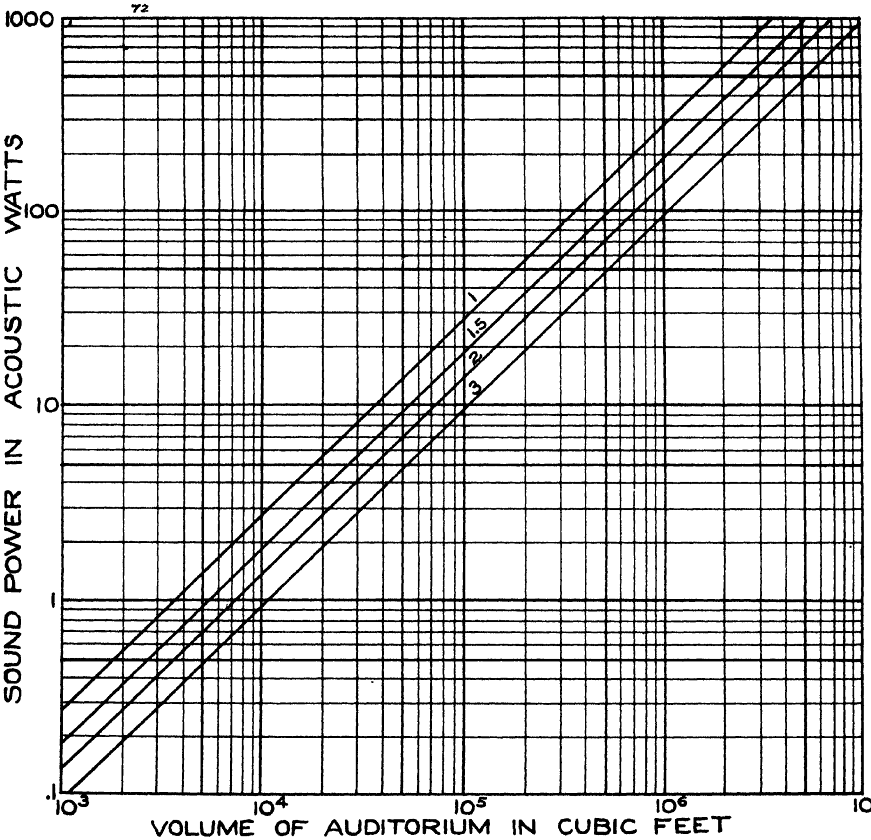


CHART NO. 72

Acoustic watts required in various size rooms to secure a uniform sound pressure of 100 dynes/cm.[2] throughout the room for the various reverberation time values in seconds marked on the curves. The acoustic power required to secure any other sound pressure, p, may be obtained by multiplying the ordinates by $(P/100)^2$. (Note: Peak sound pressures of the order of 100 dynes/cm.[2] are necessary to secure realistic musical reproduction.)

Chart 73 shows the acoustic power required per 1,000 sq. ft. of area as a function of the sound pressure required over that area, assuming 100% sound absorption by the area.

Sample Problem

An area 500 × 200 feet is to be supplied with a sound pressure = 10 dynes/cm²., find the acoustic power dissipated over the area assuming complete absorption by the area.

Solution

Total area = 500 × 200 = 100,000 sq. ft. For the abscissa = 10 dynes/cm². we find the intersection with the *B* curve whose ordinate scale is on the right of the chart and gives a value of .22 watts per 1000 sq. ft.

Total power required by the area is

$$P = \frac{.22 \times 100{,}000}{1{,}000} = 22 \text{ acoustic watts.}$$

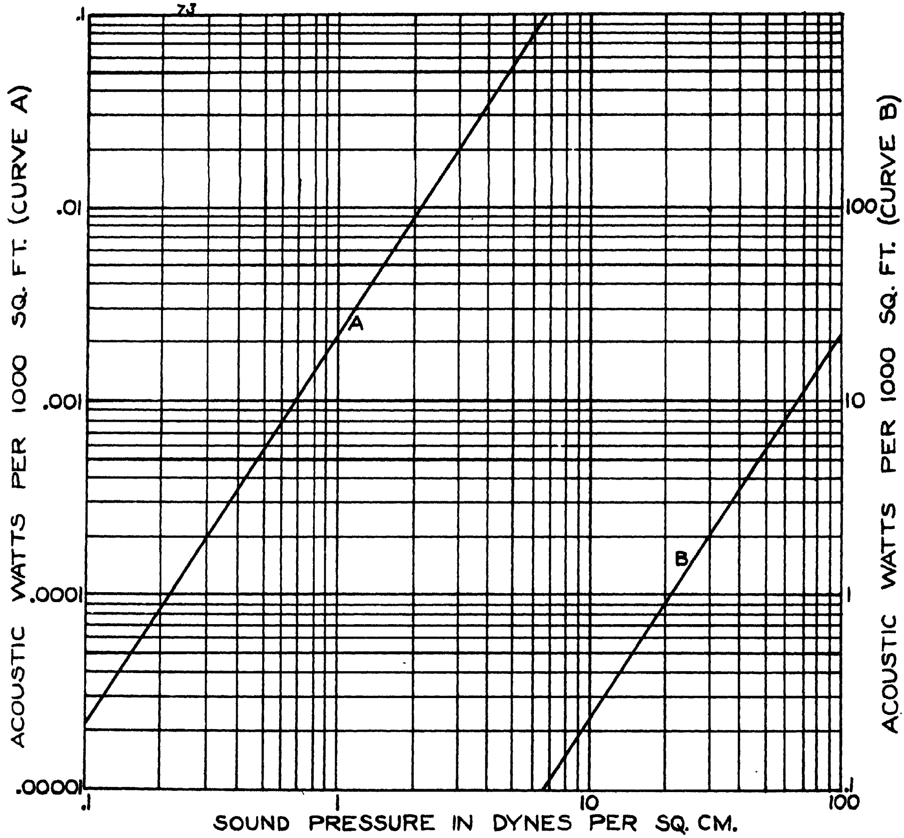


CHART NO. 73

Acoustic power required per 1000 square ft. of area as a function of the sound pressure that is to be maintained over the area (100% sound absorption by the area is assumed).

Chart 74 shows the contours of equal loudness for normal ears. Each curve shows the sound pressure necessary at various frequencies in order to keep constant loudness level.

Sample Problem

Find the increase in acoustic power necessary to raise the loudness level of a 100 cycle and 500 cycle signal from 40 db. to 80 db. above threshold.

Solution

At 100 cycles find the difference in intensity between a 40 db. loudness level and 80 db. loudness level as $82 - 62 = 20$ db. At 500 cycles the intensity ratio to produce the same change in loudness is $80 - 42 = 38$ db. Thus at 100 cycles an acoustic power increase of 20 db. will change a 40 db. loudness level to an 80 db. loudness level and at 500 cycles an acoustic power increase of 38 db. is necessary to produce the same increase in loudness.

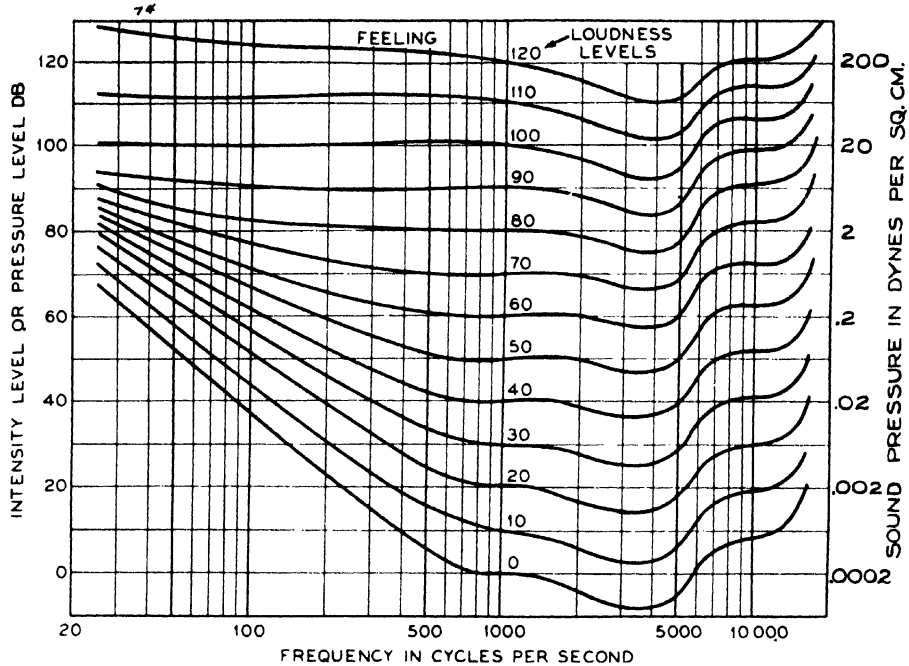


CHART NO. 74

Contours of equal loudness for normal ears. Zero db. equals an intensity of 10^{-16} watts per sq. cm. which is equivalent to a sound pressure of .000204 dynes per sq. cm. in a free progressive wave in air at 20° C. and 760 mm. pressure. (From Fletcher and Munson *J A.S.A.* Oct., 1933.)

SECTION 8

Exponential Horn Loud Speakers

CHART 75. Throat area vs. throat resistance of an exponential horn.

CHART 76. Cut-off frequency of an exponential horn vs. distance along axis for diameter to double.

CHART 77. Cut-off frequency of an exponential horn vs. per cent increase in area along the axis.

CHART 78. Acoustic power generated by a vibrating piston coupled to the throat of an exponential horn vs. piston diameter, piston amplitude, throat area and frequency.

CHART 79. Second harmonic generated in the throat of an exponential horn vs. acoustic power output and frequency.

CHART 80. Maximum theoretical efficiency of an exponential horn loud speaker driven by an electrodynamic piston having a *copper* wire voice coil vs. frequency and flux density.

CHART 81. Maximum theoretical efficiency of an exponential horn loud speaker driven by an electrodynamic piston having an *aluminum* wire voice coil vs. frequency and flux density.

CHART 82. Maximum theoretical efficiency of an exponential horn loud speaker vs. frequency, voice coil mass, and piston mass.

Chart 75 shows the relation between the throat area of an infinite exponential horn and its acoustic resistance. The curve marked "IN." should be used with the right hand ordinate scale and the curve marked "CM." should be used with the left hand ordinate scale. NOTE.—For all practical purposes a horn whose mouth diameter exceed ½ wavelength of the sound being radiated may be considered infinite. If the throat resistance in mechanical ohms is desired, the abscissa should be multiplied by the square of the throat area in sq. cms.

Sample Problem

Find the acoustic resistance at the throat of an exponential horn whose area is 10 sq. ins.

Solution

At the intersection of the right hand ordinate = 10 sq. ins. with the curve marked "IN." find the value of acoustic resistance = .64 acoustic ohm.

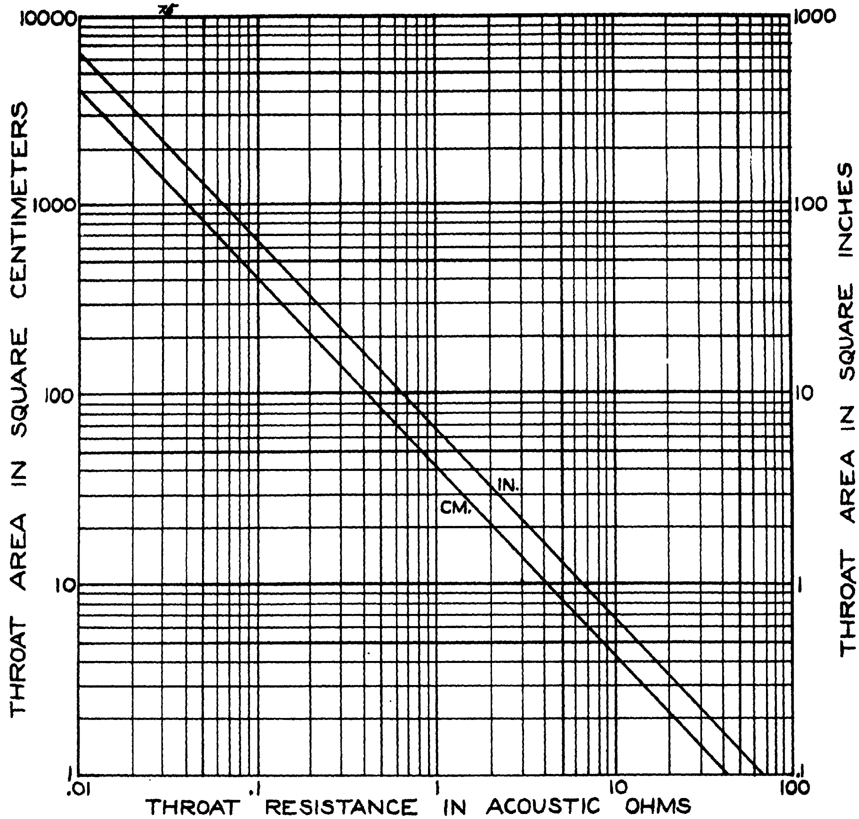


CHART NO. 75

Acoustic resistance of an infinite exponential horn as a function of the area of its throat.

Chart 76 shows the relation between the cut-off frequency of an exponential horn and distance along the axis (in inches or centimeters) for the diameter to double. If the cross section is not circular the ordinates may be interpreted as the distance along the axis for the area to increase four times.

Sample Problem

An exponential horn has a flare in which the diameter doubles every 5 inches; find the cut-off frequency of the horn.

Solution

At the intersection of the ordinate = 5 inches with the curve marked "IN." find the cut-off frequency = 300 cycles.

