REDUCTION OF NOISE

by

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It was only during the Second World War that much interest was taken in noises in and from ships. The use by the enemy of acoustic under-water weapons necessitated effective counter-measures ; and these cover the main field of research. Air-borne noise is of importance for operational reasons too ; high noise-levels in engine and boiler rooms reduce efficiency of communication, and noisy boiler-room fans have the same effect on the bridge. It may also be that high noise-levels reduce the efficiency of personnel directly by irritation and fatigue, but the point has not yet been satisfactorily established.

On the other hand, it is interesting to note that sound has many commercial uses. At high frequency it has been used for crack-detecting in metals, for facilitating the tinning of metals, for laundry work in assisting the removal of dirt from clothes, causing smoke to coagulate, and in Australia, scaring birds, as well as for echo-sounding. The Service use of the Asdic is well known. Whilst some of these uses are still being developed, there is no doubt that these applications are only a beginning.

Definition

Noise has been defined as " sound undesired by the recipient." This far-reaching definition has a most important subjective aspect for, in general, the decision whether a sound is, or is not, noise must be a matter of personal opinion. It has been found that it is extremely difficult to define it in absolute units, for even an ardent musician hearing music in the middle of the night when he wants to go to sleep might consider the music to be noise.

Sound is the name given to longitudinal waves in any substance having elasticity. Its velocity of propagation depends on the mass and elasticity of the substance and is given by $c = \sqrt{\frac{E}{\rho}}$ for solids ($c = \sqrt{\frac{K}{\rho}}$ for liquids), E being the elasticity, K the bulk modulus and ρ the density. For gases, $c = \sqrt{\gamma RT}$ where T is the absolute temperature, R the gas constant, and γ the ratio of the specific heat at constant pressure to that at constant volume. Velocities of propagation in air, water, and steel are given in Table I.

TABLE I

Velocities of Sound in Various Substances

Air 32°F.	1,083 ft/sec.
700°F.	1,668 ft/sec.
Water, Fresh	4,660 ft/sec.
Sea	4,920 ft/sec. (approx.)
Steel	16,650 ft/sec.

The human ear responds to sound of a limited frequency-band only, from

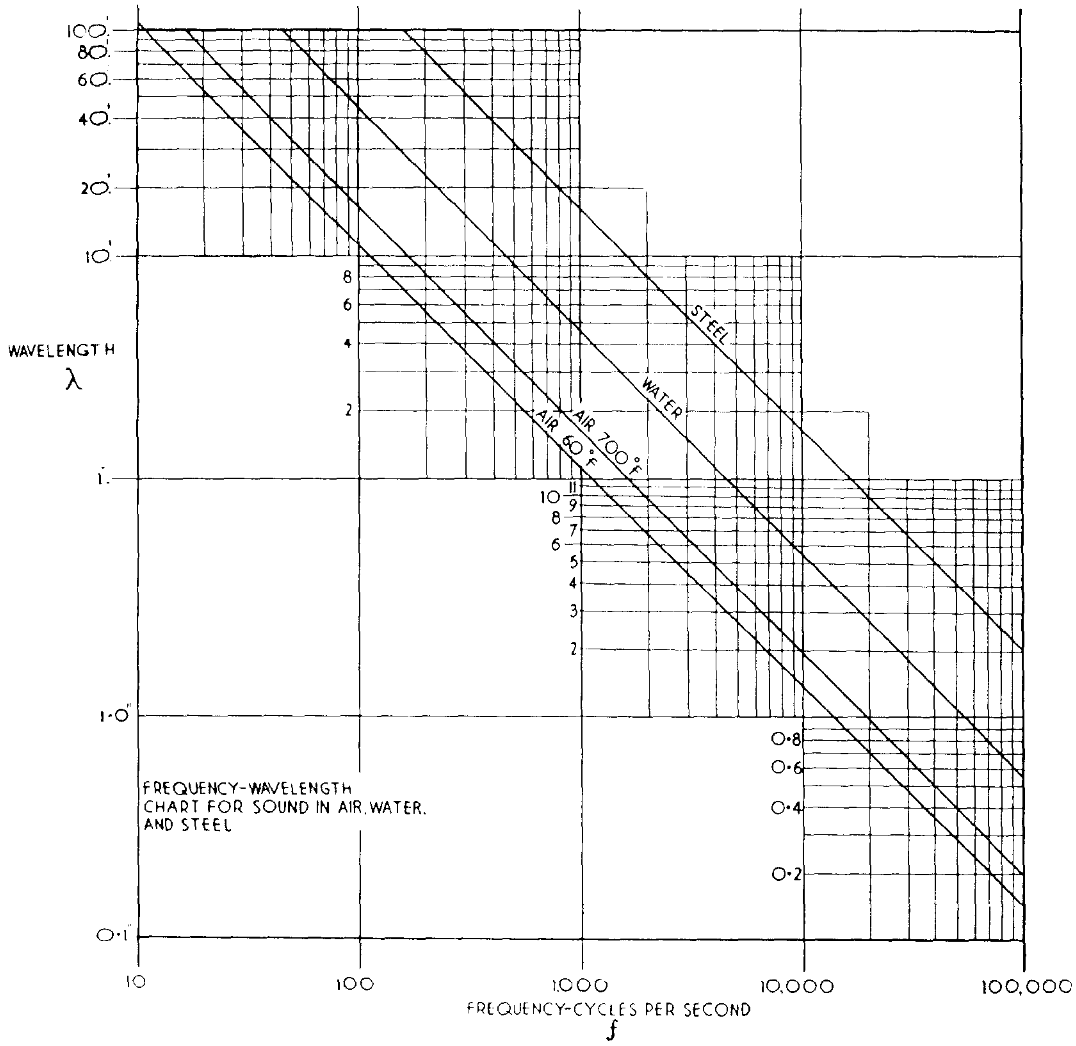

FIG. 1

about 20 to about 15,000 cycles per second, the upper limit varying somewhat with age. The piano covers the range 20—4,000 cycles per second.

