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Cavity Pressure Method for Measuring the Gain of Hearing Aids

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A cavity pressure method for measuring the gain of hearing aids has been developed. It has the advantage of requiring no "dead" room, allowing a compact setup. The method has been investigated as to its validity and the degree to which diffraction effects are avoided. Comparisons with free-field data are made. The applicability of results obtained by this method to the specification of gain characteristics for hearing aids is discussed.

I. Introduction

The gain of a hearing aid is a numerical quantity expressing the degree of amplification that the aid will provide. Knowledge of the gain of a hearing aid is of importance to both manufacturers and users, as the gain largely determines the degree of hearing loss that can be compensated. Although the performance of a hearing aid depends on other factors, such as the presence or absence of harmonic distortion, and its suitability involves such considerations as durability, battery economy, and even size, a hearing aid is fundamentally a device for amplifying sound waves. Hence the degree of amplification, or gain, of a hearing aid is a quantity that is always taken into account whenever the performance of the instrument is evaluated.

The procedure of measurement in general use at present[1] involves exposing the hearing aid to a sound field set up in a free-field, or "dead" room. This is a room that must be sensibly free of echoes or standing sound waves. To that end, a room of large volume is constructed, the walls of which are covered with a material having a high sound-absorption coefficient. The room must also be free of extraneous sound disturbances, necessitating a sound- and vibration-isolating type of structure. The construction and maintenance of such a room is expensive.

The technique to be described in this paper was devised in an effort to avoid the use of a dead room. It is an easily standardized procedure by means of which the sound pressure applied to the hearing aid may be determined. No specially treated room is required, although the location should be reasonably quiet. The measuring equipment can be set up on an ordinary laboratory table. The only special construction involved is the source cavity, which may be built in the average shop. The method has the additional advantage of being readily adaptable to a recorder technique. By the use of two matched amplifier systems, the sound pressure that is applied to the hearing-aid microphone and the sound pressure generated by the receiver can be recorded simultaneously. The relative freedom from diffraction effects is of great assistance in permitting the evaluation of the combined microphone, amplifier, and receiver performance, as distinct from the characteristics of the hearing aid when it is worn under various conditions.

II. Measurement of Gain

The actual gain of a hearing aid may be defined as the ratio of the sound pressure produced by the receiver in the ear canal of the user to the sound pressure incident at the face of the microphone. The gain varies with the frequency of the incident sound, and depends not only on the intrinsic properties of the aid, but is also affected by the acoustic impedance of the user's ear.

If results found at various times for different hearing aids are to be comparable, the measurements must be made in a standardized way. The use of a coupler to represent the ear canal and to

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[1] Tentative code for measurement of performance of hearing aids, by American Hearing Aid Association, J. Acous. Soc. Am. 17, 144 (1945).

measure the acoustic output of a hearing-aid receiver has been generally accepted. The pressure gain of a hearing aid may be defined as the ratio of the sound pressure in whatever receiver coupler is used to represent the ear canal to the sound pressure at the diaphragm of the microphone. The pressure gain approximates the actual gain only to the extent that the receiver coupler represents, in volume, shape, and impedance, the average ear canal. However, there appears to be significant agreement between the pressure gain and the gain as it appears to the user of the aid.

III. Comparison of Free-Field and Pressure Techniques

In the gain measurements to be described in this paper, the sound pressure generated by the hearing-aid receiver is measured by placing it on an "artificial-ear" coupler of 2-cm^3 volume. This coupler is employed in both free-field and cavity methods. The coupler is similar to the 2-cm^3 receiver coupler designed by Romanow,[2] except for the addition of a small capillary leak, which prevents a building up of pressure in the coupler when the receiver of the hearing aid is sealed on to it. The sound pressure at frequencies used in testing hearing aids is not affected appreciably by the leak.

The technique commonly used for applying the input sound level is to expose the hearing-aid microphone to sound pressures in a free field. The sound field is arranged to approximate a plane wave incident upon the microphone in a direction perpendicular to the plane of the microphone diaphragm. The free-field sound pressure is measured (with the hearing aid removed) at the point in the field in which the hearing-aid microphone is to be placed, and is taken to be the input sound level.