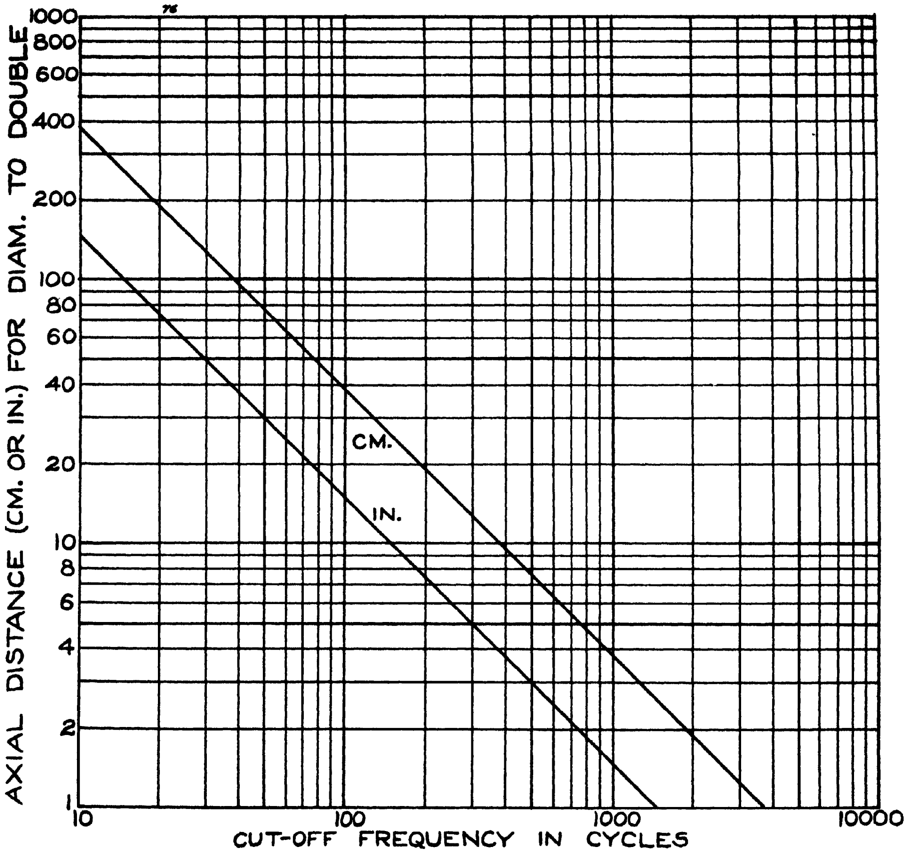


CHART NO. 76

Relation between cut-off frequency of an exponential horn and the distance along the axis over which the cross sectional diameter is doubled. If the cross section is not circular, the axial distance over which the area is increased four times may be used for the ordinates.

Chart 77 shows the relation between the cut-off frequency of an exponential horn and per cent increase in area per ft., per inch, or per cm. along the axis.

Sample Problems

An exponential horn has a shape such that the area increases 20% per cm. length along the axis. Find the cut-off frequency of the horn.

Solution

At the intersection of the ordinate = 20% with the curve marked "CM." find the cut-off frequency equal to 500 cycles.

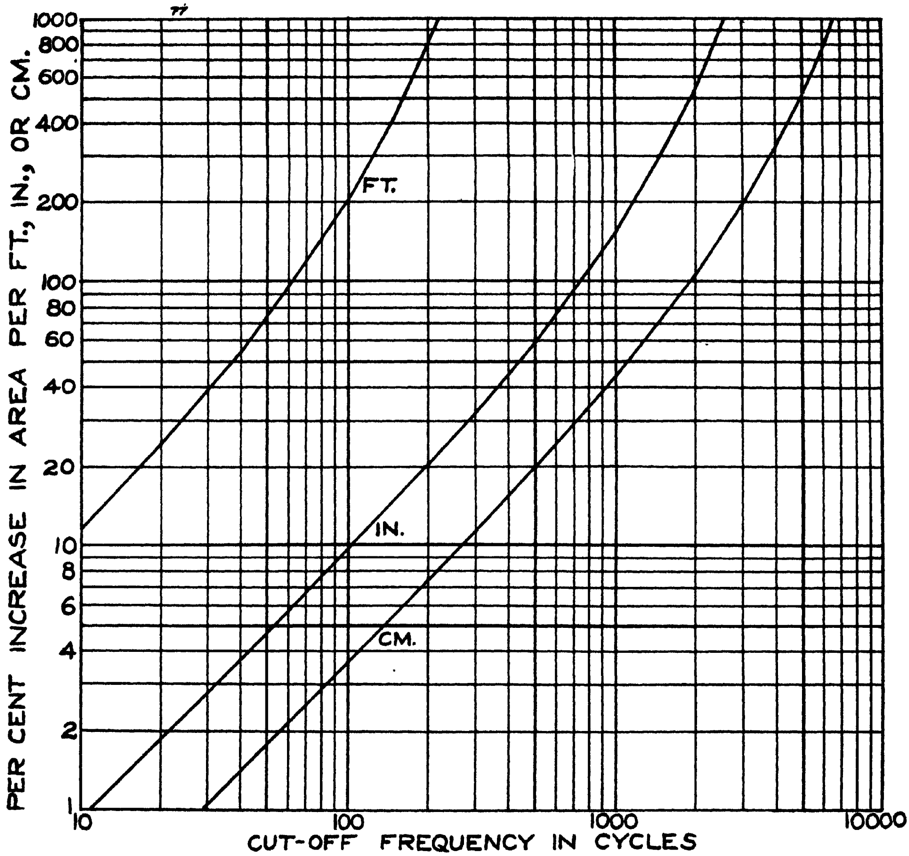


CHART NO. 77

Relation between the percentage increase in cross sectional area per foot, per inch, or per centimeter of axial distance along an exponential horn as a function of its cut-off frequency.

Chart 78 shows the r.m.s. acoustic power generated in an exponential horn when it is driven by various size pistons vibrating at different peak amplitudes. The numbers on the family of curves indicate the piston diameter in inches.

Sample Problem

A 6 inch diameter piston vibrates with a peak amplitude of .060″ at 100 cycles and drives an exponential horn having a throat area of 10 sq. inches. Find the r.m.s. acoustic power output.

Solution

From the conditions of the problem, the product of frequency × peak amplitude = 100 × .060 = 6. At the intersection of the ordinate = 6 with the curve marked 6 inches find the abscissa = 100. Since the throat area = 10 sq. inches, the acoustic power output = $^{100}/_{10}$ = 10 watts.

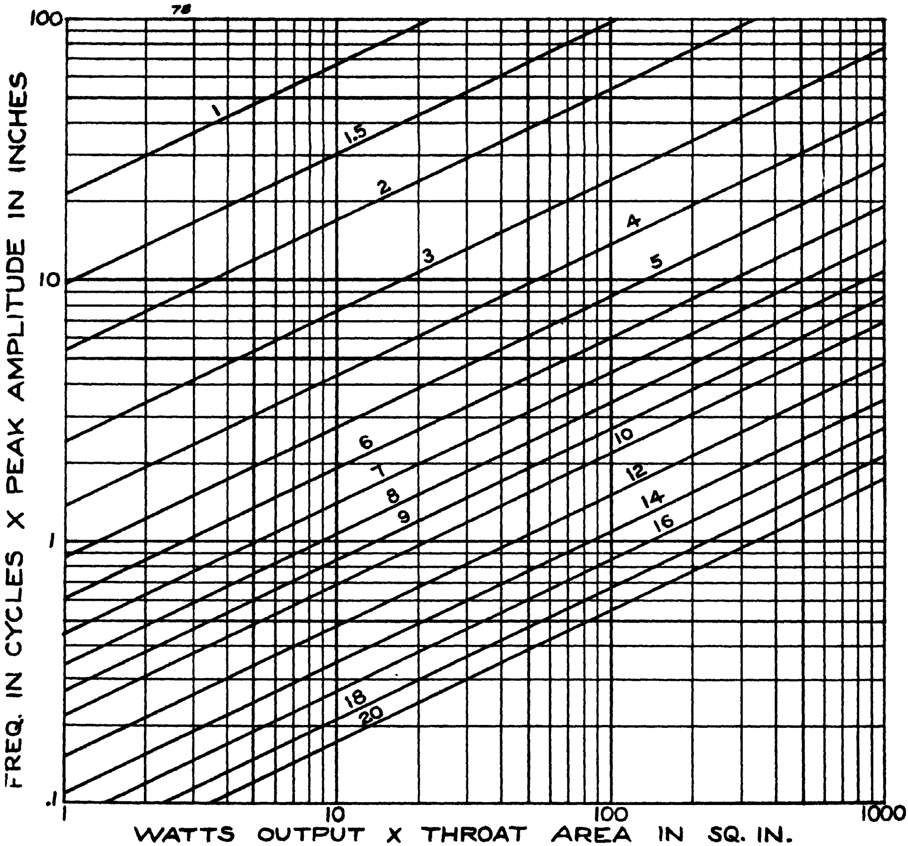


CHART NO. 78

Family of curves showing the r.m.s. acoustic power generated at various frequencies for various peak amplitudes of a piston driving exponential horns of various throat areas. The horn mouth is assumed large enough so that no reflections occur at the frequency concerned. The number on each curve represents the piston diameter in inches.

Chart 79 shows the second harmonic generated in an infinite exponential horn as a function of the ratio of the frequency being propagated (f_1) to the cut-off frequency of the horn (f_c). The numbers on the curves indicate the acoustic watts being radiated per square inch of throat area. NOTE.—For all practical purposes if the mouth diameter of the horn exceeds ½ wavelength of the sound being radiated, the horn may be considered infinite.

Sample Problem

Find the highest frequency at which 10 acoustic watts can be transmitted through a horn having a throat area of 10 square inches and a cut-off frequency of 80 cycles if the maximum second harmonic component is not to exceed 10%.

Solution

The acoustic power per sq. in. of throat $= 10/10 = 1$. For the ordinate equals 10% second harmonic, find the intersection with the curve labelled 1 and read the abscissa $f_1/f_c = 10.5$. The highest frequency at which the 10 watts may be radiated without exceeding 10% second harmonic $= 80 \times 10.5 = 840$ cycles.

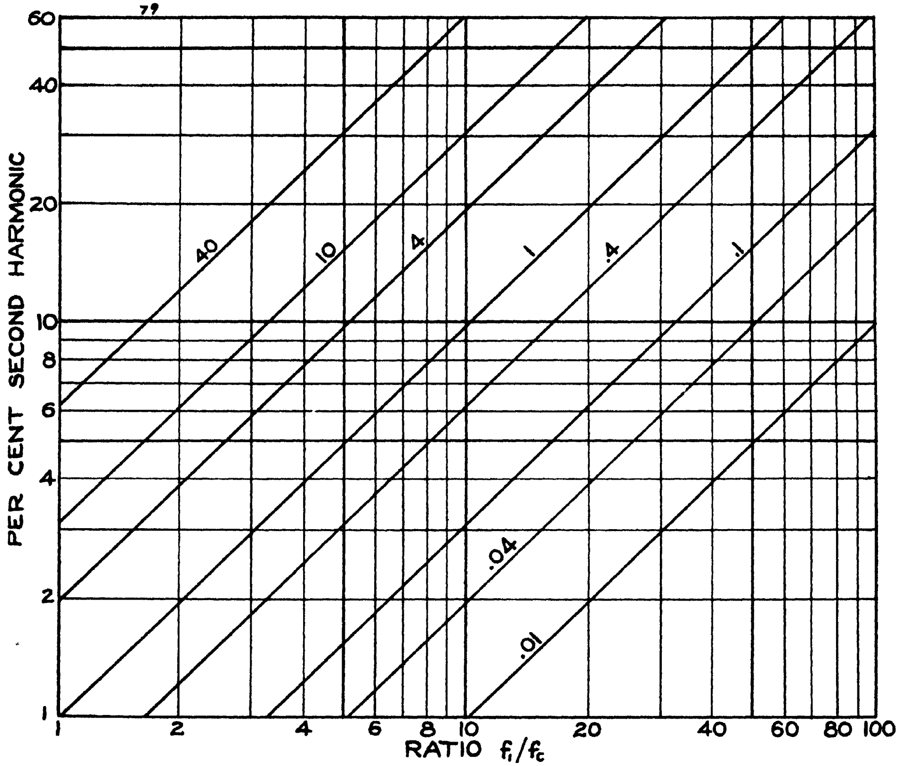


CHART NO. 79

Second harmonic distortion generated in an exponential horn at a frequency f_1 when the cut-off frequency due to flare is f_c. Numbers on curves indicate acoustic watts being radiated per square inch of throat area.

Charts 80 and 81 shows the maximum theoretical efficiencies that may be realized in an ideal horn loud speaker driven by a mass controlled piston which is actuated by a pure resistance voice coil residing in air gap having the flux densities marked on the family of curves. The horn throat resistance is assumed equal to the piston reactance at each frequency. In an actual speaker this match is generally obtained at only one frequency and the efficiency deviates from the maximum efficiency curves shown on the charts at other frequencies. The solid curves are computed for the case in which the mass of the piston is zero, and the dotted curves are for the condition in which the voice coil mass equals the effective mass of the remainder of the vibrating system. Chart 80 applies for copper wire voice coils and chart 81 applies for aluminum wire voice coils.

Sample Problem

Find the maximum efficiency of a horn loud speaker at 4,000 cycles when driven by a piston equipped with a copper voice coil of equal mass and operating at an air gap flux density of 10,000 gauss. Find the efficiency if an aluminum coil of equal mass is substituted for the copper.

Solution

From chart 80 find the intersection of the abscissa = 4,000 cycles with the dotted curve marked 10 Kilogauss and read the efficiency = 6%. For an aluminum voice coil read the corresponding points on chart 81 and find the efficiency = 11½%.