The wavelength, λ, of a sound is the distance travelled by the wave in one cycle. Thus $\lambda = c/f$ and Fig. 1 gives the relationship between wavelength and frequency for air, water, and steel.

Measurement of Sound

The magnitude of a sound is usually taken as the Root Mean Square (R.M.S.) value of the pressure of the wave, although sometimes the energy of the wave is used. Due to the large range of magnitudes to which the ear is sensitive, *i.e.*, $10^6 : 1$, a logarithmic scale is used, called the decibel scale. On this scale, the difference between two sounds of pressure P_1 and P_2 is—

$$20 \log_{10} \frac{P_1}{P_2} \text{ decibels (db)}$$

whilst if the energy scale is used, the difference is—

$$10 \log_{10} \frac{E_1}{E_2} \text{ db}$$

It has been internationally agreed that if P_2 is .0002 dynes/sq. cm. then the above figure in db is the intensity of the sound. The corresponding figure for energy is 10^{-16} watts/sq. cm.

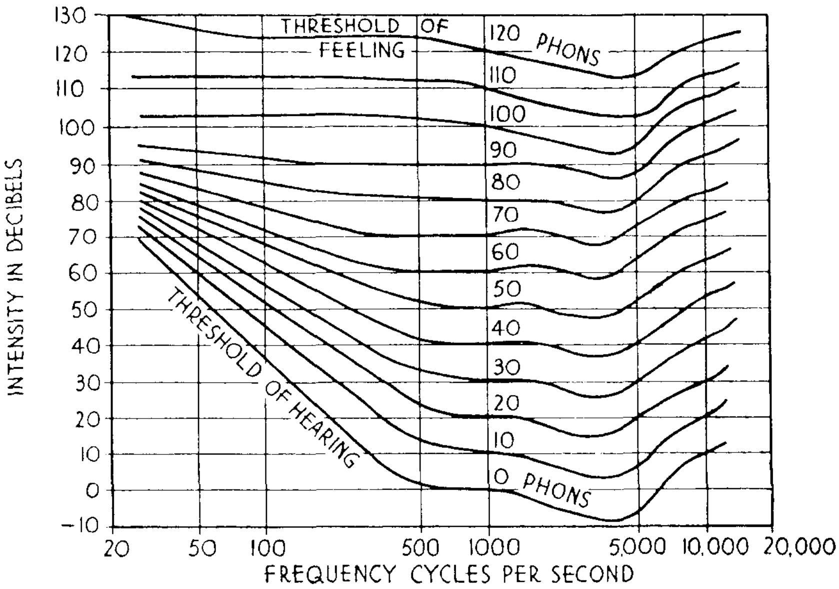

FIG. 2.—LOUDNESS CONTOURS

The human ear is not uniformly sensitive to sounds of different frequency. Fig. 2 shows the relationship between the intensity level and the loudness of the sound, expressed in phons, often called the Fletcher-Munson curves. To measure a sound in phons, it is compared with a 1,000-cycle pure tone. When the two appear equally loud to the ear, the loudness in phons numerically corresponds to the intensity level of the pure tone in db.

The lowest curve—the threshold of audibility—represents the weakest sound which can be heard, and it can be seen that the ear is relatively insensitive at low and very high frequencies, being most sensitive at about 3,500 c/sec. The threshold of feeling—the top curve—represents the point when the sound is felt rather than heard. At this point the ear is saturated, aural communication impossible, and the ear cannot discern sounds of greater intensity.

The ear is very unreliable for estimating the intensity of a sound so some form of meter is needed. Sound-level meters are of two types—subjective and objective. The former type generates a reference tone of 1,000 c/sec. which is compared with the sound to be measured. The reference tone is altered in intensity until it appears equally loud, when the setting on the instrument reads phons. This comparative method follows the definition of the phon.

Objective sound meters usually consist of a microphone, amplifier, and an output meter, and the intensity of the sound is indicated direct on the meter. Weighting networks are introduced so as to approximate with the phon ; two networks are often used to correspond with 40 phons, and 70 phons respectively. Above 85 phons, the meter is set to " flat response." These meters give reliable results and are very convenient in operation. They are made by General Radio, Western Electric, the Dawe Instrument Co. and others. Their readings are not exactly phons but for most purposes are near enough.

It is frequently required to know the intensity of the individual components of a mixed sound. For this purpose, the output of the sound-level meter is led to a frequency analyser which can be tuned to the required frequency. The intensity level of the component is then read off the meter on the analyser. The frequency analyser finds great application in measurements of machinery noises ; the source of the components can often be deduced from their frequencies.

Octave analysis is also used in this connection. A band-pass filter is used which passes a selected octave, and the average intensity over the band is measured. It is very useful for an indication of the components of the noise where no definite frequencies are present, such as living space and traffic noises. It is also used for under-water noises for the same reason.