In the cavity procedure the hearing-aid microphone is placed on a source cavity in which sound pressures are produced by a dynamic speaker and measured by means of a calibrated condenser microphone. As in the free-field method, the output of the hearing-aid receiver is measured on the 2-cm^3 coupler. The cavity method must be used under conditions such that the pressure indicated by the measuring microphone is substantially the same as the sound pressure applied to the hearing-aid microphone.

The free-field gain of the hearing aid is the ratio of the sound pressure produced in the receiver coupler to the sound pressure in the free field at the locus of the hearing aid, with the hearing aid removed. Expressed in decibels, it is the difference between the sound-pressure level produced in the receiver coupler and the sound-pressure level incident at the location of the hearing aid in the free field. In the cavity method, the pressure gain is the ratio of the sound pressure developed in the receiver coupler to that in the source cavity, and is expressed as the difference in decibels between the sound-pressure level in the receiver coupler and the sound-pressure level measured in the source cavity.

Neither of these methods yields an accurate representation of the actual gain of the hearing aid. In actual use, the sound is incident on a hearing aid worn on the user's body; it may be worn out in the open, or under one or more layers of clothing. Furthermore, the impedance of the receiver coupler is only a rough approximation to the impedance of an actual human ear, and the sound pressure developed in the ear of the user depends on his ear mold and the volume of his ear canal. However, both free-field and cavity methods do serve to indicate the general gain characteristics of the hearing aid being measured.

IV. Experimental Results and Discussion

The design of the source cavity is shown in figure 1. Because it is impractical to measure the sound pressure with the measuring microphone directly at the face of the hearing aid microphone, a symmetrical arrangement is used to achieve this condition in effect. The face of the measuring microphone is placed opposite the face of the hearing-aid microphone at an equal distance from the axis of the source tube. The transverse dimensions of the cavity have been kept to a minimum in order to keep the first transverse mode of the cavity outside the range of frequencies for which the gain of the aid is to be determined. The first transverse resonance of this cavity when terminated at the hearing-aid opening with a flat plate is at about 6,800 cycles per second. The diameter of the hearing-aid opening of the cavity

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[2] F. F. Romanow, J. Acous. Soc. Am. **13,** 294 (1942). Methods for measuring the performance of hearing aids.

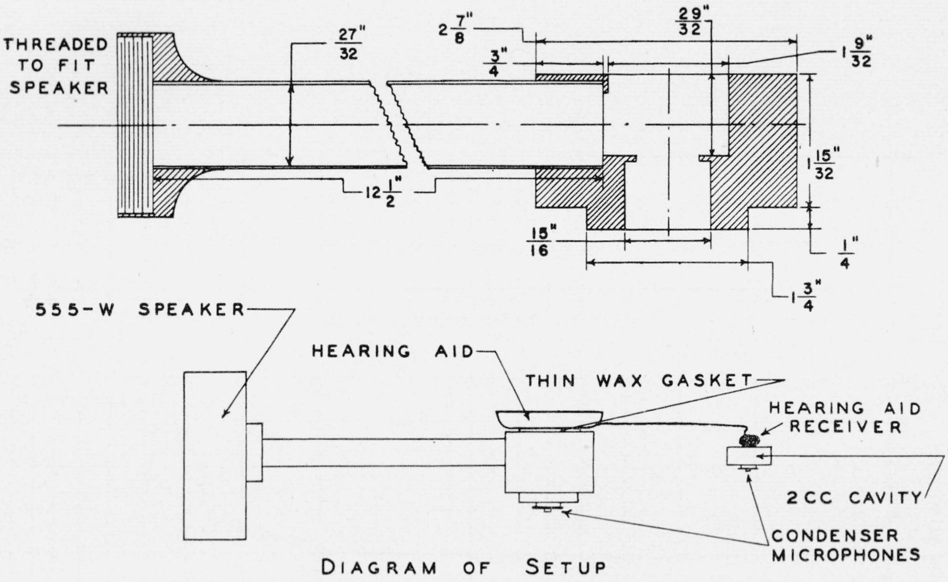

FIGURE 1. *Cross section of cavity.*

is about the same as that of the usual hearing-aid microphone.