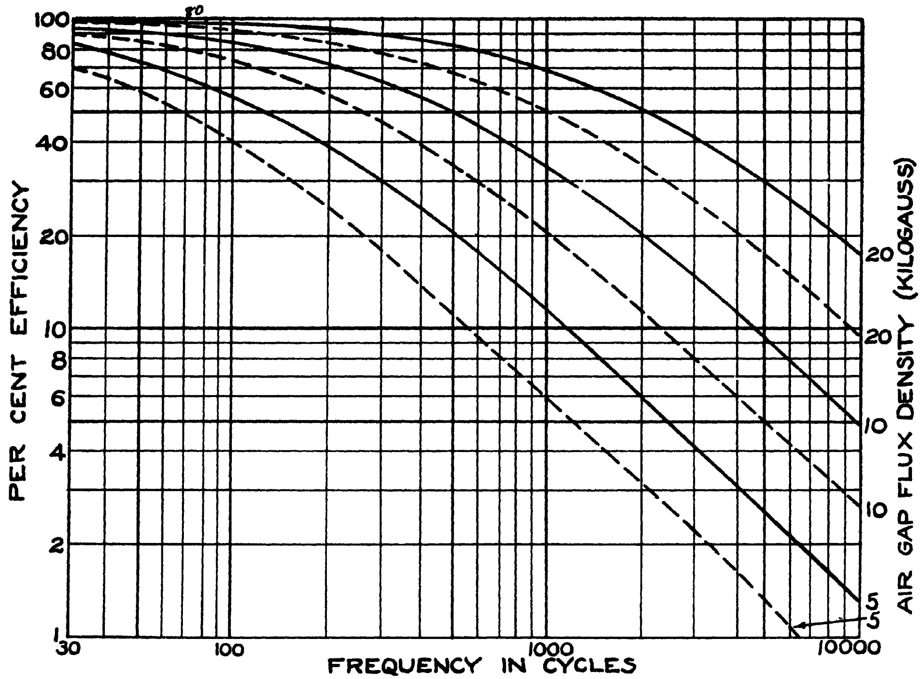


CHART NO. 80

Maximum theoretical efficiencies obtainable in an idealized, electrodynamically driven horn loud-speaker employing a *copper voice coil* at the various air gap flux densities marked on the curves. The solid curves assume the voice coil mass is the entire mass of the vibrating system (mass of diaphragm = 0). The dotted curves assume the voice coil mass equals the effective mass of the remaining portion of the vibrating system.

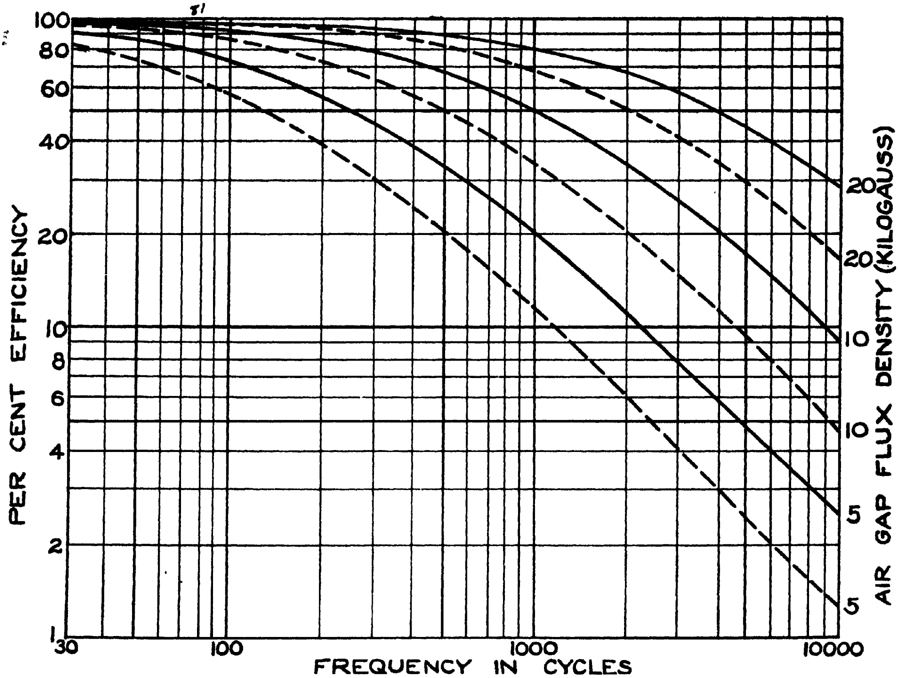


CHART NO. 81

Maximum theoretical efficiencies obtainable in an idealized, electrodynamically driven horn loud-speaker employing an *aluminum voice coil* at the various air gap flux densities marked on the curves. The solid curves assume the voice coil mass is the entire mass of the vibrating system (mass of diaphragm = 0). The dotted curves assume the voice coil mass equals the effective mass of the remaining portion of the vibrating system.

Chart 82 shows the maximum theoretical efficiencies which may be realized in a horn loud speaker having an aluminum voice coil and an air gap flux density of 20,000 gauss. The efficiency is shown for the three frequencies marked on the curves and as a function of the ratio of voice coil mass to the remaining mass of the vibrating system, which is plotted as abscissas.

Sample Problem

Find the mass of aluminum conductor which is required to drive a 10 gram piston which is matched to a horn for optimum efficiency at 1,000 cycles. The air gap flux density is 20,000 gauss and the desired efficiency = 50%.

Solution

At the intersection of the ordinate = 50% efficiency with the 1,000 cycle curve, find the abscissa = .32. Thus voice coil mass over piston mass = .32 or the voice coil mass required = .32 × 10 = 3.2 grams.

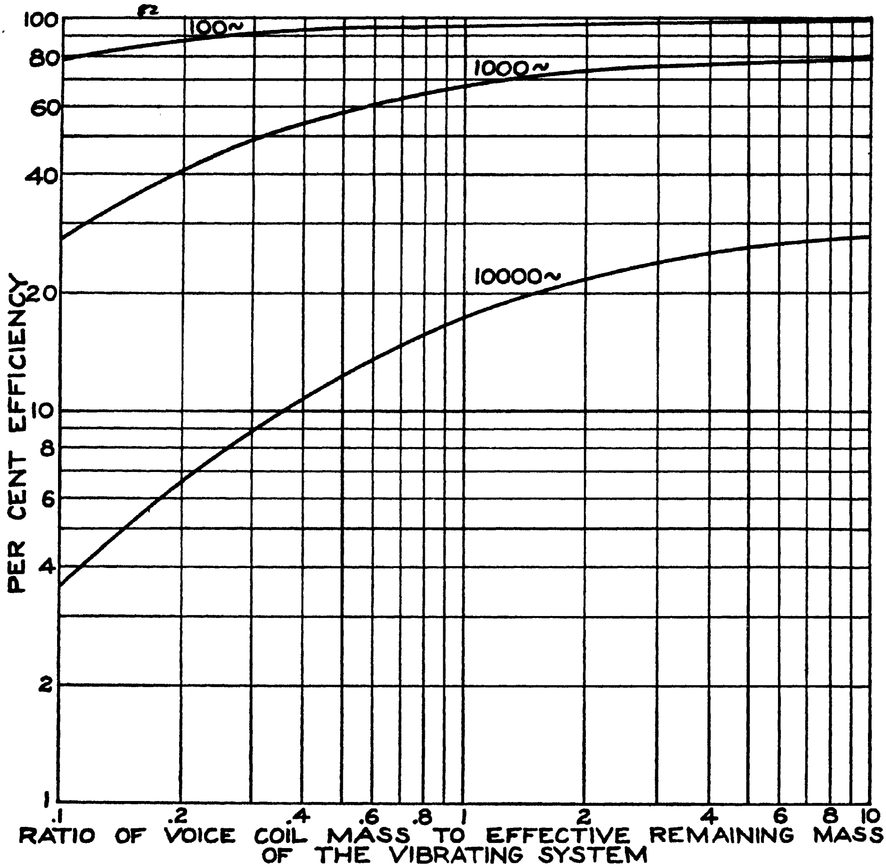


CHART NO. 82

Maximum theoretical efficiency that may be realized in an idealized horn type loudspeaker as a function of the ratio of the mass of the voice coil conductor to the effective mass of the remainder of the vibrating system. Aluminum wire voice coil and 20,000 gauss air gap flux density is assumed. Figures on curves indicate frequency in cycles per second.

SECTION 9

Electro-magnetic Design Data

CHART 83. Length per ohm of aluminum and copper wire vs. wire size.

CHART 84. Length per gram of aluminum and copper wire vs. wire size.

CHART 85. Ohms per gram of aluminum and copper wire vs. wire size.

CHART 86. Ohms vs. length and mass of aluminum and copper wire.

CHART 87. Magnetizing force and field power dissipation vs. weight of copper wire wound on spools having various ratios of winding thicknesses to spool lengths (inside diameter of winding = 1″).

CHART 88. Magnetizing force and field power dissipation vs. weight of copper wire wound on spools having various ratios of winding thicknesses to spool lengths (inside diameter of winding = 1.4″).

CHART 89. Magnetizing force and field power dissipation vs. weight of copper wire wound on spools having various ratios of winding thicknesses to spool lengths (inside diameter of winding = 2″).

CHART 90. Magnetizing force and field power dissipation vs. weight of copper wire wound on spools having various ratios of winding thicknesses to spool lengths (inside diameter of winding = 2.8″).

CHART 91. Magneto-motive force required across an air gap vs. flux density and air gap size

CHART 92. Magneto-force drop in various magnetic materials vs. flux density.

CHART 93. Force exerted on a conductor carrying a current and located in an air gap vs. flux density, length of conductor and current.

CHART 94. Pull exerted between two parallel magnetic surfaces vs. flux density between surfaces.

CHART 95. Increase in magnetic pull caused by tapered pole pieces vs. angle of taper.

CHART 96. Reluctance between two long parallel iron rods vs. rod diameter and separation between rods.

CHART 97. Demagnetization curves of typical permanent magnet alloys.

CHART 98. Volume of permanent magnet required to maintain flux in air gaps vs. air gap size and flux density.

CHART 99. Weight vs. volume and specific gravity.

Charts 83, 84, 85 and 86, show the electrical properties of aluminum and copper wires.

Chart 83 shows the relation between the gauge size and the length in centimeters per ohm.

Chart 84 shows the relation between the gauge size and the length in centimeters per gram of bare conductor.

Chart 85 shows the relation between the gauge size and the resistance in ohms per gram of bare conductor.

Chart 86 shows the relation between the length of conductor and its electrical resistance for a mass of one gram. For any other mass of conductor, divide the value of resistance on the chart by the mass in grams.

The above charts are useful in the design of electrodynamic systems. For example, the proper size of wire can be found immediately for a particular voice coil requirement. Suppose we wish a 1 gram aluminum voice coil with a resistance of 10 ohms, chart 85 tells us that 32 gauge aluminum wire will meet the requirements; then from chart 86 we see that a 10 ohm coil of aluminum wire with a mass of 1 gram has a length of conductor equal to about 1,200 centimeters.

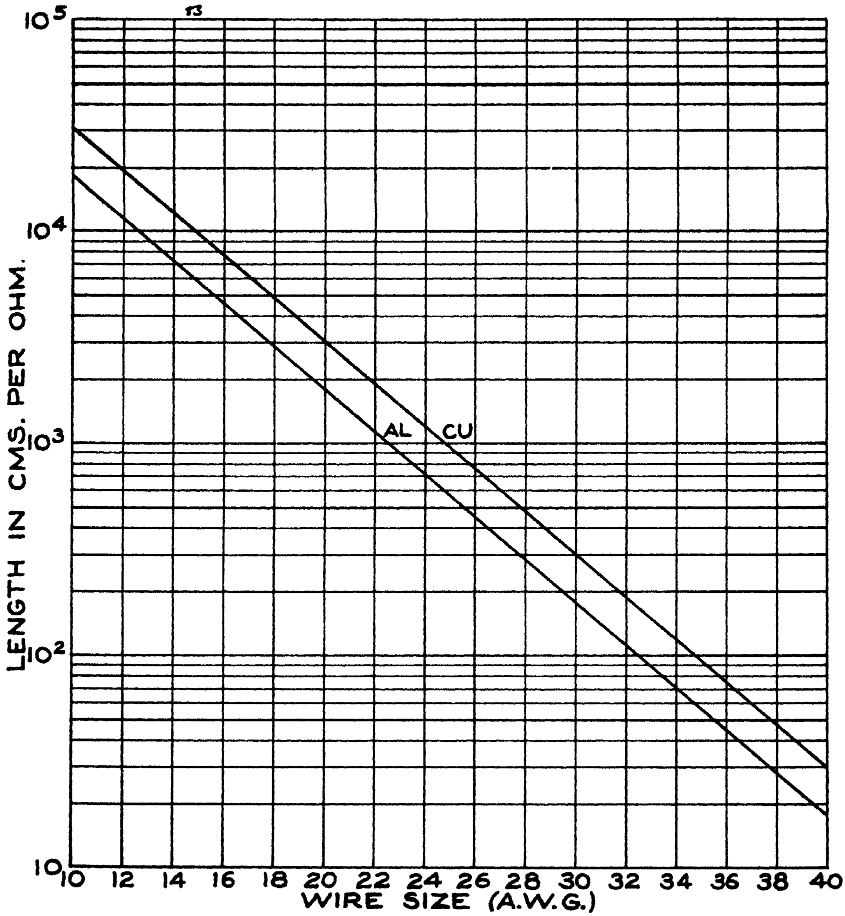


CHART NO. 83

Length per ohm of bare aluminum and copper wire at 20° C.

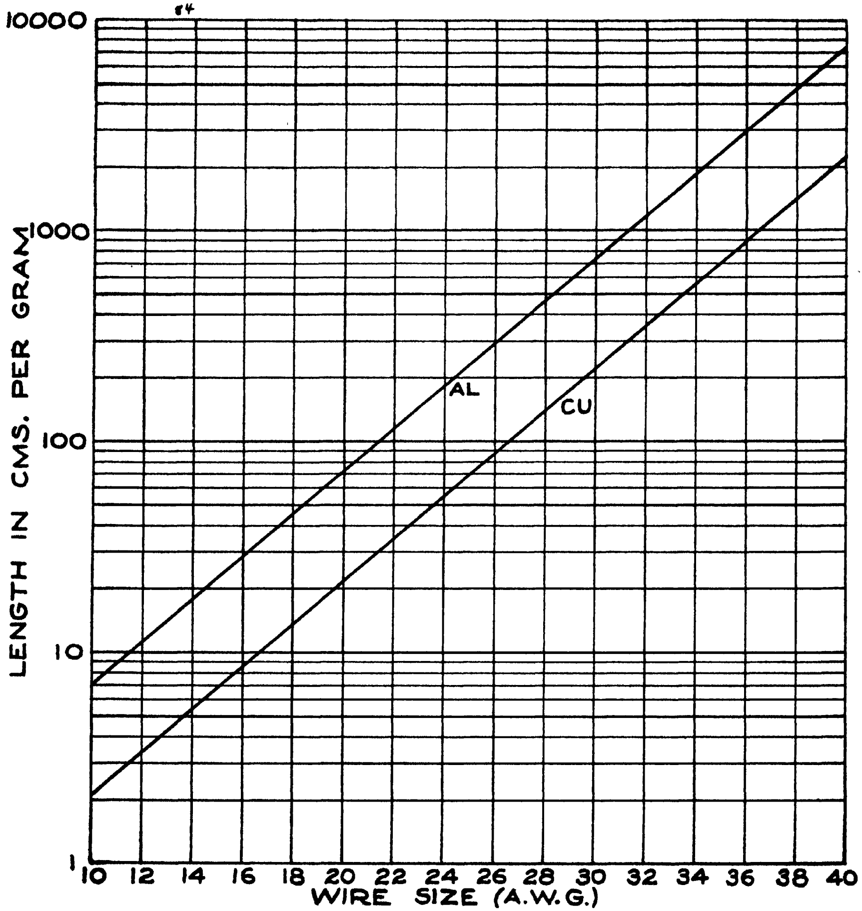


CHART NO. 84

Length per gram of bare aluminum and copper wire.

