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RESEARCH DEPARTMENT

THE DESIGN OF THE PGD AND PGS RIBBON MICROPHONES

FINAL REPORT

Report No. M-015/2

(1956/17)

THE BRITISH BROADCASTING CORPORATION

ENGINEERING DIVISION

RESEARCH DEPARTMENT

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SUMMARY

This report completes the account begun in Report M-015, of the design and performance of the new ribbon type pressure-gradient microphones. Additional information on performance, including measurements of wind noise and non-linearity, is given.

1. INTRODUCTION.

In the first report under the above title, the essential features of the PGD and PGS microphones were discussed and a certain amount of information on the performance of the prototypes was given. In this final report, which is concerned only with the type PGS microphone, various design considerations which were omitted or only briefly touched upon in the first report are discussed and illustrated by experimental data. Details are given of more recent work on high-frequency resonance in ribbons and of changes in ribbon design made as a result of experience with the first models. Finally, complete performance data is given for PGS microphones produced by Equipment Department. The nature and extent of the production variations are also indicated.

2. DESIGN DETAILS.

2.1. Magnet System.

Reference was made in the first report to experiments carried out with an electrostatic model to find the ratio of useful to total flux with various shapes of pole piece. Fig. 1 shows typical data obtained by this method; in each case the flux crossing the central area is plotted as a percentage for various gap widths. Recessed poles show a slight advantage, particularly with narrow gaps, but, for the present purpose, leave too large a leakage space on either side of the ribbon. The effect of the recess is nevertheless worth noting for possible use in future designs.

The useful flux density in the PGS microphone is fairly constant over the length of the poles, but varies across the gap from 6500 gauss at the pole tips, to 4500 gauss at the centre. The flux density in the mild steel pole pieces is not high and the substitution of materials such as Permendur, having a relatively high magnetic saturation point, produces only about 5% increase in the gap flux. For the purpose of the PGS design, this small advantage was not considered sufficient to outweigh the manufacturing difficulties associated with the alternative pole materials; in large-scale production, however, using pole pieces produced by the method of investment casting, the increase in efficiency obtained might prove worth while, if only because it would permit the specification for the permanent magnet to be slightly relaxed.

2.2. Ribbon.

In the first report, the effects of ribbon tension, type of corrugation and acoustic damping on the low-frequency response of the microphone were discussed. Further investigations have been carried out on the effect of ribbon corrugation on the frequency response of the microphone and on susceptibility to mechanical shock.

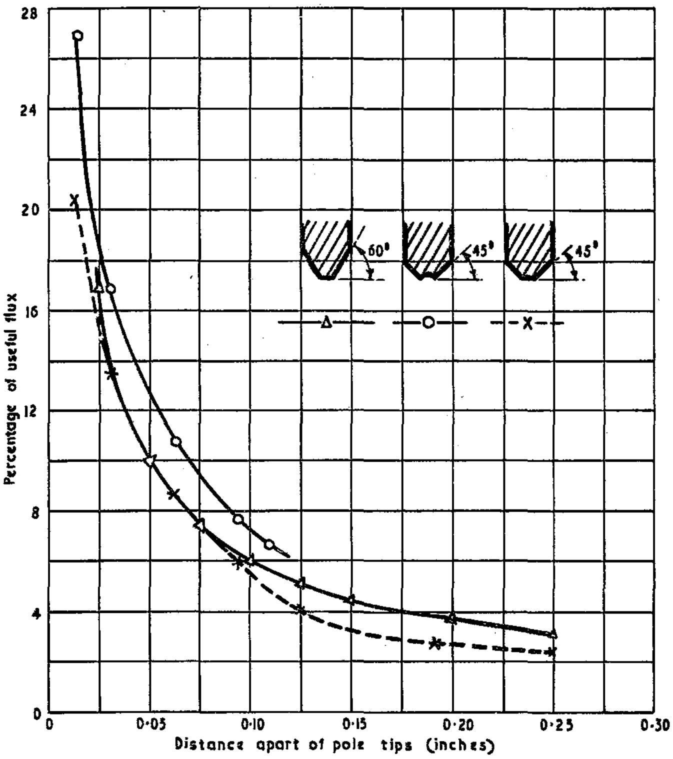

Fig. 1 - Microphone Type PGS. Ratio of useful flux to total flux between pole pieces. Data obtained by electrostatic model