Under-water noises are measured in the same way as air-borne noises. They can, however, be accurately measured to a much higher frequency than air-borne noises because of the larger wavelengths, the upper frequency limit being set by the physical size of the microphone. Where the size approaches λ of the sound to be measured, the results become very unreliable and reducing the size, whilst overcoming this difficulty also reduces the output of the microphone and makes amplification difficult due to the self-made noises in the amplifier. For air, a microphone 2 in dia., becomes unreliable above about 8,000 c/sec., whilst in water the corresponding figure is of the order of 40,000 c/sec.

Table II gives an estimate of the sound intensity of some common sounds.

TABLE II

Db	
0	Threshold of audibility
10	Rustling of leaves
20	Whispering
40	Suburban house
50	Average conversation, business office
60	Loud conversation, mess deck, noisy office
80	In tube train (windows open), lorry
90	Heavy street traffic, riveter in street
100	Near express train, noise on bridge of noisy M.T.B.
110	High speed Diesel—150 h.p., " screaming " manoeuvring valve, B.R. fan intake, good main gearing, steering-gear compartment
120	Heavy gun fire, noisy engine-room, submarine Diesel engine, inside noisy aircraft, noisy gearing
130	Threshold of feeling, noisy I.C.E. Supercharger, noisy boiler-room fans.

Many attempts have been made to state suitable noise levels for various purposes such as offices, living spaces, machinery compartments, etc. Wide discrepancies are found from different investigators and it seems that knowledge on this point is, as yet, insufficient. Many investigators have found that noise as such has no or very little effect on production commercially ; but most agree that loud noises produce irritation. Some hearing loss is experienced after exposure to loud noises and one investigator found that after 8 hours' exposure at 115 db (in an aeroplane), hearing loss was 40 db at 4,000 c/sec. Recovery is usually complete in 24 hours, half the loss being regained in 3 hours. Various writers have also attempted to differentiate between the effect of high and low frequency noises and also between intermittent and continuous noises on degree of fatigue and irritation experienced by the subject. As these tests are made on routine industrial operations however, they are not applicable to watch-keeping in engine rooms. The Royal Naval Personnel Research Committee (R.N.P.R.C.) will, it is hoped, perform suitable tests to ascertain the effect of various types of noise on watchkeepers.

At present, suggested levels are :—

90-100 db for machinery compartments, turrets, etc.,
85 db for off-duty compartments,
75 db for operational control positions, etc.

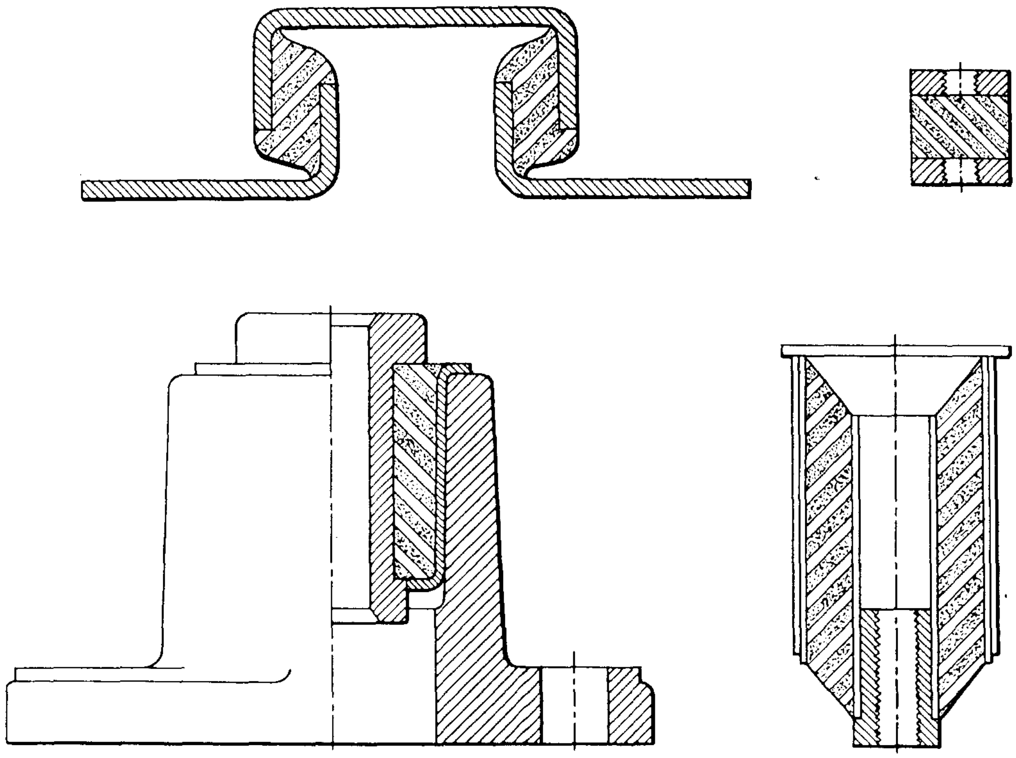

FIG. 3.—EXAMPLES OF COMMERCIAL RUBBER MOUNTINGS

but these are only a start and make no provision for frequency. If the above levels were concentrated in a single note of say 1,000 c/sec., the result would be highly objectionable. The level quoted for off-duty compartments is probably high.

Reasons for Reduction of Noise

Reasons for reduction of noise in order of priority are :—

(i) To minimise the effect of acoustic homing weapons, acoustic mines, and enemy listening devices,

(ii) to reduce interference with our own asdic and listening devices,

(iii) to increase efficiency in operational control compartments and facilitate communications, and

(iv) to minimise reduction of efficiency of personnel in off-duty compartments.