The computation of gain from data obtained by the cavity technique involves the assumption that the sound pressure indicated by the measuring microphone is the same as that applied to the microphone of the hearing aid. The extent to which this assumption is valid under various conditions can be inferred from the data in figure 2.

The results plotted in figure 2 were obtained by substituting another condenser microphone for the hearing aid. This microphone was mounted in brass fittings by means of which the plane of the diaphragm could be set at various fixed distances from the plane of the cavity opening. These distances from the plane of the cavity opening will be referred to in the succeeding discussion as "offsets". The brass fittings provided a series of offsets ranging from a nearly flush closure of the cavity to an offset greater than the total thickness of most hearing aids. The diameter of the offset fittings was the same as that of the cavity.

It is evident that if care is taken to set the instrument on the cavity so that the face of the hearing-aid microphone is as close as possible to the cavity opening, no significant error will be introduced. The error may be kept to less than 5 db at the high-frequency end of the range. The effects of cavity sound pattern will not be serious unless a hearing aid with a deeply set microphone is being measured or unless the sealing gasket is made too thick. Variations in gain definitely traceable to cavity pattern are not usually encountered, even where they might be expected. This may be due to the damping of the cavity resonance by the resistance and leak produced by the grill-work of the aid.

As the cavity method involves only the face of the microphone, the pressure gain may be expected to show less dependence upon the shape of the hearing-aid case than would the free-field gain. This inference is confirmed by the results shown in figure 3. For these data, cavity pressure and free-field responses of a commercial hearing-aid microphone were measured. Measurements of response were made on the unmounted microphone, and also on the microphone when it was mounted in two hearing-aid cases differing considerably in size. All other components of the hearing aids were left in place, and the microphone leads were brought out through the receiver plug. This was intended to simulate the actual mounting of a microphone in a hearing aid. The data presented in figure 3 were obtained for a microphone cartridge of the type that is provided with an integral pinhole-and-cloth grillwork. This type was chosen for graphical presentation because its generally flat response and the protected mounting of its diaphragm make it possible to show directly the diffraction introduced by the cases and grillworks. The same measurements were also made on an ordinary crystal microphone with