Attempts were made to reduce still further the residual irregularities in the low and middle-frequency response which result from longitudinal resonance modes of the ribbon. For reasons given in an earlier report[1], the damping screens lose some of their effectiveness unless they are placed very close to the ribbon. It was not considered practicable, however, to reduce the spacing to less than the $\frac{1}{32}$ in (0·08 cm) allowed in the present design and any increase in damping could only be achieved by a change in the ribbon itself. With relatively thick ribbon material, some increase in damping can often be obtained by annealing subsequent to corrugation but with the thin aluminium leaf used in the PGS microphone, little change results. It was found possible nevertheless to remove the residual resonance effects almost completely by causing the tension of the ribbon, on which the frequencies of the modes depend, to vary continuously across its width; this effect was produced by using fine corrugations formed initially more deeply on one side of the ribbon than on the other. The smoothing of the frequency characteristic was not however accompanied by any audible change in quality and as ribbons corrugated in the manner described were found to be susceptible to the effects of mechanical shock, it was decided not to employ the artifice of uneven tension in the final design.

At frequencies above about 3 kc/s, the response of the microphone is affected to some degree by transverse resonance modes of the ribbon; the extent to which these modes are excited depends on the degree of accidental asymmetry of the ribbon, and the result is therefore not always under control. Consistent performance can be achieved by using corrugations of fine pitch as described in the first part of this report, but such corrugations, when applied to the ribbons of the prototypes, were later found to straighten out after a time as a result of the vibration and shock to which microphones are subjected in use. In the course of the investigation attempts were made to simulate this aspect of service conditions by such expedients as passing a.c. of square waveform through the ribbon to produce abnormally large deflections; these methods however gave grossly over-optimistic results, and impact tests were found to be essential. As a result of these experiments the ribbon profile used in the prototype PGS microphones was modified in the production models; the ribbons were formed with 20 corrugations per inch (7·8 per cm) but these corrugations were pulled nearly flat on fitting; with this arrangement, sagging of the ribbon is prevented, while the production variation in high-frequency response is confined to about ± ½ dB.

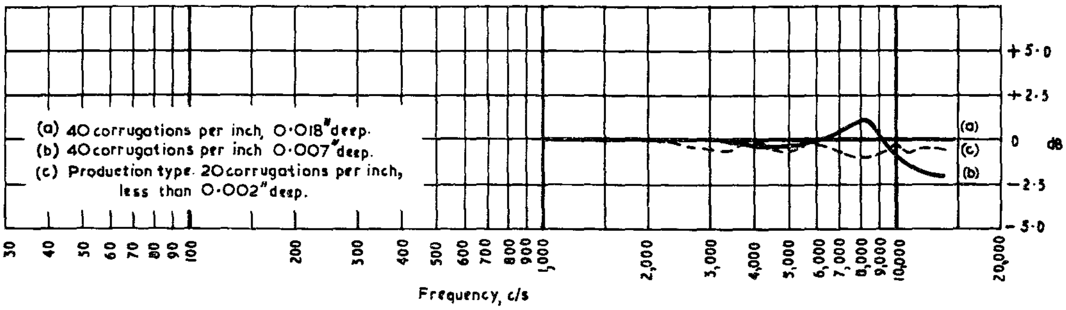

Fig. 2 - Microphone Type PGS. Change in high-frequency response with form of ribbon corrugation

Fig. 2 shows the effect of ribbon corrugation on high-frequency response in three typical cases. For the sake of clarity, only differences in frequency response are shown, the datum line (a) being the response of a microphone having a ribbon so deeply corrugated that the first transverse resonance mode lay above 20 kc/s. Curve (b) shows the effect of transverse resonance within the working band, a result which could in some circumstances be turned to good account if the ribbon could be made sufficiently stable. Curve (c) relates to a typical PGS microphone.

Reference was made in the first report to the use of a motional impedance bridge for investigating irregularities in the low-frequency response of ribbon microphones. It has been found possible, by some refinement of technique, to employ the same artifice up to frequencies of the order of 10 kc/s and much of the investigation into the effects of transverse resonance was carried out by this means. Fig. 3 shows a typical example of a characteristic obtained with a particular experimental ribbon using the motional impedance bridge described in an earlier report[2]; the initial balancing operation was carried out at 10 kc/s. In the absence of the damping screens, the longitudinal resonance modes of the ribbon are very prominent at frequencies below 1000 c/s; in this frequency range, the acoustic response of the microphone followed closely the curve of Fig. 3. The two peaks at approximately 10 kc/s and 11 kc/s are associated with transverse resonance modes of the ribbon. Because of the non-uniformity of the magnetic field, which is about 30% weaker in the centre of the ribbon than at the edges, these modes are more strongly excited when the ribbon is driven electrically than they would be under normal working conditions and the change in motional impedance which they produce is greater than the corresponding change in acoustic response.