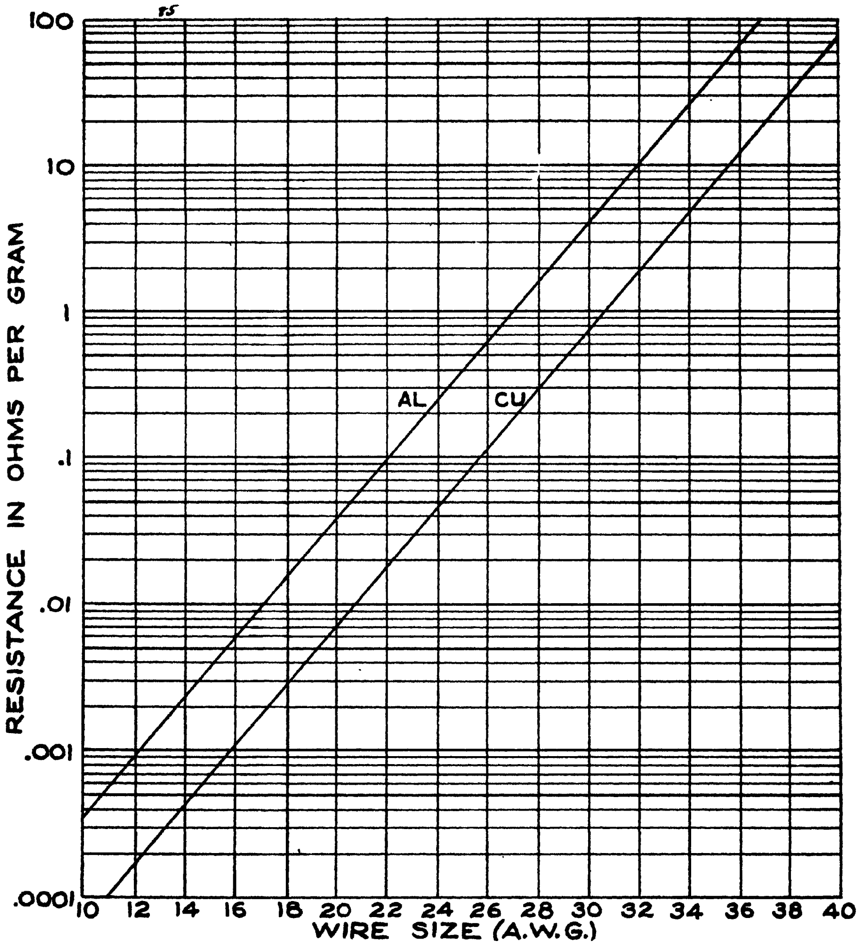


CHART NO. 85

Resistance per gram of bare aluminum and copper wire at 20° C.

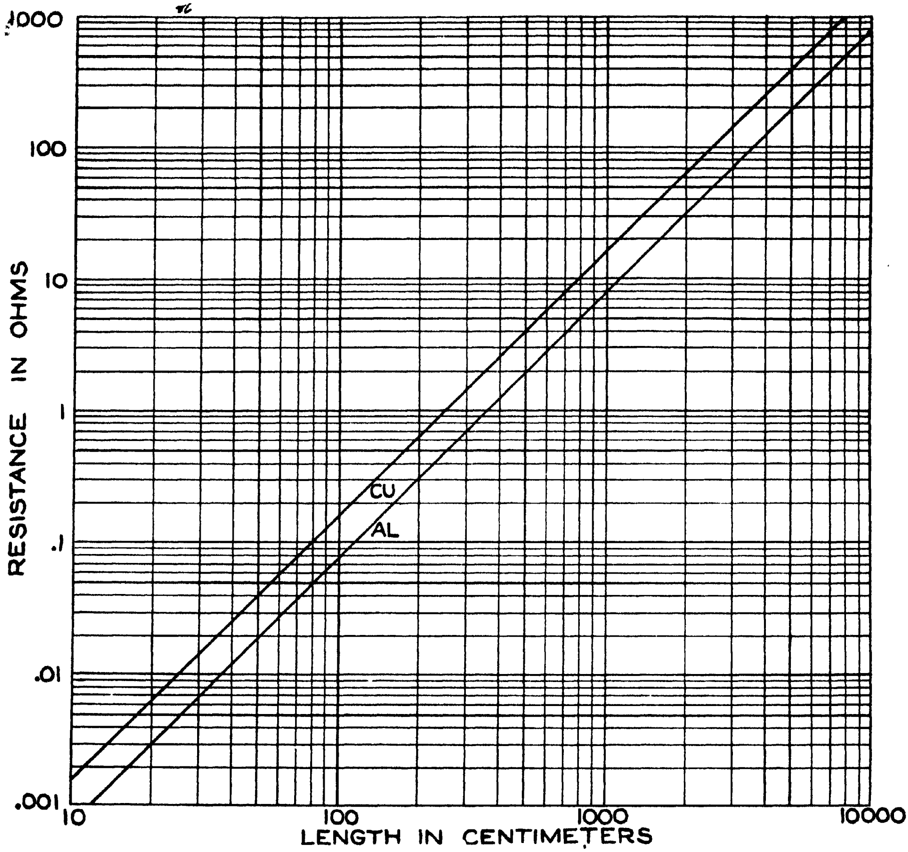


CHART NO. 86

Relation between the electrical resistance of a copper and aluminum conductor at 20° C. as a function of its length. Mass of conductor = 1 gram. For any other mass divide the resistance given above by the mass in grams.

Charts 87, 88, 89, and 90, show the ampere turns generated by a field coil for various ratios of winding length, L, to winding thickness, W, as indicated on the insert drawings on the charts. The four charts are for four different sizes of inside diameter of the coil winding, namely: 1, 1.4, 2, and 2.8 inches.

The magneto-motive force in ampere turns is shown for a field power consumption of 10 watts. For any other value of field power, P, the ampere turns obtained from the chart should be multiplied by the ratio $\sqrt{P/10}$.

Sample Problem

Find the weight of copper wire necessary to produce 2,000 ampere turns with a field consumption of 10 watts if the diameter of the inside turns = 1 inch.

A. Ratio of winding length to thickness, $L/W = 4$.

B. Ratio of winding length to thickness, $L/W = 1/2$.

Solution

A. For 2,000 ampere turns on chart 87, read the intersection with the curve $L/W = 4$ and find weight of copper required = 2.7 lbs.

B. If the winding shape is $L/W = 1/2$, read the intersection on the curve labeled ½ and find the necessary weight of copper required to produce the same 2,000 ampere turns = 17 lbs.

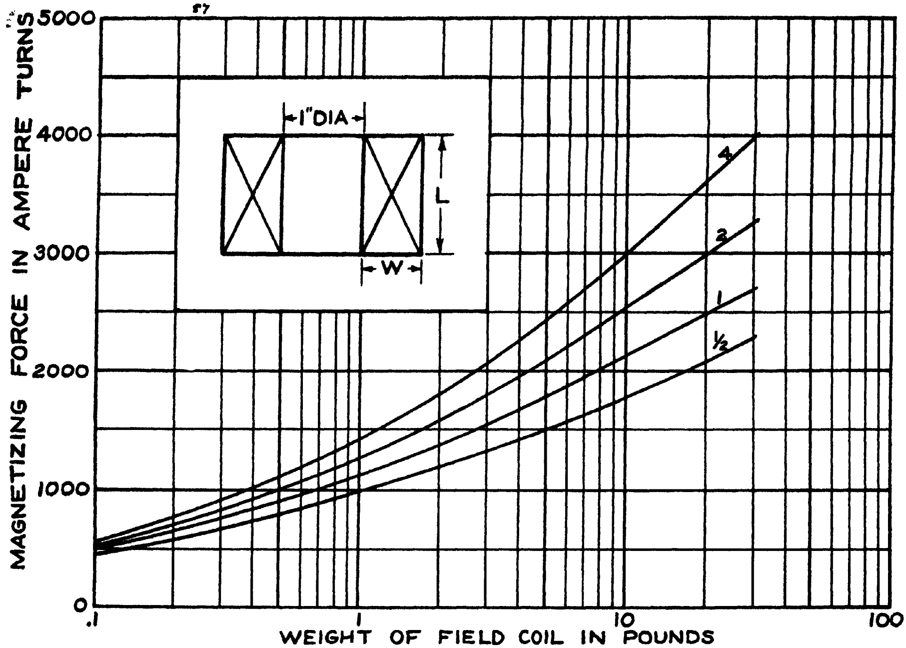


CHART NO. 87

Magnetizing force versus weight of a circular enamelled copper wire field coil for the various ratios of L/W shown on the curves. Inside diameter of copper coil = 1 inch. Field power = 10 watts. For any other value of field power, P, multiply ordinates by $\sqrt{P/10}$.

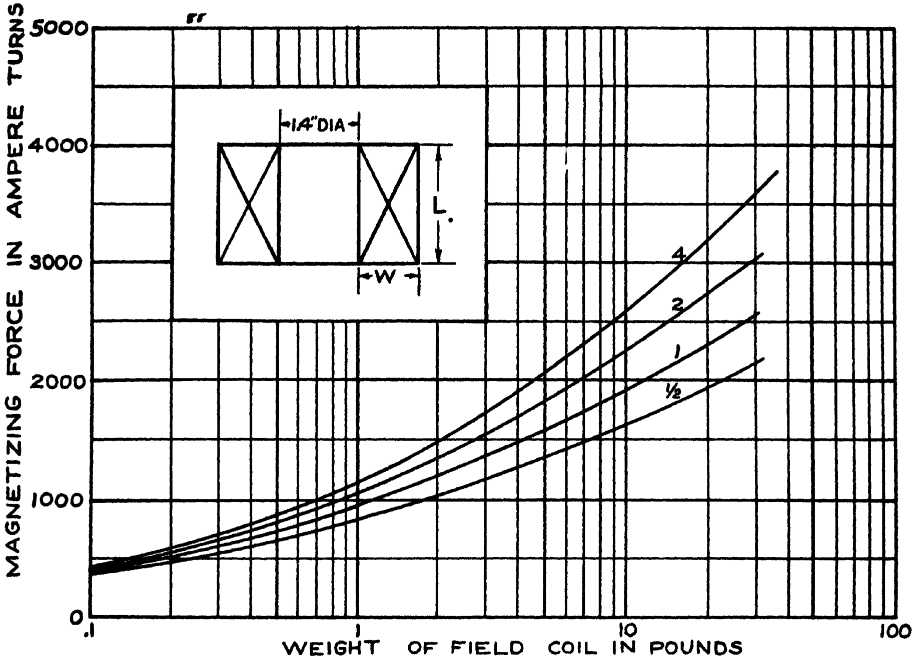


CHART NO. 88

Magnetizing force versus weight of a circular enamelled copper wire field coil for the various ratios of L/W shown on the curves. Inside diameter of copper coil = 1.4 inches. Field power = 10 watts. For any other value of field power, P, multiply ordinates by $\sqrt{P/10}$.

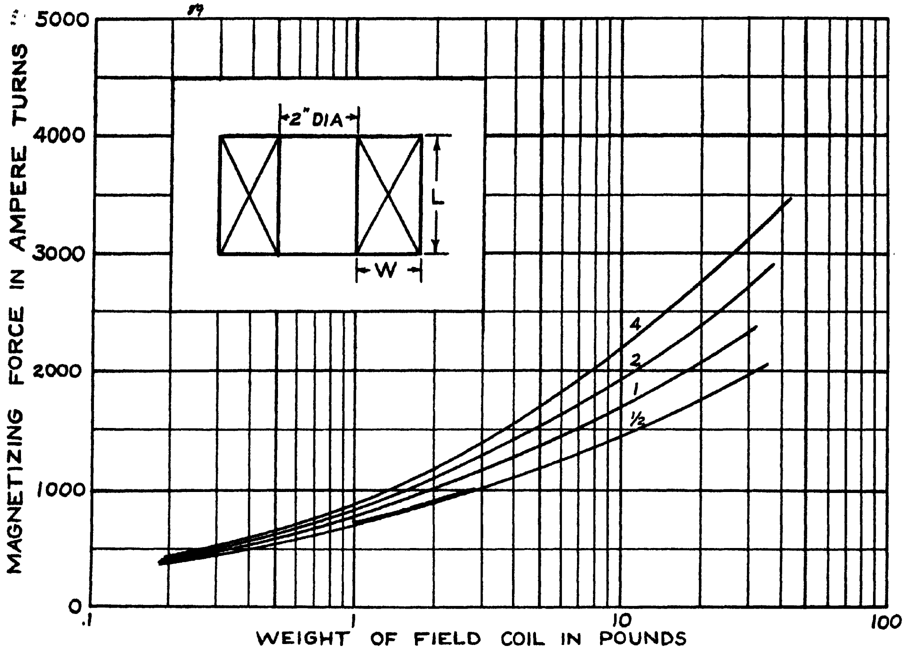


CHART NO. 89

Magnetizing force versus weight of a circular enamelled copper wire field coil for the various ratios of L/W shown on the curves. Inside diameter of copper coil = 2 inches. Field power = 10 watts. For any other value of field power, P, multiply ordinates by $\sqrt{P/10}$.