At high speeds, under-water noise from propellers can be picked up as far as 25 miles away under favourable conditions. At low speeds, the propeller noises drop and the main noise is then from gearing and machinery.

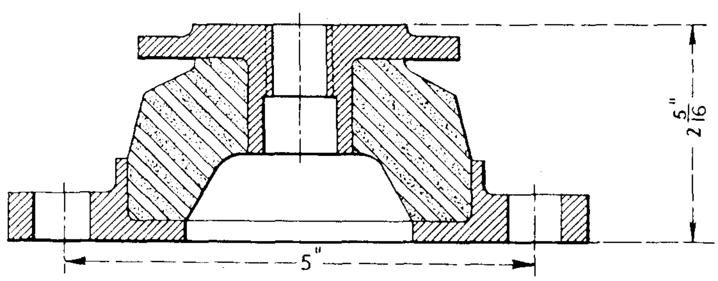

FIG. 4.—250 LB A.R.L. MOUNTING

As regards the types of ships, the highest priority is given to screening craft and submarines. Items (iii) and (iv) affect all types of vessels, but only in coastal craft is air-borne noise outside the vessel of operational importance.

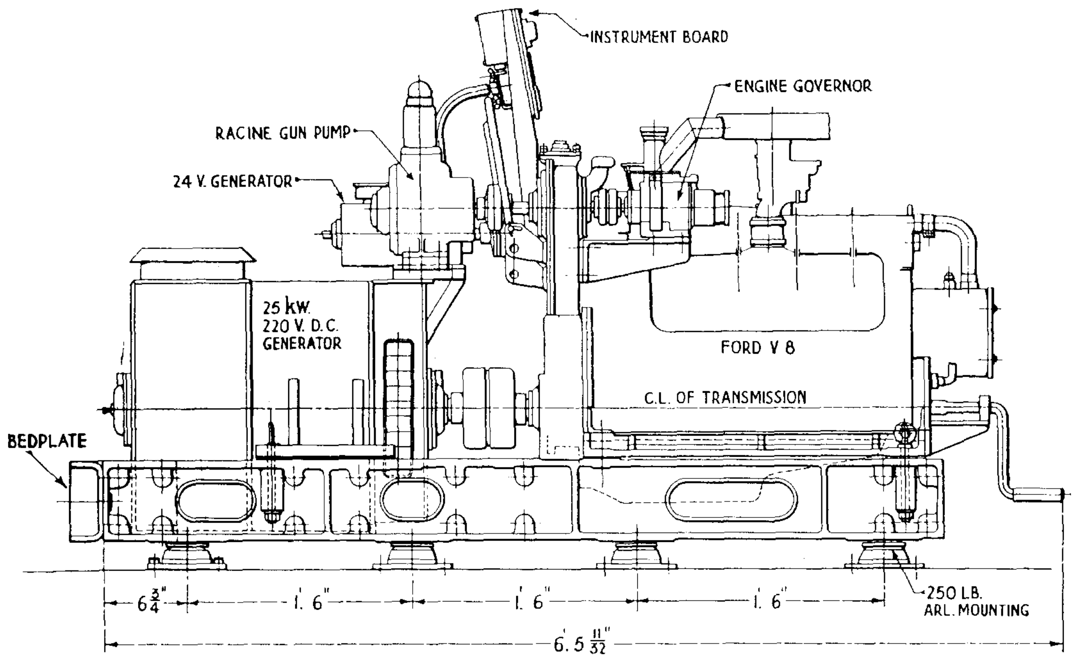

FIG. 5.—M.T.B. GENERATOR SET MOUNTED ON 250 LB A.R.L. MOUNTINGS

Attenuation of structure-borne Noise and Vibration

Solidly-mounted machines, however well balanced, usually transmit some vibration and sound to their seatings. The noise and vibration travel with ease along the ship's structure and may often be heard a considerable distance away, especially if a portion of the hull or bulkhead resonates with the particular frequency. It may also be transmitted to the sea. The noise and vibration may easily be attenuated if it is possible to interpose elastic mountings between the machine and the seating, and many types of mountings have been developed for this purpose.

The Admiralty Research Laboratory (A.R.L.) have developed a series of rubber mountings suitable for different loadings, as have many commercial firms such as Silentbloc Ltd., Andre Rubber Co., British Tyre and Rubber Co., and others. In general, commercial mountings are not suitable for naval purposes as they are unsuitable to withstand shock loads caused by under-water explosions. Some typical types of commercial mountings are shown in Fig. 3 whilst Fig. 4 illustrates a 250 lb A.R.L. mounting. At least 3 mountings are needed for a single machine for stability, and usually far more are required. A generator set mounted on 250 lb A.R.L. mountings is shown in Fig. 5.

The degree of insulation obtained with a mounting depends on the natural frequency of the machine on its mounting and the frequency generated by the machine, usually corresponding to its running speed and the harmonics thereof. It also depends on the damping present in the mounting. The amount of transmission of the vibration (or sound) rises to a peak when it corresponds to the natural frequency of the mountings and falls away at higher frequencies (Fig. 6). In general, if the natural frequency of the machine on its mountings is one-third or less of the running speed of the machine, satisfactory insulation is obtained.