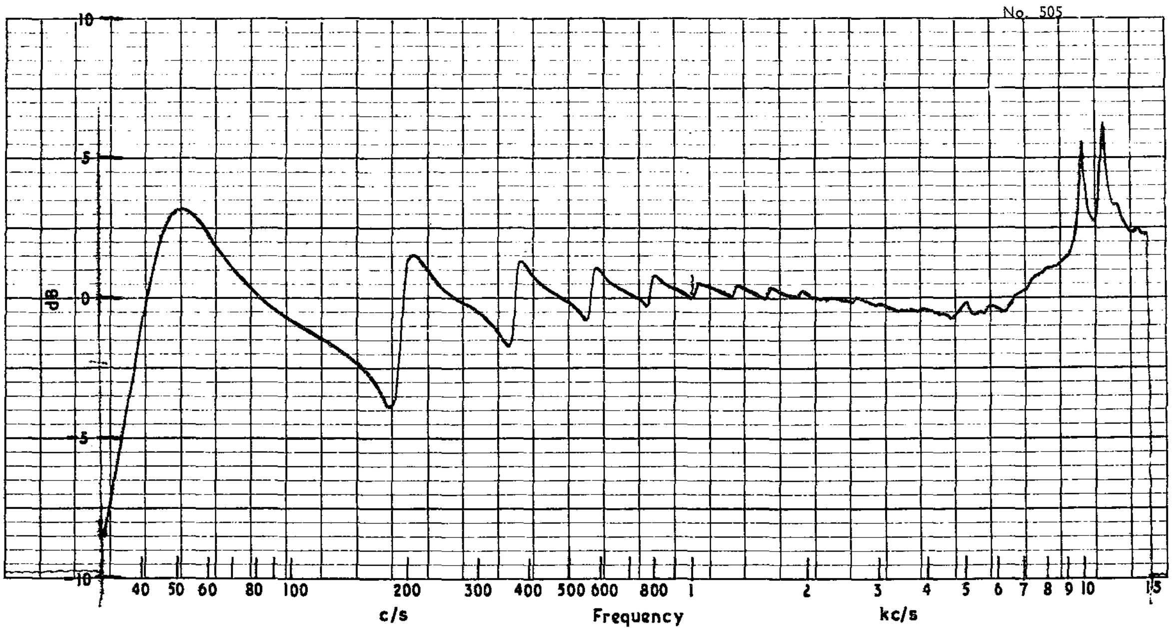

Fig. 3 - Example of curve taken with experimental ribbon using motional impedance bridge

2.3. Low-Frequency Baffle.

A brief account was given in the first report of the use of a porous baffle to raise the low-frequency response of the microphone and to compensate for the loss introduced by the damping screens.

No mathematical treatment of the behaviour of a porous baffle has yet been attempted and only a qualitative account of its action can therefore be given. The device was first used for electrostatic microphones in 1935 by von Braunmühl and Weber[3], but in 1941 a patent covering its application to ribbon microphones was applied for by Olson[4]. The effects obtained were attributed by von Braunmühl and Weber to a supposed variation in the acoustic impedance of the baffle with frequency. In fact the desired result can be obtained with baffles of fine gauze having an acoustic impedance substantially constant over the frequency range of interest. A more satisfactory explanation lies in the fact that the acoustic impedance of the external path between front and back of the microphone diaphragm increases with frequency, so that a porous baffle having a fixed impedance so low that its influence is negligible at high frequencies can act as an obstacle at lower frequencies.

2.4. Case and High-Frequency Reflectors.

Some account was given in the first report of the effect of the case upon the microphone response and of the use of reflector plates to modify the high-frequency response.

It should be noted that the degree of obstruction presented by the microphone case to sound at high frequencies increases not only with the proportion of the total area obstructed but to a large extent with the thickness of the material. For example, perforated metal produces a greater change in high-frequency response than does fine wire mesh while with bars or grilles, even if narrow and widely spaced, the effects are even more pronounced.