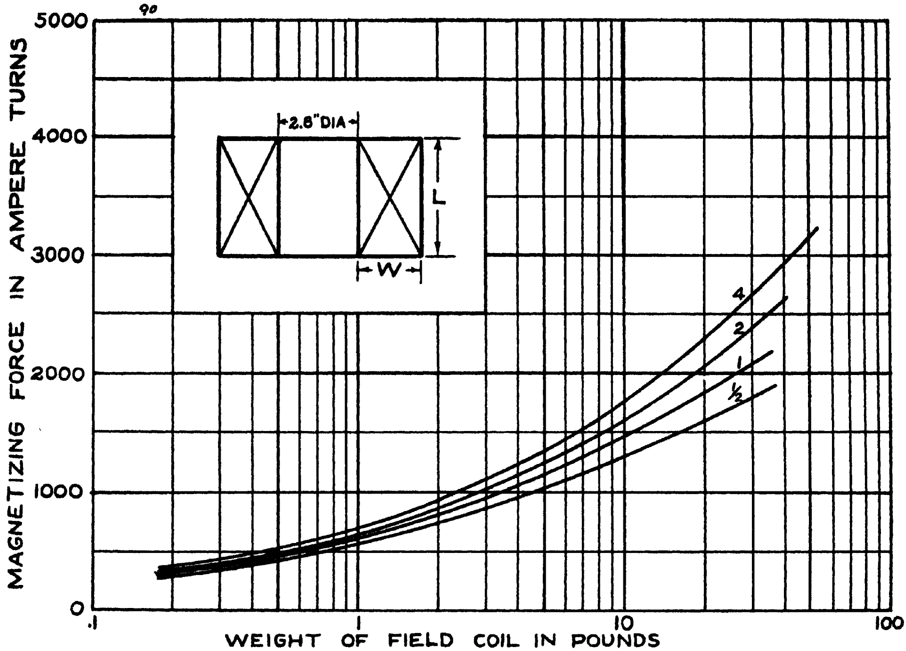


CHART NO. 90

Magnetizing force versus weight of a circular enamelled copper wire field coil for the various ratios of L/W shown on the curves. Inside diameter of copper coil = 2.8 inches. Field power = 10 watts. For any other value of field power, P, multiply ordinates by $\sqrt{P/10}$.

Chart 91 shows the magneto-motive force in gilberts or ampere turns required to maintain various flux densities in air gaps of various lengths. (The length of air gap is in the direction parallel to the flux.)

Sample Problem

Find the ampere turns required to produce a flux density of 10,000 gauss in an air gap .1 inch long.

Solution

The product of flux density × air gap length is 10,000 × .1 = 1,000.

For the abscissa = 1,000 read the intersection on the curve marked "A.T." and find the necessary ampere turns = 2,000.

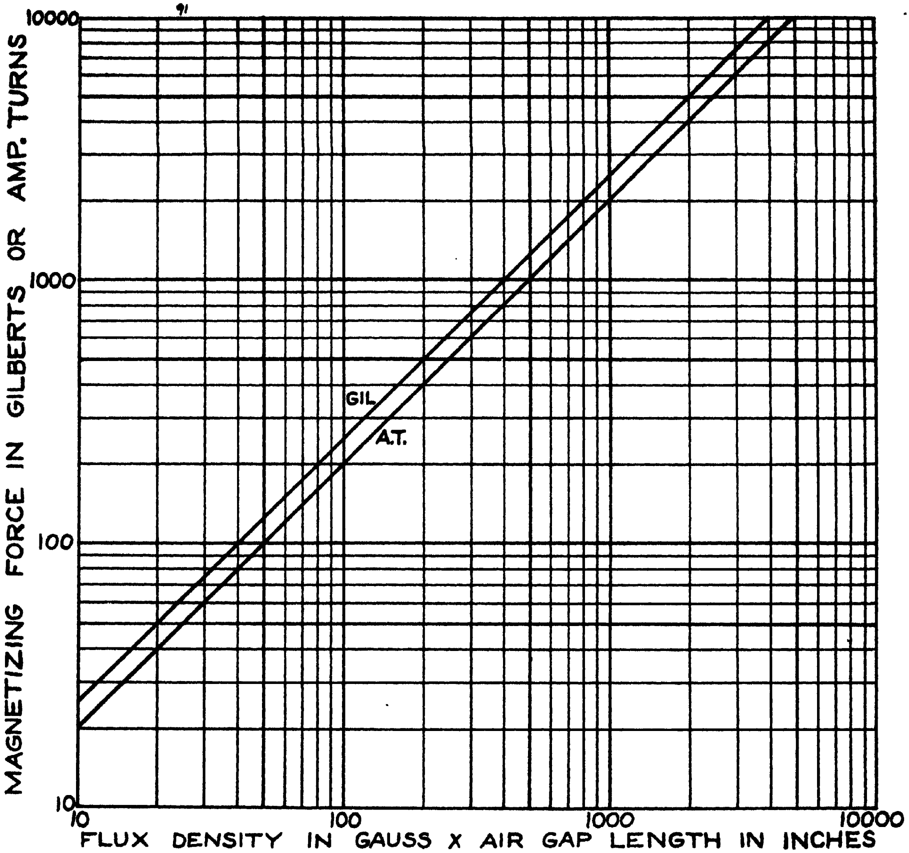


CHART NO. 91

Magneto-motive force in gilberts or ampere turns necessary to maintain a required flux density in air gaps of various lengths.

Chart 92 shows the magnetic potential drop in Armco iron, soft cold rolled steel, and cast iron as a function of the flux density in the iron. The data are presented in two ways: The solid curves give the drop in gilberts per cm. of iron path and the dotted curves show the drop in ampere turns per inch of iron path.

Sample Problem

A. Find the loss in ampere turns in an Armco magnetic structure having a path length of 20 inches and operating at a uniform flux density of 16,000 gauss.

B. Find the loss in ampere turns if the weight of iron is doubled (assume the flux density for doubled area = 8000 gauss in the iron).

Solution

A. For a flux density = 16 kilogauss, find the m.m.f. drop = 40 ampere turns per inch. Total loss in structure = $20 \times 40 = 800$ ampere turns.

B. For $B = 8$ kilogauss, the m.m.f. drop = 3.6 ampere turns per inch. Total loss in structure is now reduced to $3.6 \times 20 = 72$ ampere turns.

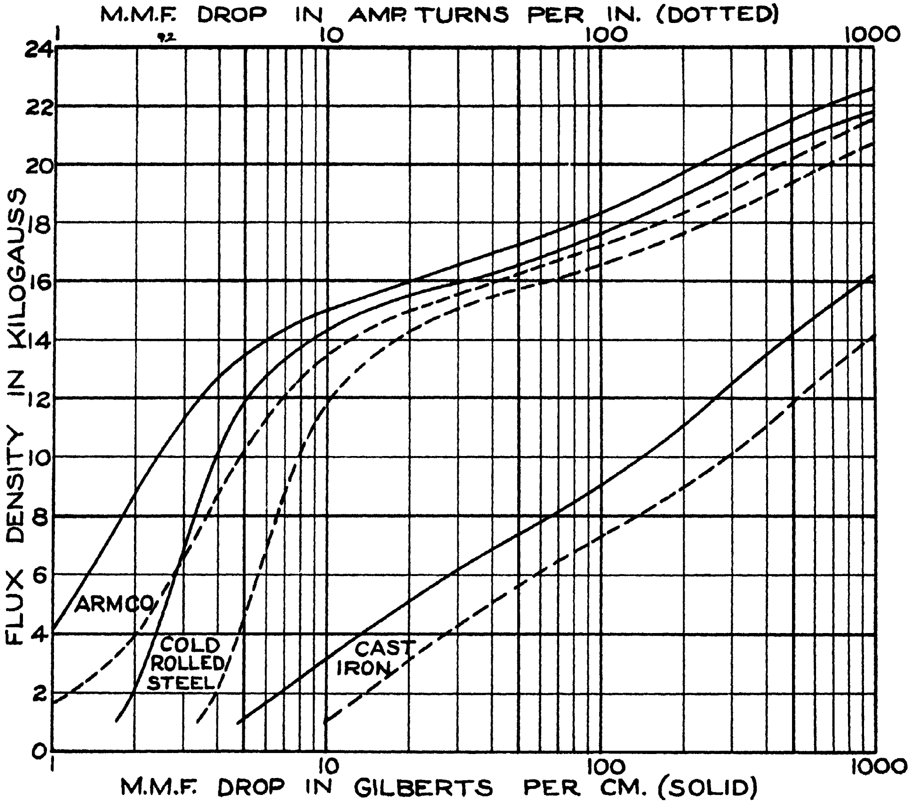


CHART NO. 92

Magneto-motive force drop in various materials as a function of the flux density in the material.

Chart 93 shows the force exerted on a conductor per ampere of current flowing through it when it is located in a magnetic field with the flux lines normal to the axis of the conductor. Two curves are shown on the charts one marked "*A*" gives the force in pounds per ampere and curve "*B*" gives the force in dynes per ampere.

Sample Problem

Find the force in dynes produced in a voice coil having a conductor 1,000 cms. long and operating in an air gap having a flux density = 10,000 gauss. The voice coil current = 100 milliamperes.

Solution

The product of flux density × length of conductor equals $10{,}000 \times 1{,}000 = 10^7$.

For the abscissa $= 10^7$, read on curve *B* the value of force $= 10^6$ dynes per ampere. Since the current in the problem = .1 ampere, the force generated in the voice coil is equal to:

$$F = 10^6 \times .1 = 10^5 \text{ dynes.}$$

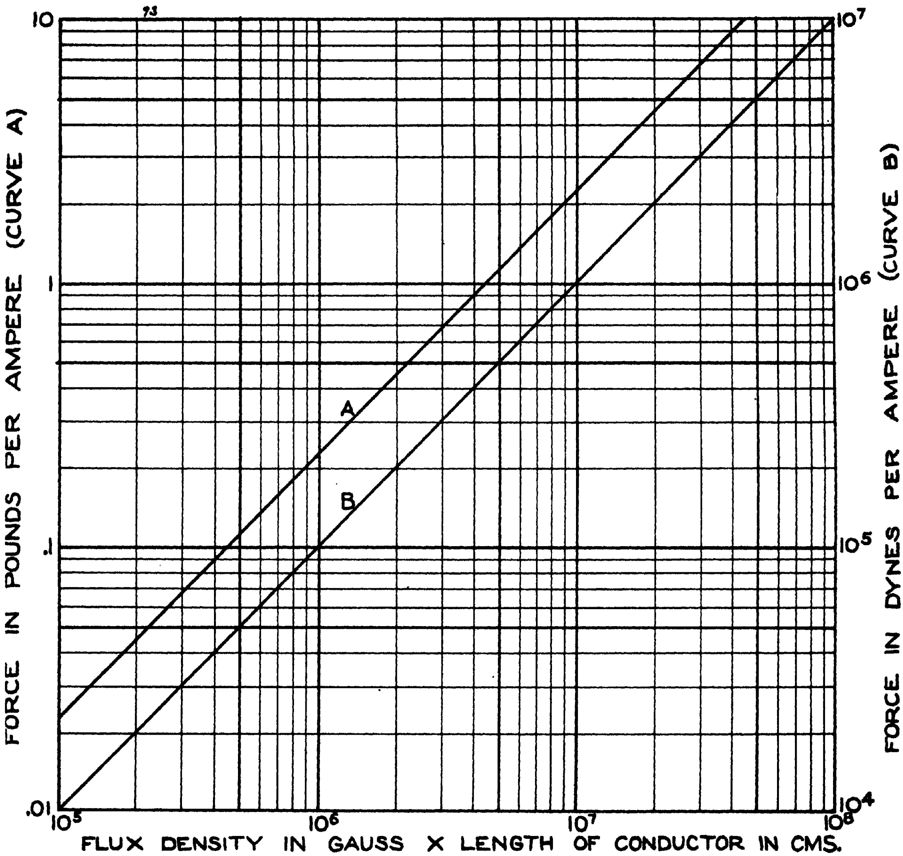


CHART NO. 93

Force exerted on a conductor carrying a current and situated in a magnetic field with its axis normal to the direction of the flux.

Chart 94 shows the pull exerted per unit area of two parallel magnetic surfaces as a function of the flux density between them. Two curves are shown: Curve *A* expresses the pull in lbs./sq. in. and curve *B* shows the pull in dynes/sq. cm.

Sample Problem

Find the flux density between two magnetic surfaces having an area of 100 sq. ins. if it takes 6,000 lbs. to pull the surfaces apart.

Solution

From the conditions of the problem we can obtain the force per unit area holding the surfaces together; this quantity is equal to

$$F = \frac{6{,}000}{100} = 60 \text{ lbs./sq. in.}$$

Referring to curve *A*: For a value of $F = 60$ lbs./sq. in. find the corresponding value of flux density = 10,000 gauss.

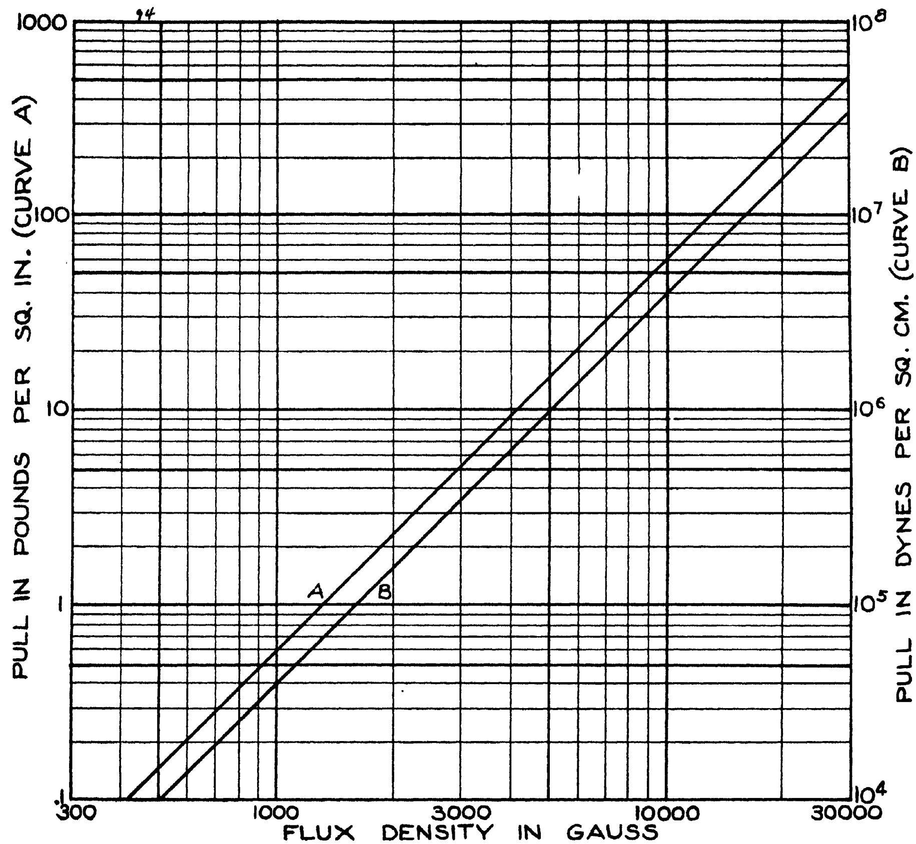


CHART NO. 94

Pull exerted between two parallel magnetic surfaces having a constant flux density between them.