The natural frequency of a machine on its mountings (treating the mounting as a simple spring) depends only on the deflection at rest, and Fig. 7 shows the relationship between resonant frequency and static deflection. Insulation at low frequencies demands a large deflection with consequent risk of movement of the machine due to rolling, etc. This difficulty can be overcome with limit

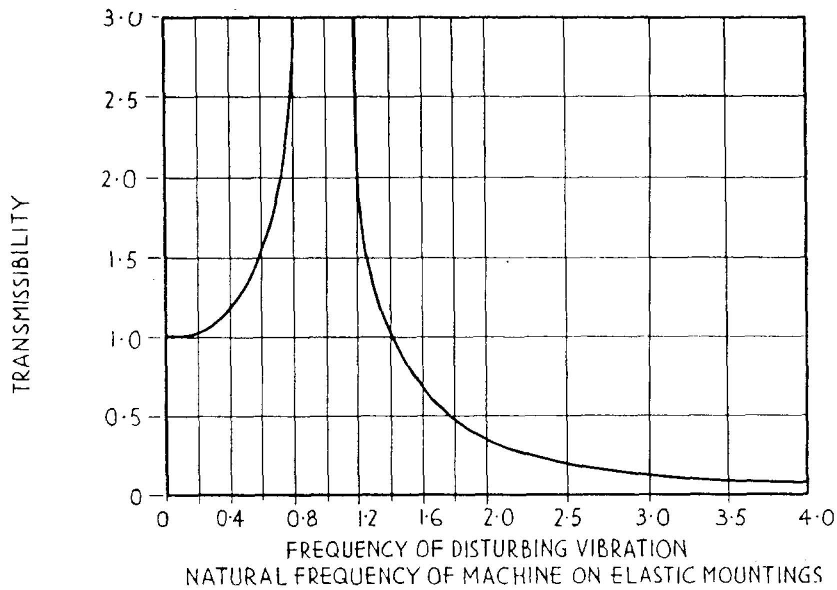

FIG. 6

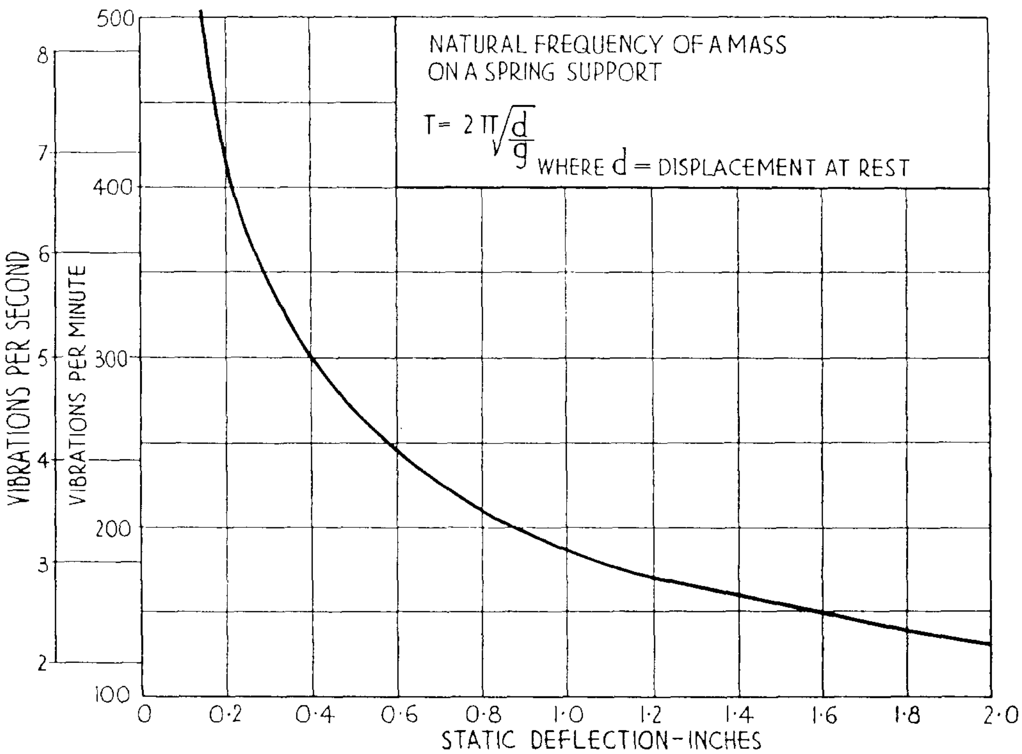

FIG. 7.—NOTE THAT HALF THE OBSERVED DEFLECTION SHOULD BE USED WITH RUBBER MOUNTINGS AS THE DYNAMIC STIFFNESS IS ABOUT TWICE THE STATIC STIFFNESS

stops fitted on the mountings, but should be avoided if possible as shock accelerations are increased thereby ; it is of importance when the machine had to drive some external shaft such as a propeller shaft. Limit stops are usually unnecessary in the case of self-contained units such as Diesel generators, motor-driven pumps, etc. In all cases there must be no rigid connection to the hull, and all pipes and leads must have flexible lengths included. Structure-borne noise may be measured with similar equipment as for air-borne noise, except that a vibration pick-up is used instead of a microphone.