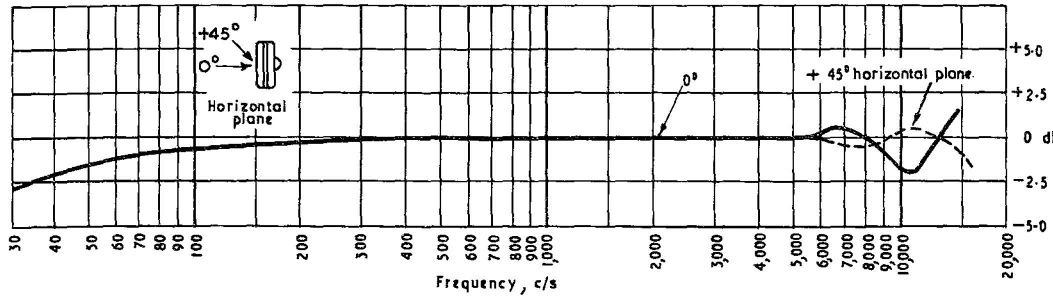

Fig. 4 - Microphone Type PGS. Change in response produced by case

Fig. 4 shows the change in frequency response produced by the upper part of the PGS microphone case; it will be seen that there are still some signs of internal reflection above 6 kc/s. Fig. 4 also shows a slight loss at low frequencies. A small part of this loss is accounted for by the increased resistive air loading imposed on the ribbon by the wire gauze but the effect is mainly due to modification by the cover, of the sound field acting on the ribbon.

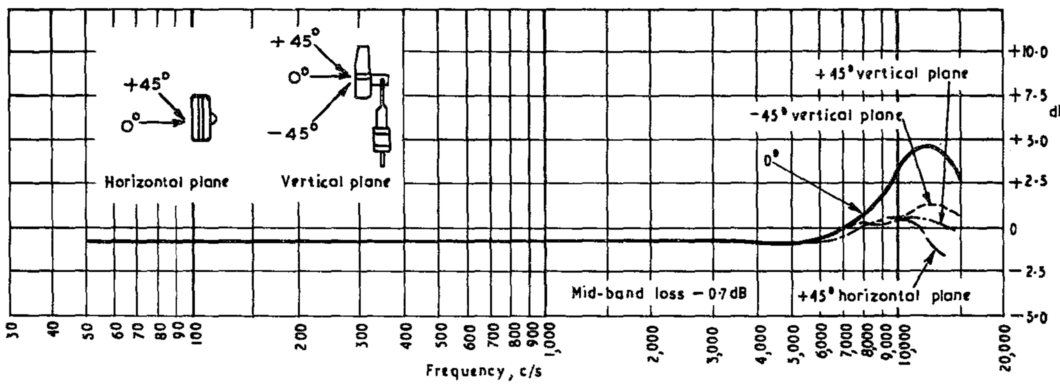

Fig. 5 - Microphone Type PGS. Change in response produced by high-frequency reflectors

Fig. 5 shows the influence of the perforated reflector plates on the response of the PGS microphone. The standing loss of 0·7 dB, due to the slight increase in the reactive load imposed by the air on the ribbon, is more than offset by a useful rise in axial response up to about 13 kc/s. The effect is similar in kind to that shown in Fig. 4 but because the distance between reflectors is less than the depth of the case, the maxima and minima in the curve occur at higher frequencies. The increase in high-frequency response, which is controlled by the thickness of the reflectors and the fraction of their area occupied by perforations, has been arranged to offset as far as possible the natural fall in response which occurs in a pressure-gradient microphone at high frequencies, when the wavelength of the sound is no longer large compared with the effective pathlength between the front and back of the moving element. Because the perforated plates have dimensions comparable with a wavelength in their operative frequency band and in addition give only partial reflection, the frequencies of the maxima and minima in response which they produce are not simply related to the spacing between them. In the present instance, the frequency of the first maximum shown in Fig. 5 was found to vary inversely as the cube of the spacing, within the range of interest. It will be seen from Fig. 5 that the effect of the reflectors is less for sound arriving at an angle to the axis; in this case, however, the fall in response which it is desired to correct is also less, so that the presence of the reflectors reduces the variation in overall frequency response with angle of incidence.

It may be of interest to note that perforated plates similar to those described but covered with thin cloth, were provided in some of the earliest pressure-gradient ribbon microphones as puff-shields, though the thickness of material used and the spacing were such that any fortuitous effect on the high-frequency response must have been small. The use of such reflectors for the purpose of improving the performance of the microphone at high frequencies in the manner described above was however described independently by Olson in a patent disclosed in October 1951[5].

3. PERFORMANCE.

The following data on the performance of the PGS microphone was obtained from production models.

3.1. Frequency Response.

Figs. 6, 7 and 8 show frequency response characteristics for a typical PGS microphone; the curves give the response for a number of angles of incidence in both horizontal and vertical planes.