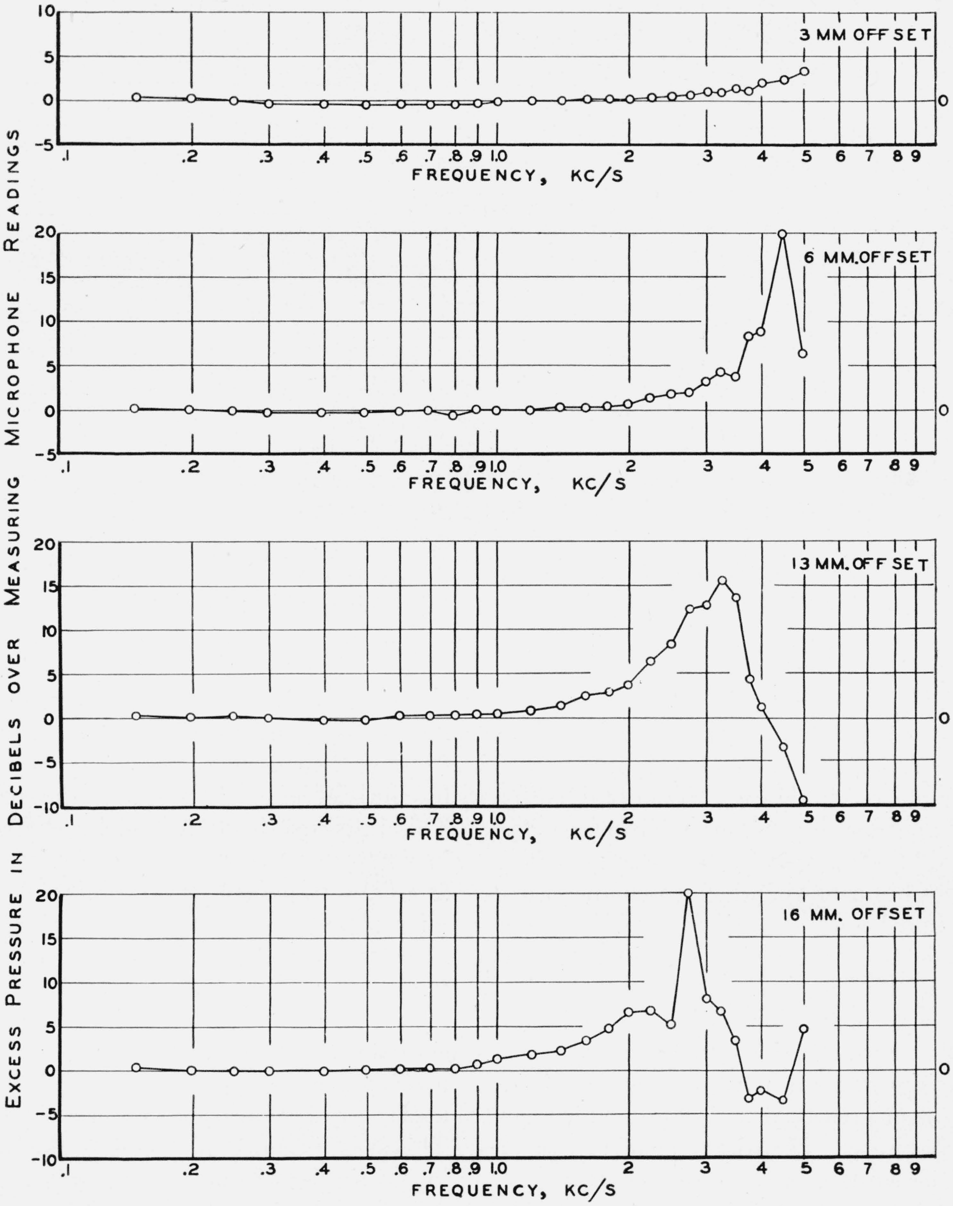

FIGURE 2. *Sound pattern in source cavity.*

Effects of off-setting microphone from flush closure.

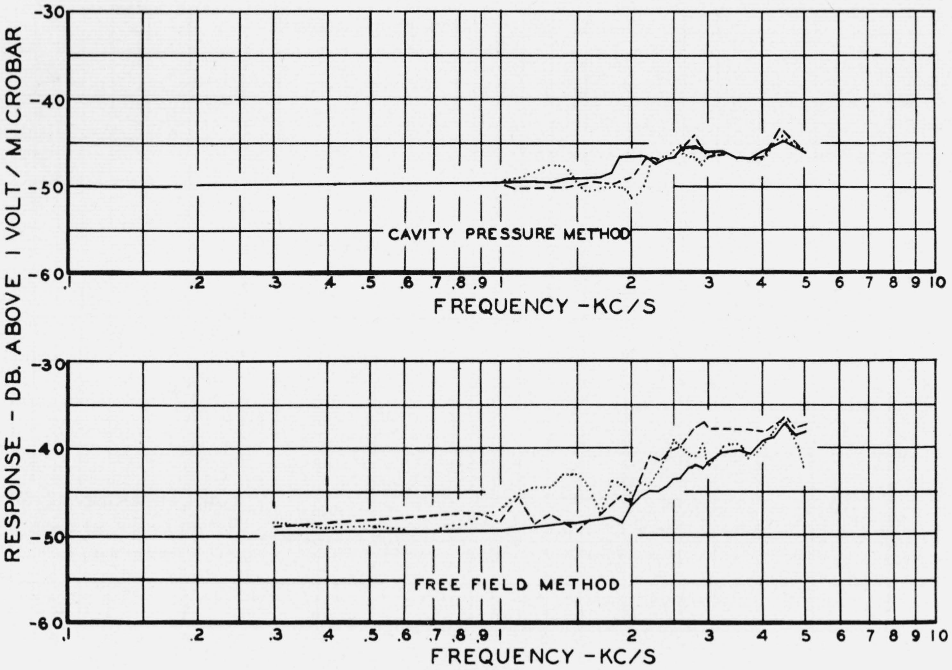

FIGURE 3. *Effect of hearing aid case on apparent microphone response.*

Crystal microphone: ——, unmounted; — — —, in small case; . . . , in large case.

a bare foil diaphragm. Mounting this type of microphone in a case depresses and broadens its resonance peak. The results of measurements on this type of microphone agreed with results obtained on the microphone of figure 3, but the differences were not so obvious because of the larger effect of the mounting on the resonance peak of the microphone.