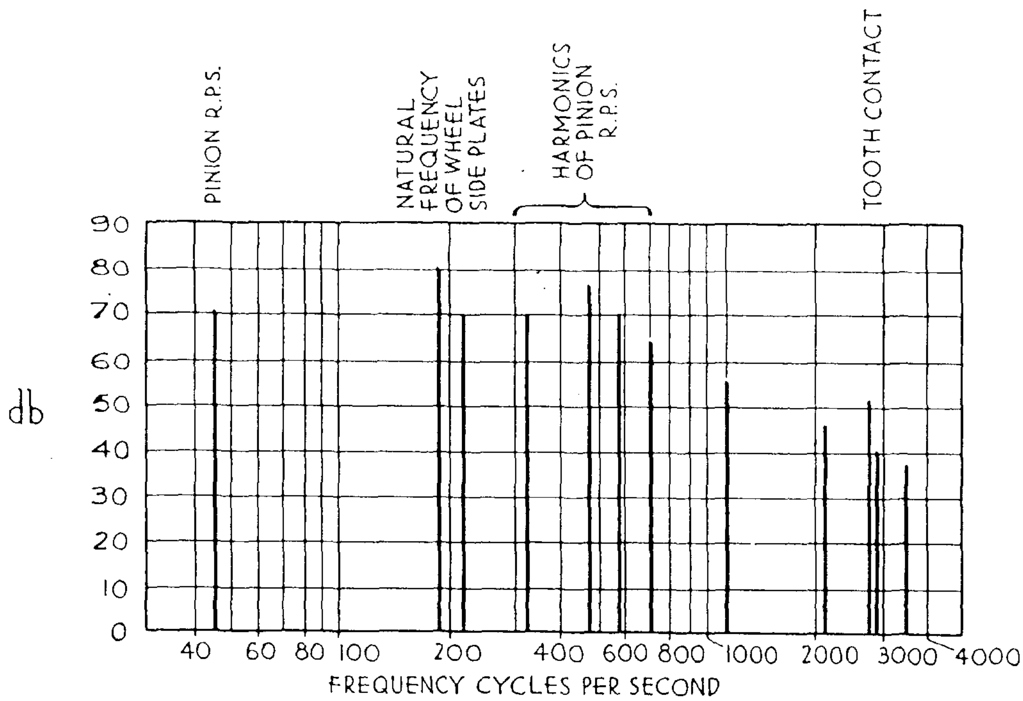

FIG. 8.—FREQUENCY SPECTRUM OF MAIN GEARING

Reduction of Hull and Propeller Noise

The great operational importance of this type of noise has been already mentioned. At high speeds almost all the water-borne noise from a ship emanates from the propeller and efforts are being directed to the production of more silent forms. Amongst others, the following methods are lines of attack on the problem :—

(*a*) Modification of existing forms of propellers.
(*b*) Absorption of noise.
(*c*) Reduction of the ship's resistance.
(*d*) Improved ship form near the propeller.

Other more obvious methods are to reduce propeller speed, and improve the finish and accuracy of manufacture.

Air-borne Noise

The reduction of air-borne noise as, indeed, of all types of noise is best done at the source. In many cases, however, a silent machine is incompatible with service requirements as they are often of large size and weight. Much can be done, for example, in the case of boiler-room fans, ventilation fans, and electric motors, by careful design, but some machines such as Diesels are inherently noisy.

Main gearing contributes a large amount of noise both air-borne and water-borne. Increased accuracy of cutting and post hobbing processes such as lapping, shaving, and grinding reduce the noise, and so far a reduction of about 10 db has been attained. A typical frequency spectrum for main gearing (Fig. 8) shows various components representing pinion revolutions per second, and harmonics thereof, tooth contact frequency and also some of uncertain origin, probably free vibrations of portions of the casing and wheel side plates.

One method of reducing the air-borne noise of a machine is to enclose it in a sound-proof hood. This has been done with some success in the case of