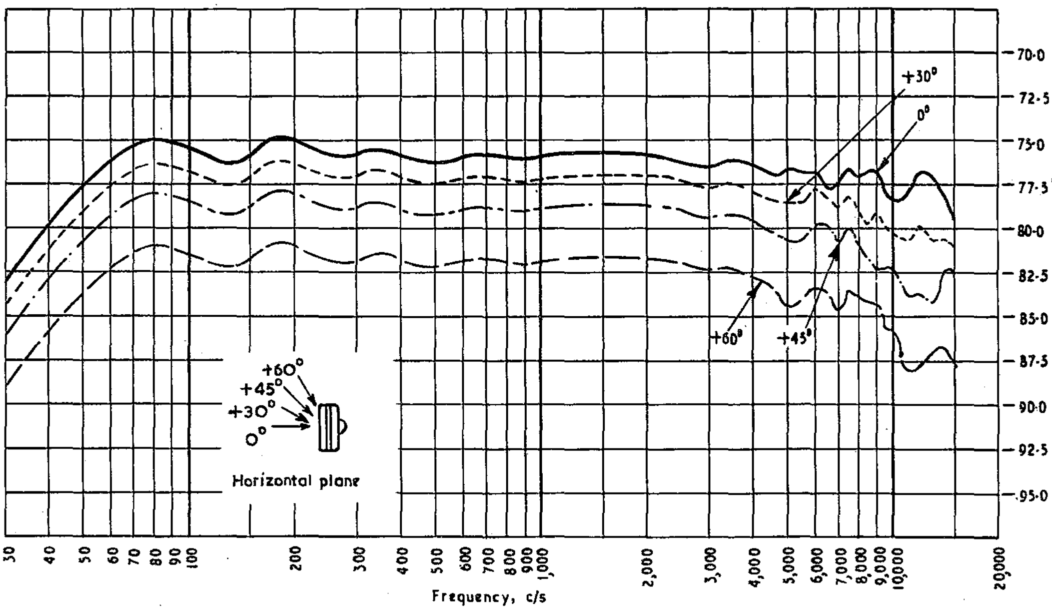

Fig. 6 - Microphone Type PGS. Open-circuit frequency response in horizontal plane

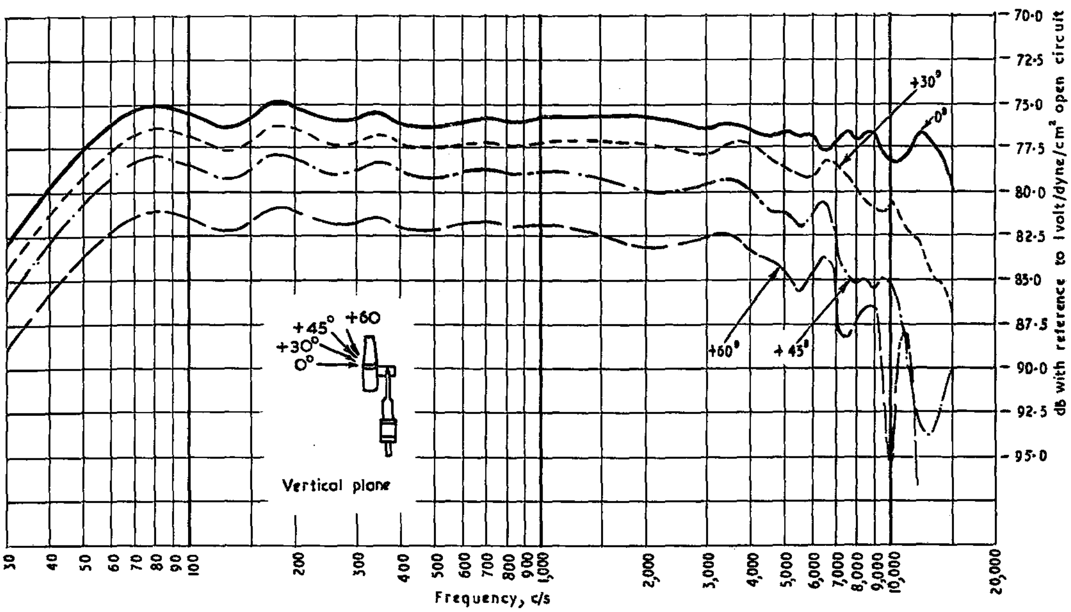

Fig. 7 - Microphone Type PGS. Open-circuit frequency response in vertical plane above axis