Chart 95 shows the increase in magnetic pull as well as the increase in total air gap flux caused by tapering the magnetic pole pieces. The axial spacing between the pole pieces is kept constant and the m.m.f. drop across the air gap is also kept constant.

Sample Problem

An electromagnetic relay having a pair of flat parallel faces is required to double the force with which the faces are attracted without changing the spacing between the faces and without increasing the magnetizing ampere turns. Find the angle θ in the cylindrical pole tip construction shown in the insert drawing on the chart that will produce the desired result.

Solution

For a pull ratio = 2, find from the chart that θ = 90 deg.

NOTE.—While the pull is doubled by the change in construction, the total flux in the circuit is also doubled; therefore, it is important to make sure that the increased flux can be carried by the parts without saturation. If not, increased cross sections will be required at the saturated portions.

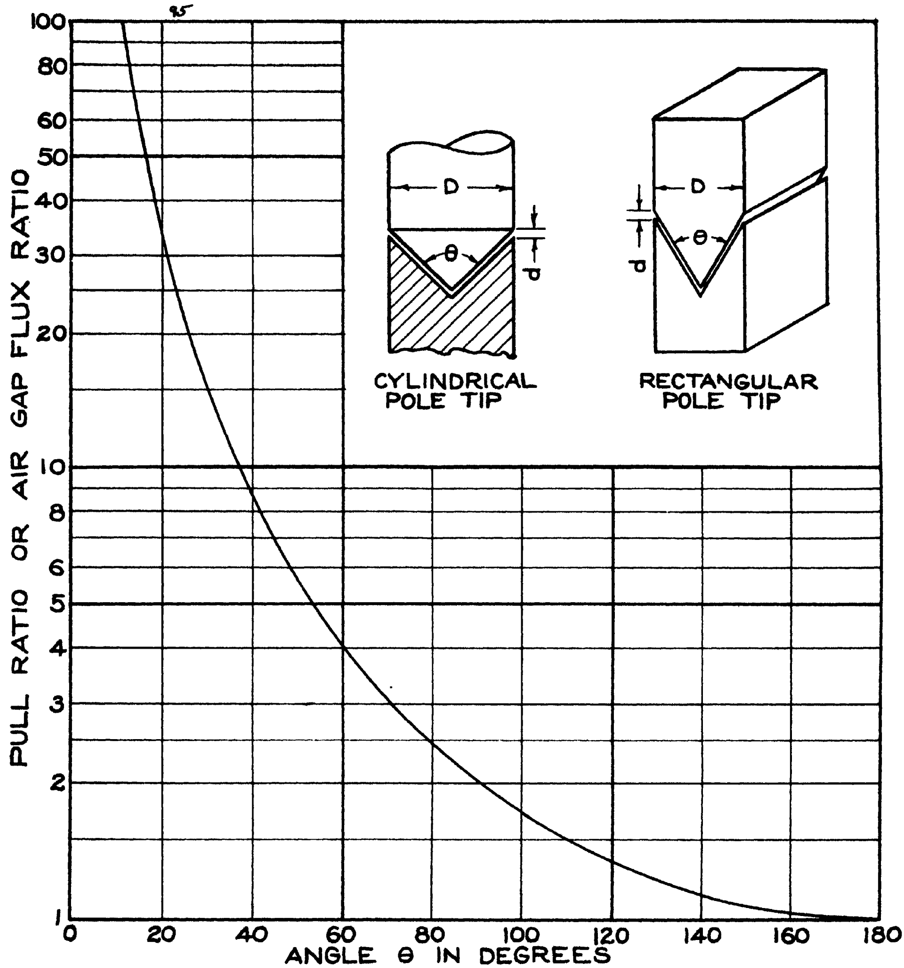


CHART NO. 95

Increase in magnetic pull and total air gap flux caused by tapered pole tips. The curve was computed on the assumption that the distance "D" is much greater than the distance "d" and also that the distance "d" is kept constant as the angle "θ" is varied. The entire reluctance of the magnetic circuit was assumed to be in the air gap.

Chart 96 shows the reluctance per centimeter of axial length between two long parallel iron rods of diameter d and separation S. (Permeability of the iron is assumed to be very high compared to the permeability of the air.)

Sample Problem

Find the reluctance between 500 centimeters of two 1 cm. diameter iron rods, separated by a distance of 4 cms. between centers. Neglect the reluctance due to the ends of the rods.

Solution

The ratio $S/d = 4$.

For the abscissa = 4, find the reluctance equal to .625 Oersteds per cm. length.

Total reluctance between 500 cms. of parallel rods = $500 \times .625 = 312$ Oersteds.

NOTE.—Oersteds is here used in the true original sense; namely, $\frac{l}{\mu A}$, where l = length of magnetic path, A its cross section area and μ the permeability. More recently many authors have begun to use the name Oersteds for magnetizing force which is truly the quantity Gilberts per cm.

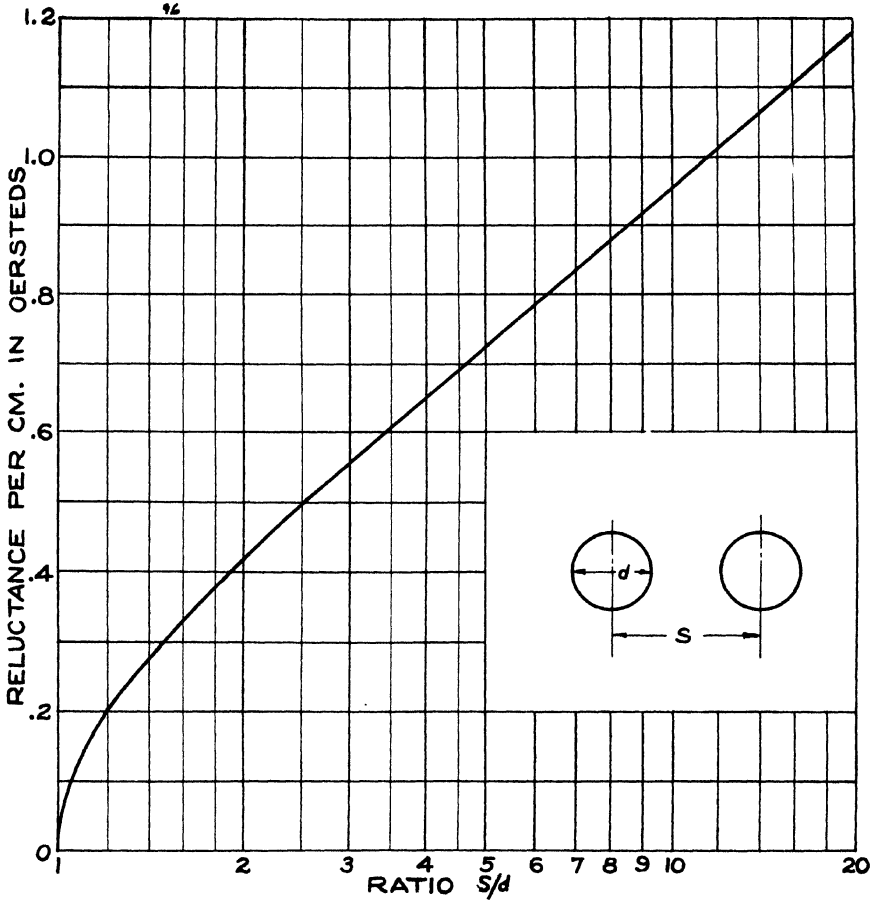


CHART NO. 96

Reluctance per centimeter of axial length of two long parallel iron rods of diameter d and separation S.

Chart 97 shows typical demagnetization curves of typical aluminum alloyed permanent magnet steels. The optimum points of B and H for each material are marked on each curve by a cross and represent the most economical state of operating of a magnet when used to supply external flux.

NOTE.—Due to the fact that the BH curves of the various alloys vary considerably with variations in compositions and heat treatments, the above curves should be used only as typical values and specific information for specific alloys should be requested from the steel companies if greater accuracy is required.

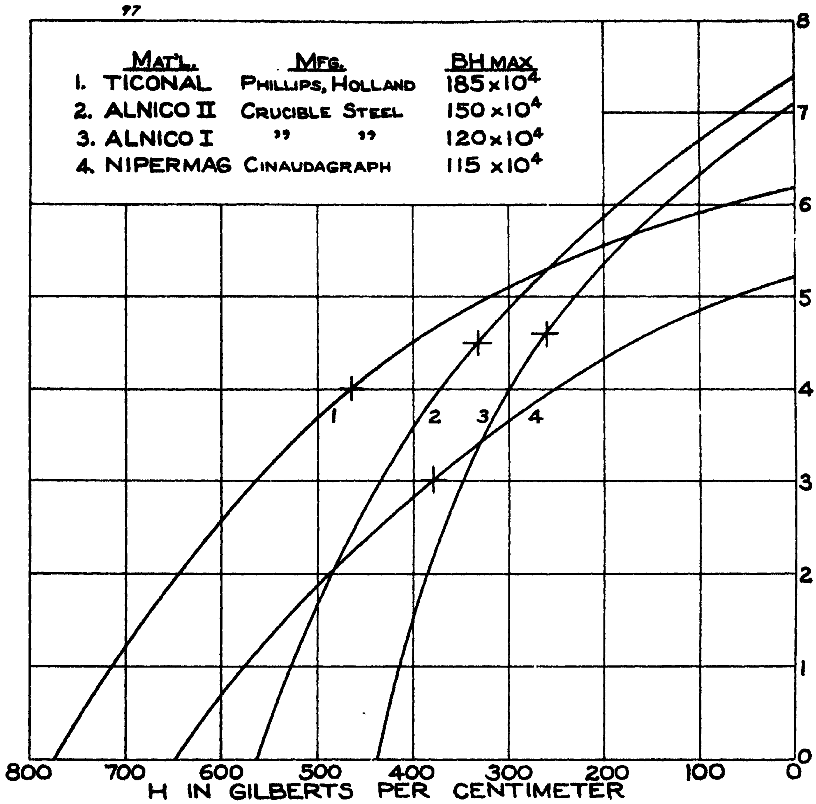


CHART NO. 97

Demagnetization curves of typical aluminum-nickel alloy permanent magnets. The points at which BH_{max} occurs are marked on each curve.

Chart 98 shows the quantity of permanent magnet required to supply various volumes of air gaps with the flux densities in kilogauss marked on the family of curves. The curves were computed for a BH product value $= 10^6$. For any other value of BH product of the permanent magnet material $= K \times 10^6$, the ordinates on the chart should be divided by K. NOTE.—The quantity of magnet obtained from the chart is only the amount required by the air gap; the leakage flux will require an additional amount of magnet equal to the ratio of leakage flux to air gap flux.

Sample Problem

Find the amount of Alnico II (chart 97) required to produce a flux density of 10,000 gauss in an air gap having a volume of 1 cc. Assume total leakage flux = air gap flux.

Solution

For an air gap volume = 1 cc., read the intersection with the 10,000 gauss line and find volume of magnet required ($BH = 10^6$) = 100 cc. Since leakage flux = air gap flux, 100 cc. will be required for leakage or a total quantity = 200 cc. (assuming $BH = 10^6$). From chart 97, Alnico II has a value $BH_{max} = 1.5 \times 10^6$. Therefore, the quantity of Alnico II required $= \frac{200}{1.5} = 133$ cc.

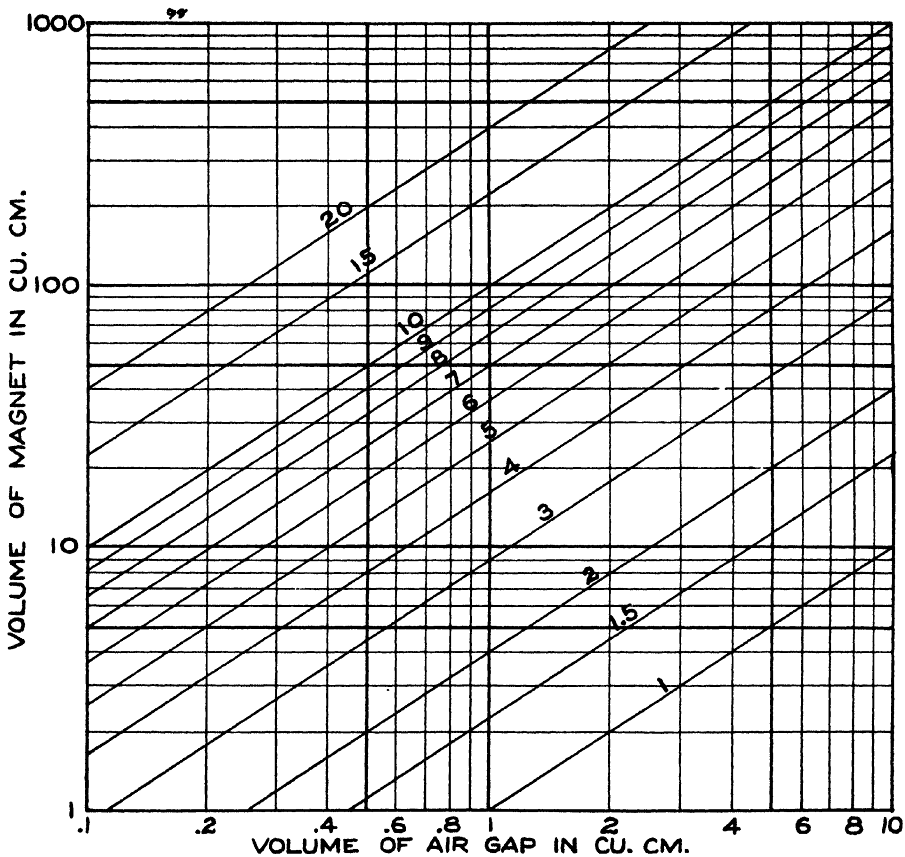


CHART NO. 98

Quantity of permanent magnet required to supply various sizes of air gaps with the flux density in kilogauss marked on the family of curves. The magnet is assumed to be operating at a value of $BH = 10^6$. For any other BH product $= K \times 10^6$, divide ordinates by K. Note: The quantity of magnet obtained from this chart is only the amount necessary to supply the air gap flux. To obtain the total amount, the values from the chart should be multiplied by the ratio of total flux to air gap flux. This factor is generally in the neighborhood of 2 for many of the conventional speaker structures.