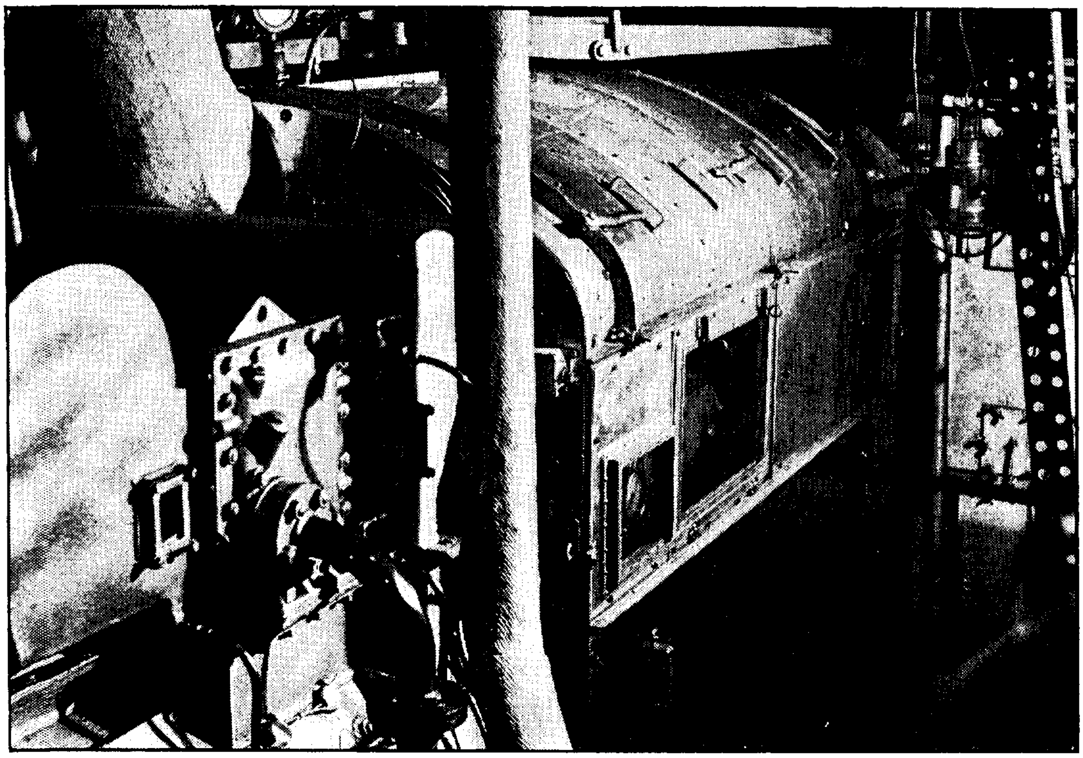

Fig. 9.—Sound-proof hood fitted in a destroyer on a Diesel generator

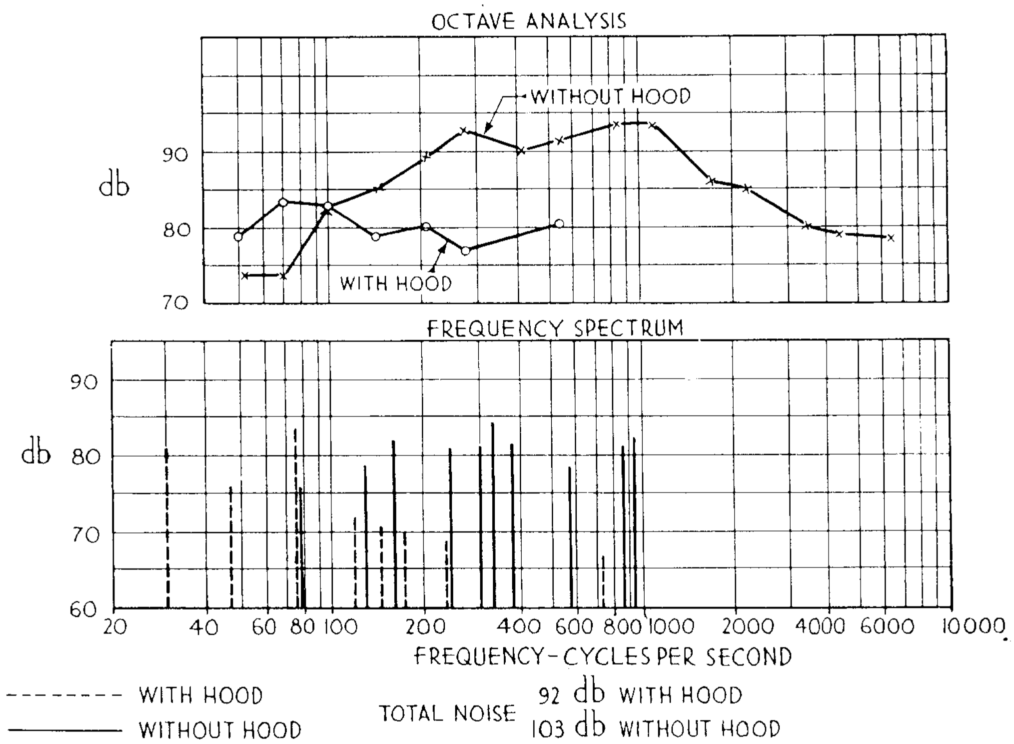

Fig. 10.—Frequency spectrum of Diesel with and without sound-proof hood

Diesel generators. A typical sound-proof hood is shown in Fig. 9, and Fig. 10 shows a frequency spectrum of another Diesel with and without a hood.*

* See also *Journal of Naval Engineering*, Vol. 1, No. 4, p. 23.

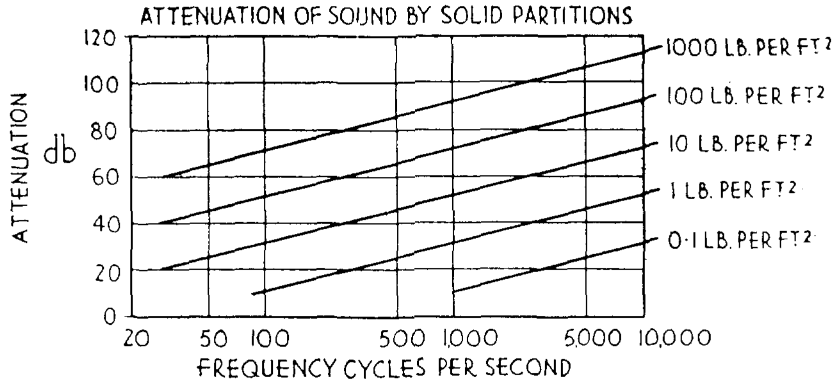

FIG. 11

The noise reduction is about 10db, but as the frequency spectrum shows, high frequencies are attenuated whilst some low frequencies are amplified. This is thought to be due to some resonance in the hood itself. The hood is effective, however, because the high frequencies are more objectionable than the low, and at higher speeds the effect of the latter diminishes.

The silencing of air-flow has been accomplished in a number of ways. I.C. engine intake and exhaust silencers are well-known examples of this type. Splitters faced with acoustic linings such as rock wool are very effective in attenuating noise, especially of high frequency and they have been used to silence the air intake of the gas turbine installed in M.G.B.2009. In this case, the splitters are 2 in apart and 30 are fitted in a trunk 8 ft wide. The noise is mainly of high frequency, and good attenuation is expected.