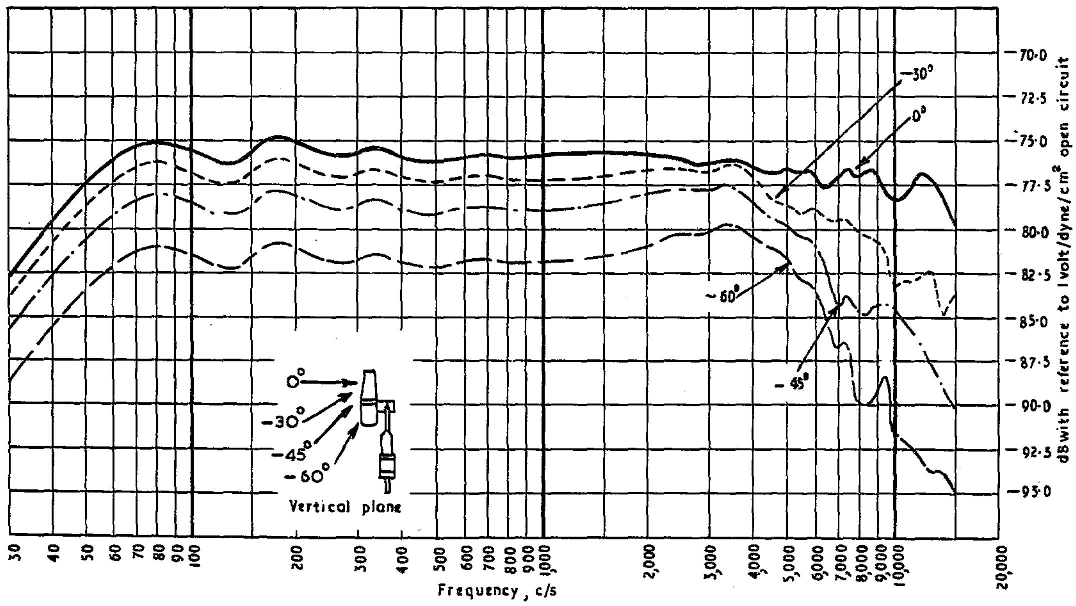

Fig. 8 - Microphone Type PGS. Open-circuit frequency response in vertical plane below axis

Fig. 9 shows the variation in open-circuit axial frequency characteristic between individual PGS microphones; the data was obtained from tests on five production specimens. Below 1000 c/s, the spread is mainly due to differences in the ribbon tension and hence in the frequencies of the longitudinal resonance modes; at higher frequencies, variations arise from differences in ribbon material and depth of corrugation, which affect the transverse modes.

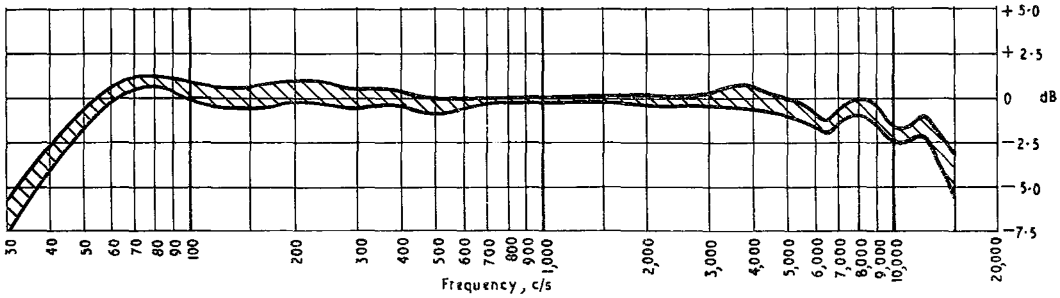

Fig. 9 - Production spread in axial open-circuit frequency response for PGS microphones

3.2. Sensitivity.

The mean open-circuit sensitivity of the first 50 PGS microphones produced was −75 dB with reference to 1 volt/dyne/cm². About three-quarters of these specimens had sensitivities within ± ½ dB of the mean while the figures for the remainder lay within ± 1 dB. Most of the spread was accounted for by differences in magnetic flux density in the gap.