Chart 99 is a conversion chart between volume in cubic centimeters and pounds for the various specific gravities shown by the family of curves. The chart is useful, for example, in converting from cc. of magnet (chart 98) to lbs. of magnet for the particular specific gravity of the material.

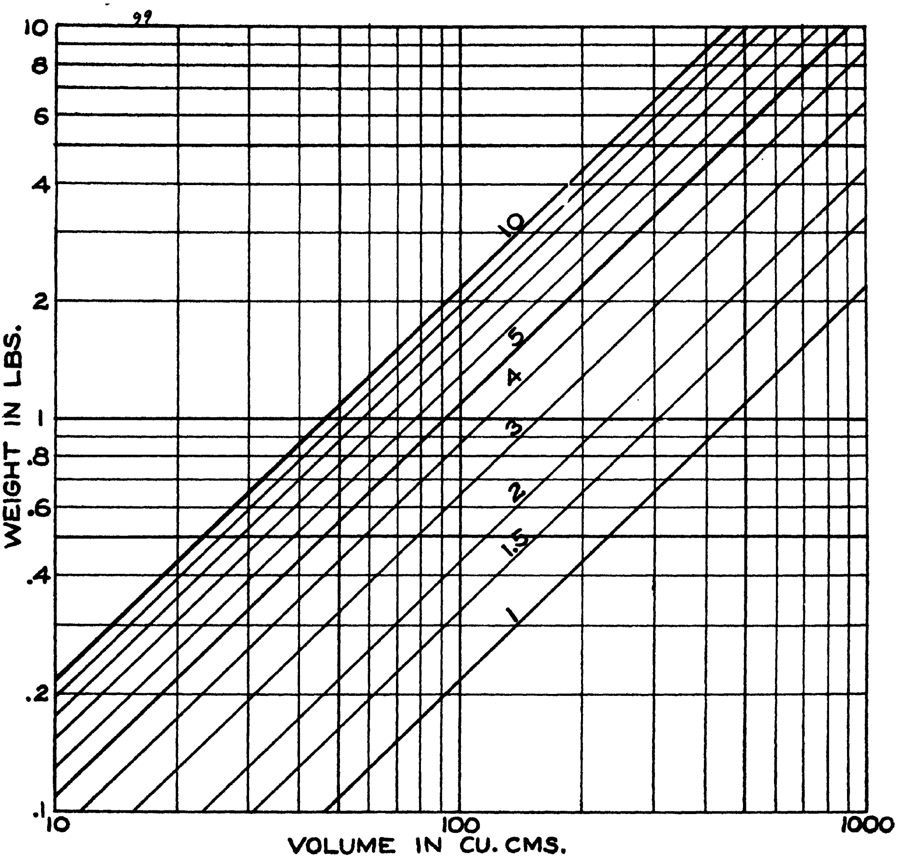


CHART NO. 99

Weight versus volume for the various specific gravities marked on the family of curves.

SECTION 10

Miscellaneous Data

CHART 100. Relation between octaves and frequency ratios.

CHART 101. Frequency ratio vs. intervals on the equally tempered scale.

CHART 102. Decibel conversion chart.

CHART 103. Decibel conversion chart.

CHART 104. Total db. energy level produced by adding two component db. levels.

CHART 105. Power loss resulting from impedance mismatching vs. absolute impedance ratio and phase angle between impedances.

CHART 106. Power loss resulting from mismatching the phase angles between two impedances.

CHART 107. Area of a spherical zone vs. subtented angle of zone and distance from source.

Chart 100 shows the relation between octaves and frequency ratios.

Chart 101 shows the relation between intervals on the equally tempered scale and frequency ratios.

Both charts are useful in determining the conversion from intervals or octaves to frequency ratios. The use of the charts is obvious without need for sample problems.

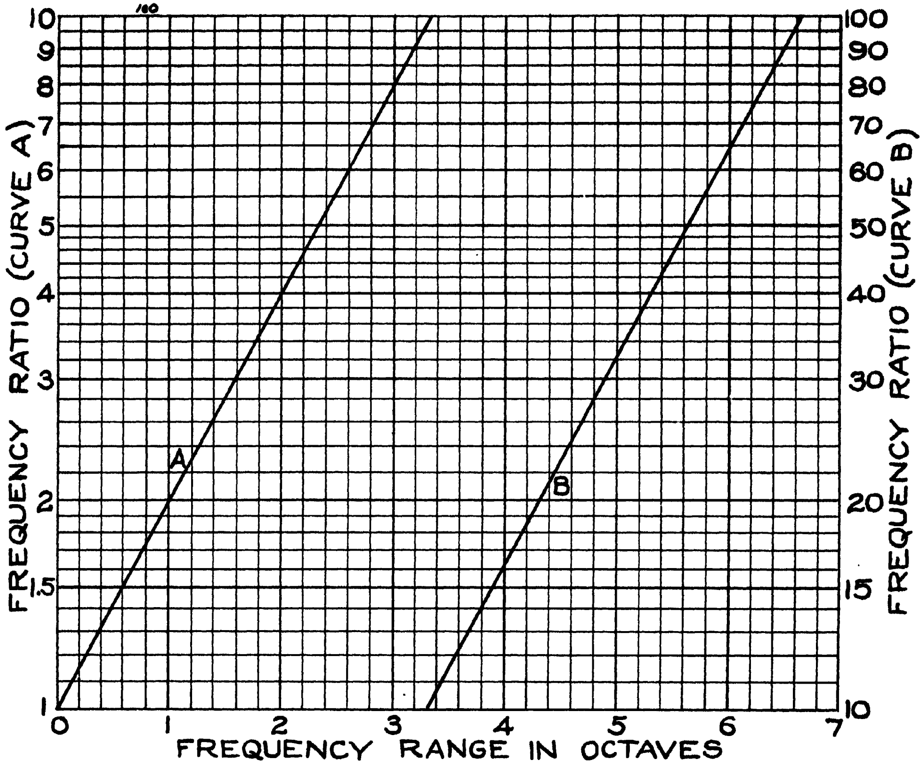


CHART NO. 100

Relation between octaves and frequency ratios.

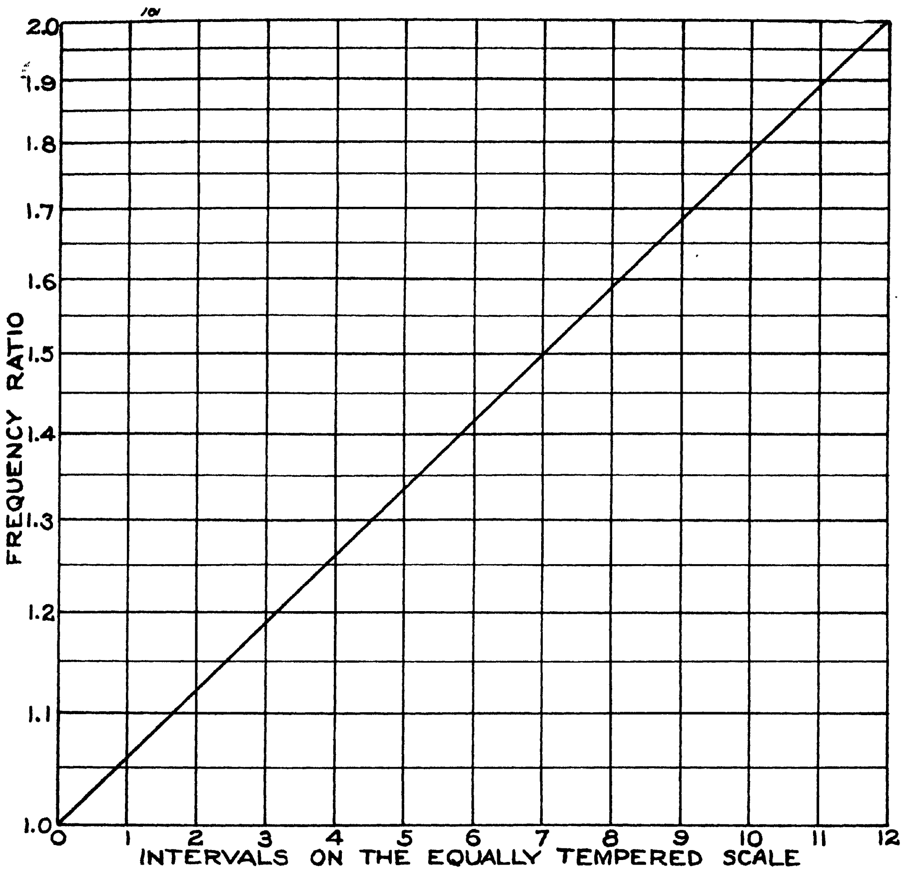


CHART NO. 101

Frequency ratio versus intervals on the equally tempered scale.

Charts No. 102 and No. 103 will permit the conversion of decibels to voltage, current, pressure or power ratios and vice versa. Chart No. 103 is effectively an enlargement of one of the squares on chart No. 102 and may therefore be used for accurate interpolation of Chart No. 102. An example will serve to show the simplicity of using the charts.

Sample Problem

Find the power represented by a level of 32.8 decibels above 1 milliwatt.

Solution

On Chart No. 102 it is seen that for a power ratio of 32.8 db. (right hand ordinate scale) the numerical ratio of powers is between 10^3 and 10^4 to 1. Turning to Chart No. 103, which can now be considered as an enlargement of the scale between 10^3 and 10^4, and reading opposite 2.8 on the right hand ordinate scale (which now means 32.8) the power ratio is read as 1.9×10^3.

Therefore, the answer to the problem is

$$P = 1.9 \times 10^3 \times .001 = 1.9 \text{ watts}$$

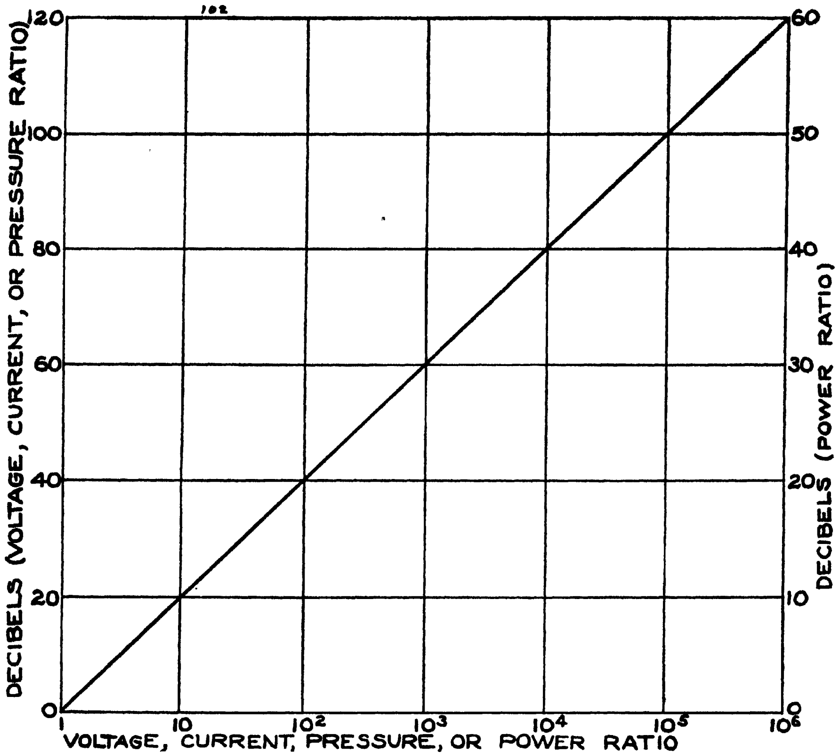


CHART NO. 102

Decibel conversion chart. For accurate interpolation values within any of the above squares, see chart 103 on opposite page.

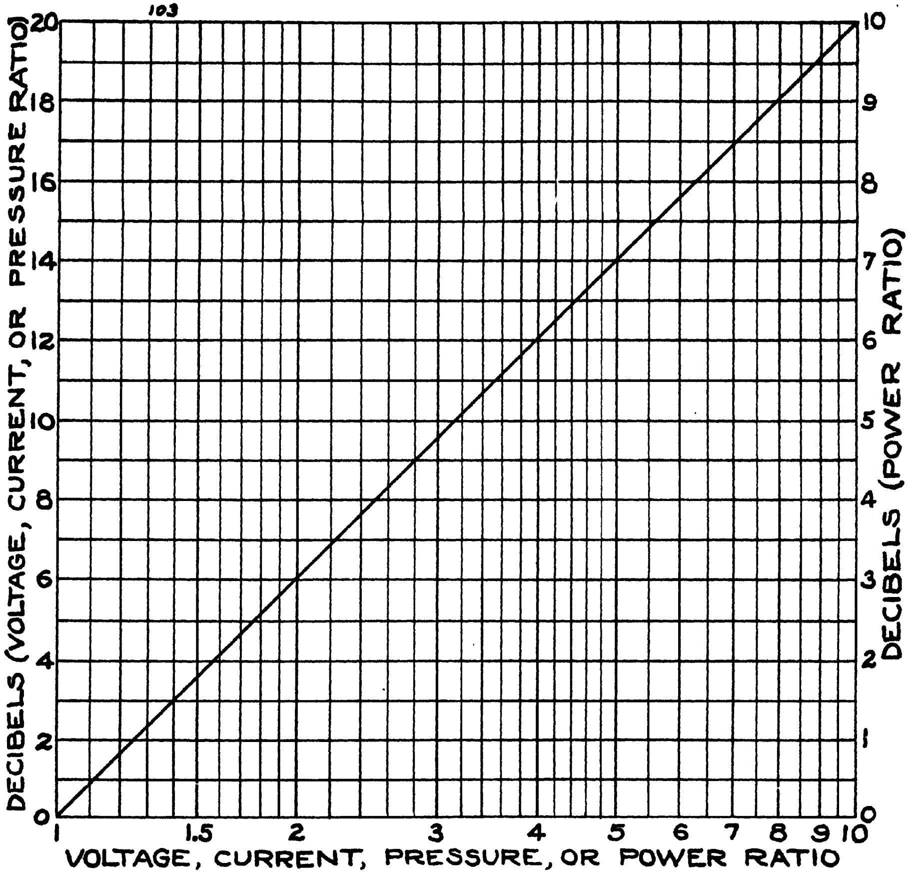


CHART NO. 103

Decibel conversion chart. See chart 102 on opposite page for higher ratios.