Noise may also be confined to a compartment by sound-insulating partitions. In this case, the attenuation depends on the mass of the partition for high frequencies, and the stiffness at low frequencies. Curves showing the effect of mass only in Fig. 11 indicate that at high frequencies, quite light partitions are effective. A steel bulkhead $\frac{1}{2}$ in thick (20 lb plate) will attenuate sound about 35 db at 100 c/sec. and considerably more than this at higher frequencies. Lining bulkheads with some sound insulant such as Paxtiles, felt, rock wool, or fibreglass reduces the reflection of sound especially at high frequencies and is used for acoustic booths. Great attenuation, such as is needed in film studios and acoustic laboratories, necessitates large thicknesses of linings and the use of multiple partitions.

Conclusions

It is hoped that this article illustrates in outline some of the work going on and that required for a satisfactory solution of the noise problem. The Research and Development Panel on Noise Reduction was formed early in 1948 to investigate and make recommendations, and systematic noise surveys of ships are being organized.

Bibliography

A brief bibliography given below may be of interest. The first two books are of a general nature covering much experimental and theoretical work ; (ii) is probably of more interest to the marine enigneer. The third publication is included as it has one section on the use of rubber for sound and vibration insulation.

(i) *A Textbook of Sound.* A. B. Wood. G. Bell & Sons.
(ii) *Acoustics.* Alexander Wood. Blackie & Sons.
(iii) *Rubber in Engineering.* H.M.S.O.
(iv) *Instruction for the Sound-Insulation of Auxiliary and Electrical Machinery in Submarines.* B.R.1269 (Restricted).

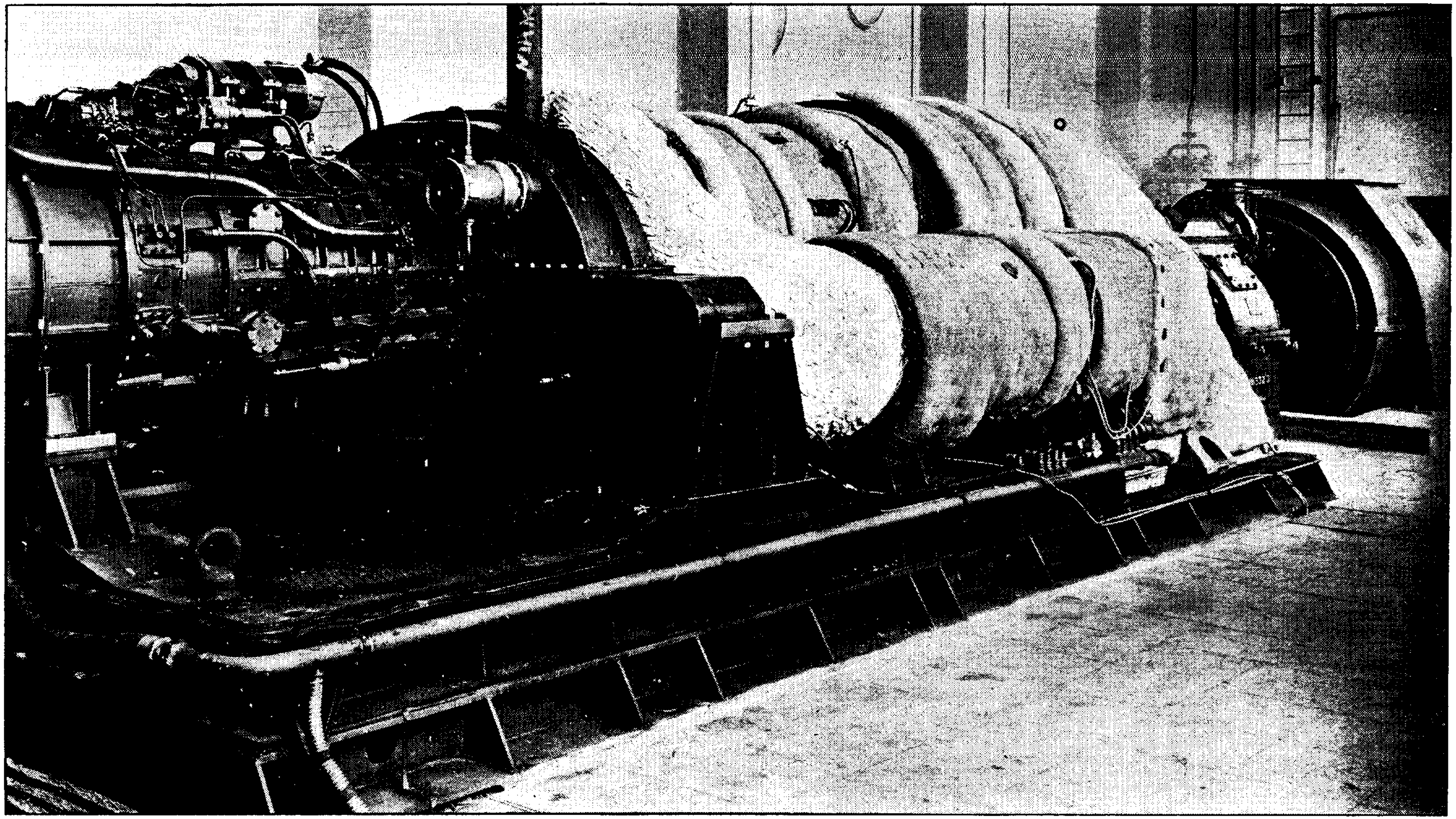

FIG. 1.—METROPOLITAN-VICKERS ELECTRICAL COMPANY'S 2,000 kW GAS TURBINE PLANT INSTALLED IN MAIN WORKS