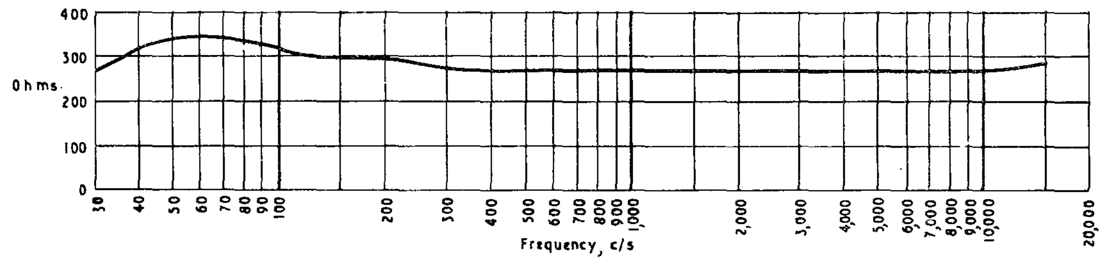

Fig. 10 - Microphone Type PGS. Modulus of output impedance

3.3. Impedance.

Fig. 10 shows the modulus of the impedance of a typical PGS microphone. Because of the rise in impedance at low frequencies, the mean impedance of the PGS microphone at 1000 c/s was designed to be a little less than the nominal value of 300 ohms. The difference in impedance between specimens is mainly due to variation in the ribbon material, which is hand beaten and varies considerably in thickness. A tolerance of +20% and −15% on a design impedance of 275 ohms is regarded as reasonable; the impedance at 1000 c/s of the first 50 microphones produced lay between 230 ohms and 320 ohms, the mean value being 270 ohms.

3.4. Magnetic Induction Pick-Up.

The levels of interference produced in a typical PGS microphone by a uniform alternating magnetic field of 1 milligauss at frequencies of 50 c/s, 1000 c/s and

10 000 c/s, expressed in terms of the sound field at 1000 c/s which would generate an equal voltage, are respectively +4 dB, +27 dB and +42 dB, with reference to 0·0002 dyne/cm².

For comparison it may be noted that the corresponding figures for ribbon microphones in which no precautions against such interference have been taken are often higher by some 50 dB at 50 c/s and 30 dB at the higher frequencies.

The figures given above are unweighted but in assessing the subjective effect of the interfering field in a specific case it is necessary to weight the results according to the frequency and the level at which the unwanted noise will be reproduced; it should be noted however that the annoyance value of a single tone or harmonically related series may exceed that of a random noise having equal loudness.

To give some idea of the significance of the data it may be mentioned that the strength of the stray fields which have been encountered at various times in studio areas varied from a few milligauss to 0·5 gauss at 50 c/s (the higher figure being associated with the presence of heavy current cables and switch gear in an adjacent room), 0·03 milligauss at 1200 c/s from a neighbouring electric railway and 0·1 milligauss at 10 kc/s in the vicinity of a television monitoring unit.

3.5. Wind Noise.

Pressure-gradient microphones are inherently more susceptible to effects of wind than those of the pressure type and for this reason are not normally used out of doors*. Even in studios, however, a microphone may be subjected to the equivalent of a light breeze when it is mounted on the end of a long boom and swung rapidly to follow the movements of a television artist; similar effects can result from the movement of a theatre curtain close to a microphone placed in the footlights. In a concert hall the combined effects of natural convection and artificial ventilation can produce an appreciable draught as may sometimes be seen by the swinging of suspended lighting fittings. Some data on the electrical output generated by a microphone subjected to an air stream of known velocity is therefore required. Fig. 11 shows the results of some wind noise tests on a PGS microphone. Most of the figures were