Chart 104 shows the change in magnitude of an energy level when another energy level is added to it.

Sample Problem

Two loud speakers are to be used simultaneously to supply energy in a particular location. Assuming that the speakers individually can generate acoustic powers of 8 db. and 10 db. respectively above one watt, find the total db. level of the two speakers operating simultaneously.

Solution

The second speaker has an output of 2 db. above the first one. For the use of the chart, the lower intensity speaker shall temporarily be used as the 0 db. reference level for the combination. The energy level of the added speaker is then 2 db. Looking on the chart, it is found that for an added component of 2 db., the level of the combination is 4.1 db. Therefore, the energy level of the combination above the level of the original speaker which has an output of 8 db. above one watt is,

$$8 + 4.1 = 12.1 \text{ db. above one watt}$$

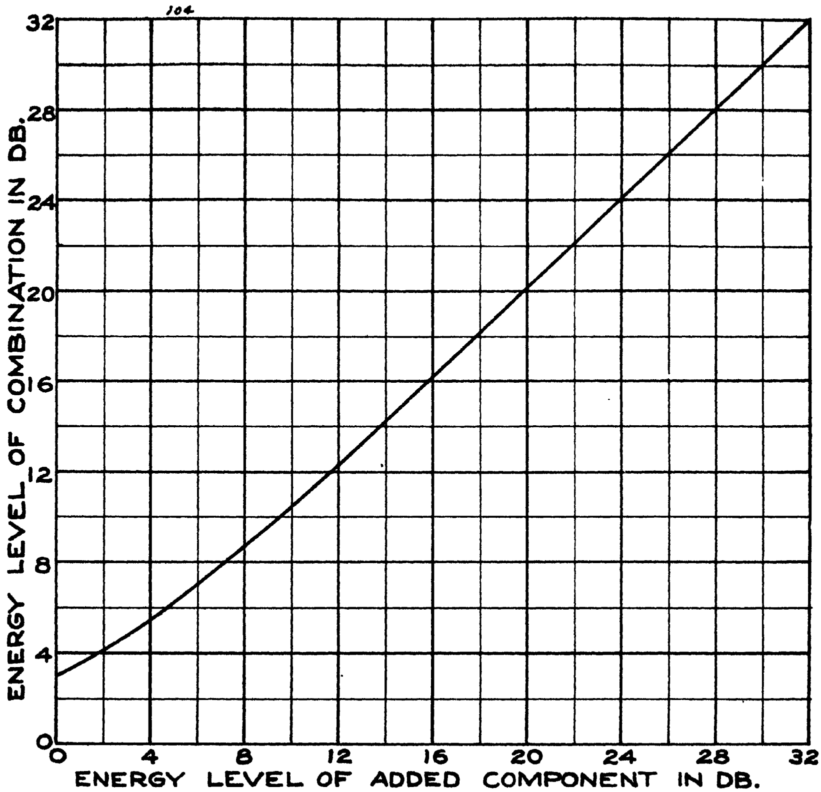


CHART NO. 104

Total db. level produced by adding two component energies together (level of lower energy component is assumed equal to zero db.).

Chart No. 105 shows the power loss that results due to mismatching the magnitude of the impedance of a generator with that of a driven load. The loss on the chart represents the amount lost due to mismatching the magnitudes of the impedances.

Sample Problem

A loud speaker having an impedance of 10 ohms and a phase angle of 60 deg. is fed directly from a generator having a 100 ohm internal resistance. Find the gain in power which will result if an ideal transformer is used to match the impedance magnitudes.

Solution

The ratio of impedance magnitudes for the mismatched condition is 10 to 1. On the abscissa scale read up at the ratio 10 until it intersects the 60 deg. phase angle line, at which point the loss due to mismatching is read as 5.7 db. This is the gain that will result if a transformer is used to match the impedances.

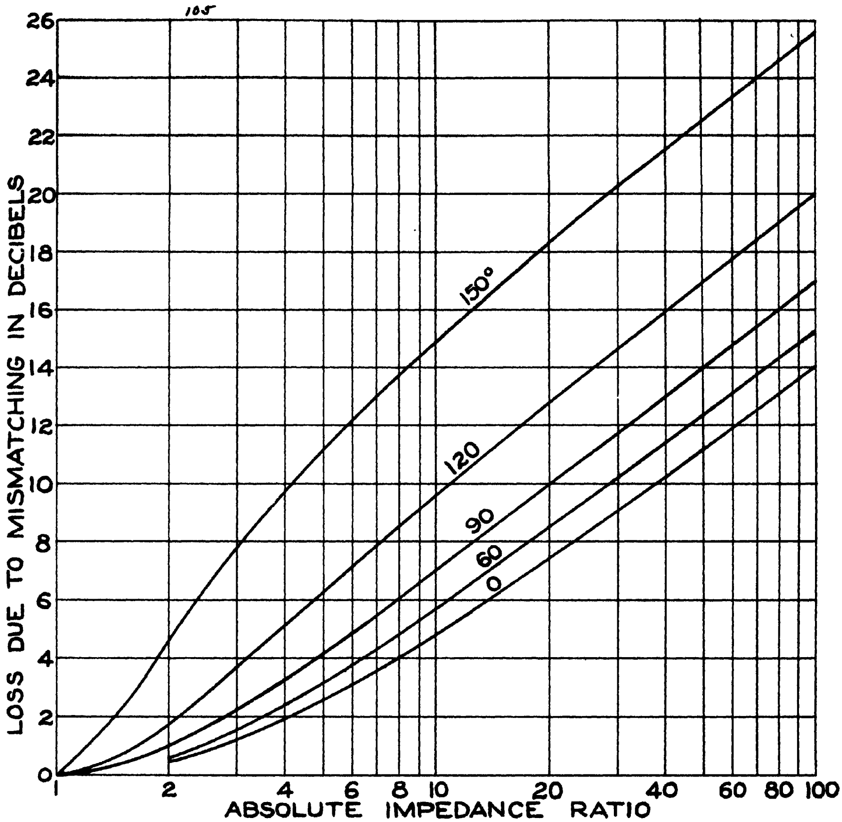


CHART NO. 105

Power loss resulting from the inequality of the absolute magnitudes of two impedances which are connected for the purpose of transferring power from one to the other. Figures on curves indicate the algebraic phase difference between the impedances in degrees.

Chart No. 106 shows the power loss that results when the generator and load impedances are equal in magnitude but different in phase angle. The loss in decibels is the reduction in power that is delivered to the load over what would be delivered if the total reactance in the circuit were made equal to zero and the absolute magnitudes of the impedances remained unchanged.

Sample Problem

A generator having an inductive impedance with a phase angle of 40 deg. supplies power to an inductive load having an impedance equal in magnitude to the generator impedance but with a phase angle of 60 deg.; find the increase in power that can be delivered to the load if the load impedance can be adjusted to be the conjugate of the generator impedance (that is, the load impedance is kept equal to the generator impedance while the power factor in the circuit is made equal to unity).

Solution

Along the abscissa find the generator phase angle equal to +40 deg. Read up to the intersection with the curve marked 60 deg. which gives the loss as 4.1 db. At unity power factor the increase in power will be 4.1 db.

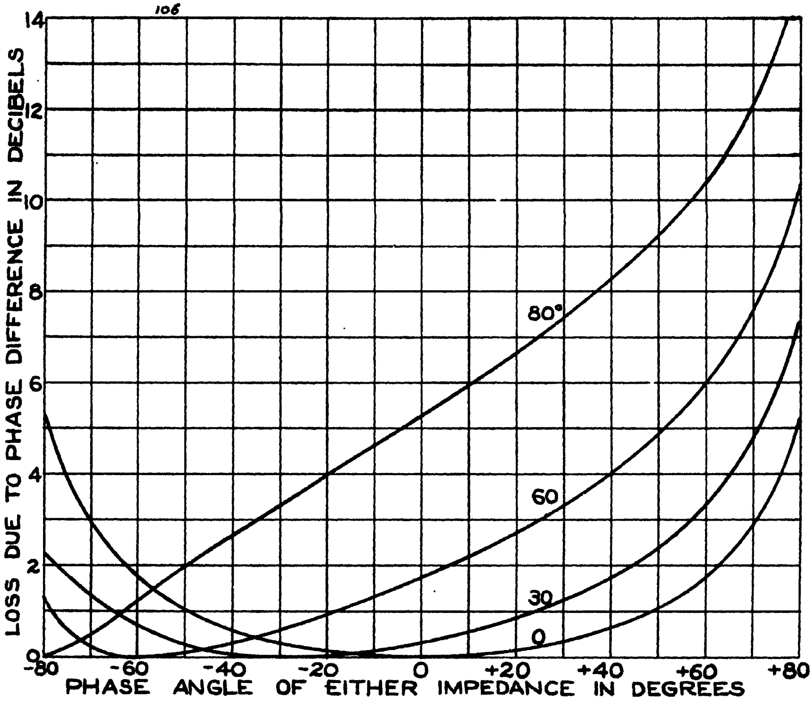


CHART NO. 106

Power loss in a circuit in which the line and load impedances are equal in magnitude but different in phase. The figures on curves indicate the phase angle of one impedance (positive) and the abscissa indicates the phase of the other impedance. Note: If both phase angles are negative assume them to be both positive in using the chart for determining the loss.

Chart No. 107 shows the area of spherical zones as a function of the subtended angle at the center of curvature and as a function of the distance from the center of curvature. The spherical area is given in square centimeters because the use of this chart is intended primarily for the purpose of finding the acoustic power output needed to supply a certain angle of coverage by a sound source, in which case the metric area is preferable.

Sample Problem

Assume the output from a sound source is confined to a total included angle of 50 deg. Find the acoustic power necessary to produce a sound pressure of 10 dynes per sq. cm. at a distance of 500 inches in free space.

Solution

At a distance $R = 500$ on the abscissa, read up to the intersection with the line $\theta = 50$ which is the condition of this problem and read the ordinate as 9.7×10^5 sq. cms. area.

From chart No. 9, for a sound pressure of 10 dynes/ cm^2, the acoustic power $= .24 \times 10^{-6}$ watts/cm^2.

Total power required $= 9.7 \times 10^5 \times .24 \times 10^{-6} =$ .23 acoustic watts.

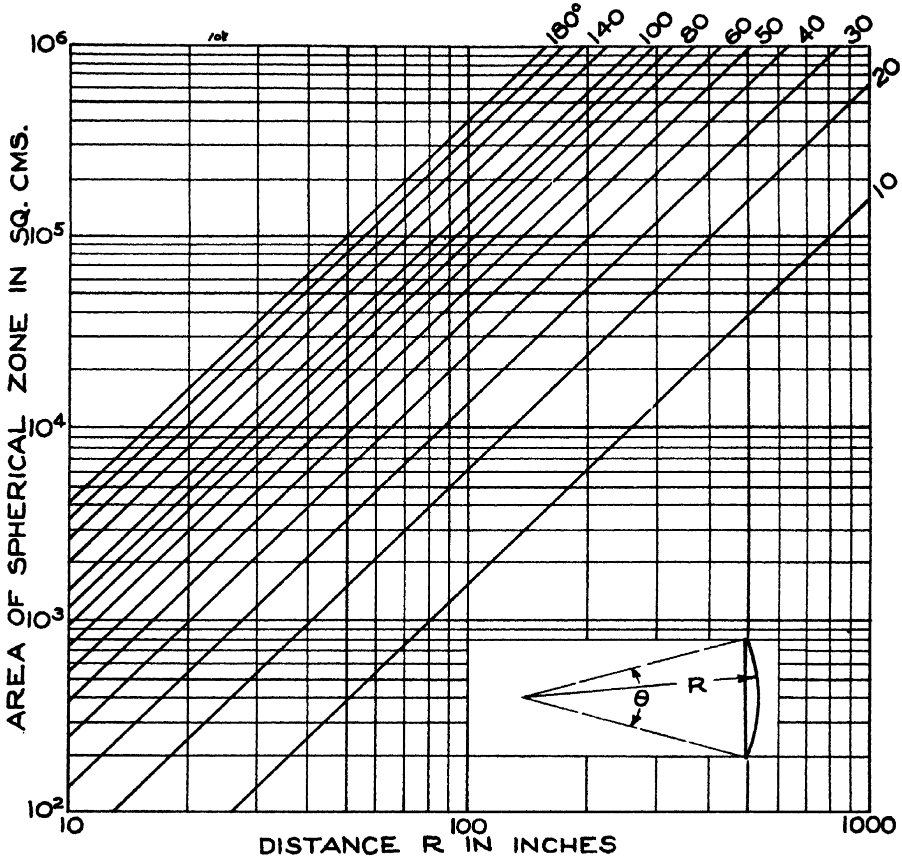


CHART NO. 107

Area of a spherical surface subtended by various angles (θ) as a function of the distance (R) from a source of sound.

INDEX

This book must be returned within 3, 7, 14 days of its issue. A fine of ONE ANNA per day will be charged if the book is overdue.