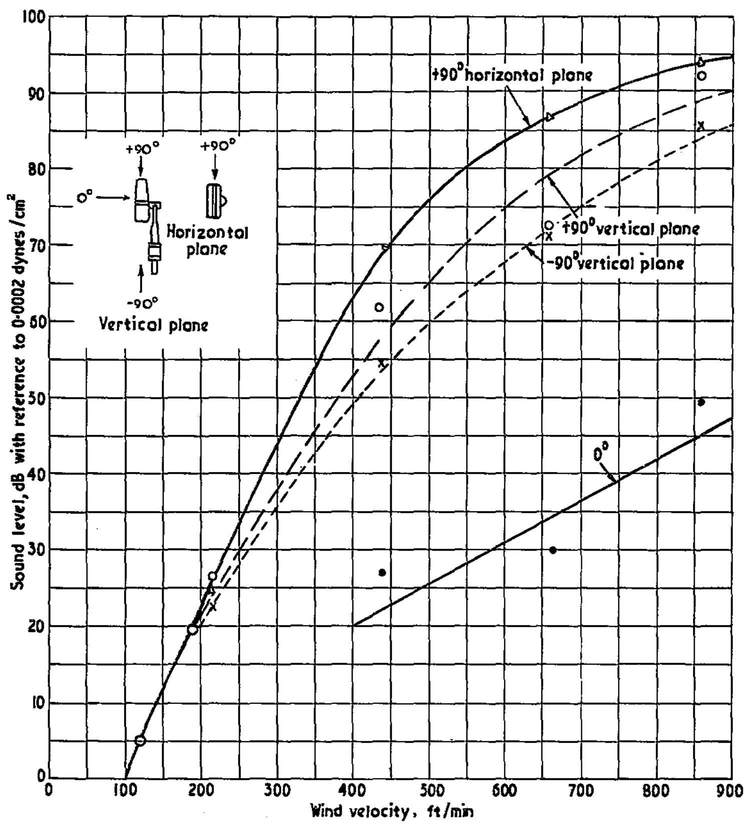

Fig. 11 - Microphone PGS. Weighted wind noise output expressed as equivalent sound level at 1 kc/s

*With the exception of the "noise-cancelling" lip microphones L.1 and L.2 which are used for close talking.

obtained by mounting the microphone on a whirling arm, giving the effect of a steady air stream. At the lowest wind velocities, however, this method of measurement became impracticable on account of the inevitable noise and vibration produced by the mechanism; the desired effect was then obtained by allowing the microphone to swing freely in still air on a 25 ft (7·6 m) pendulum suspended from the ceiling in a silent room, thus producing in effect a series of gusts of readily calculable velocity. The noise output from the microphone was weighted, after amplification, by an appropriate network[6] and read on a standard V.U. meter[7]. It is of interest that the maximum wind noise output from the microphone appears when the ribbon is edgeways-on to the air stream.

It will be seen that for wind velocities below 200 ft/min (61 m/min) the weighted wind noise output from the microphone does not exceed the output due to thermal agitation. It should be pointed out however that the data of Fig. 11 applies to a steady air stream without appreciable turbulence; the noise output increases so rapidly with the wind velocity that any local fluctuations in the latter produce a considerable net increase in the noise. It is therefore difficult in practice to assess the absolute level of wind noise and the principal use of data such as that of Fig. 11 is to provide a basis for comparison between microphones of different types.

3.6. Non-Linearity.

In any electromagnetic microphone having a substantially flat frequency characteristic, non-linear effects will be most pronounced at the lower end of the frequency range since here the excursion of the moving element required to generate a given e.m.f. is greatest. Fig. 12 shows the harmonic distortion produced by the PGS microphone when subjected to sound of high intensity at 55 c/s and 110 c/s, (these frequencies being chosen to avoid confusion in measurement with any harmonics which might be accidentally introduced into the measuring system by the 50 c/s supply). The sound field was set up in a resonant transmission duct, the microphone under test being so placed as to minimise the effect of any harmonics in the sound source. It will be seen that the distortion does not exceed 1% for peak pressures up to 110 dB above 0·0002 dyne/cm² at 55 c/s, and 128 dB at 110 c/s. These distortion figures are lower than those obtained with some high-grade electrostatic microphones; in making such comparisons it should be remembered moreover that in the latter type of microphone the non-linear effects appear at all frequencies in the working range.

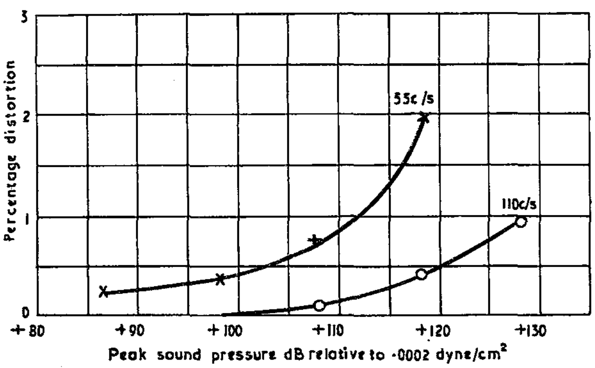

Fig. 12 - Microphone Type PGS. Total harmonic distortion

4. CONCLUSION.

From the data given in Section 3 it will be seen that the PGS microphone meets all the requirements laid down for a successor to the existing Type A microphone. The frequency range of the axial response has been extended upwards by more than half an octave and the falling off in high-frequency response with angles of incidence in the vertical plane is much reduced; as a result, there is an audible improvement in transmission quality and in some cases a better balance can be obtained between different sources of sound in the studio[8]. The weight of the new microphone has been reduced to 28%, and the volume to approximately 25% of that of the older type, while the compromise between sensitivity, size, uniform frequency response, and robust construction is believed to be the best attainable in a studio microphone of this kind at the present time.

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