In free-field and cavity methods alike, changes in measured response appear when the microphone is mounted in a hearing-aid case. The changes introduced by the case are greater in the free-field measurements because the total size of the case affects the free-field diffraction pattern. The grillwork affects the measured response in both free-field and cavity techniques, but the effect is not very large. From figure 3 it can be seen that the changes introduced by the case in the cavity-pressure method are generally less than 5 db. As threshold measurements are usually made to no greater precision than 5 db—the smallest step on most audiometers—this variation does not seriously affect the usefulness of the gain data.

Figures 4, 5, and 6 show the gains of three commercial hearing aids on which both free-field and cavity data were obtained. The agreement on general characteristics is good. The differences are chiefly due to diffraction effects and are small compared to the peculiarities of the gain characteristics produced by the receiver response.

In figure 5, an extra resonance is seen to be present in the cavity measurement at about 2,400 cycles per second, which was not found in the free-field results. This was at first supposed to be due to cavity pattern or a possible coupling between the space behind the grillwork and the cavity volume, but the results of further free-field measurements seem to show that it was an instability in the hearing aid itself. Free-field measurements have been made on the same instrument subsequent to the data from which this curve was drawn that exhibit the same peak as that found in the cavity measurements.

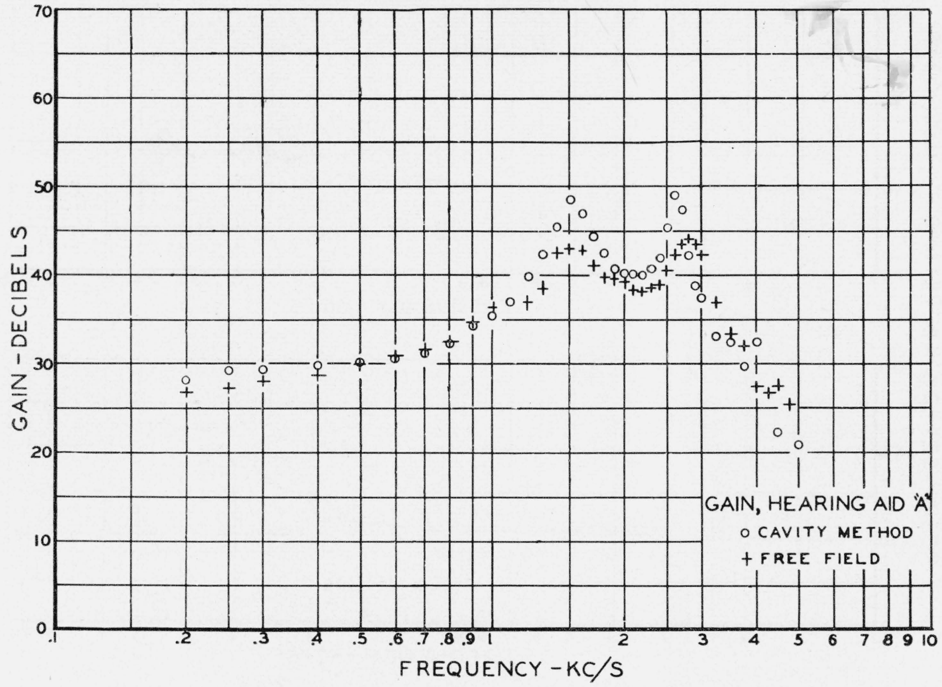

FIGURE 4. *Gains of commercial hearing aid on which both free-field and cavity data were obtained.*

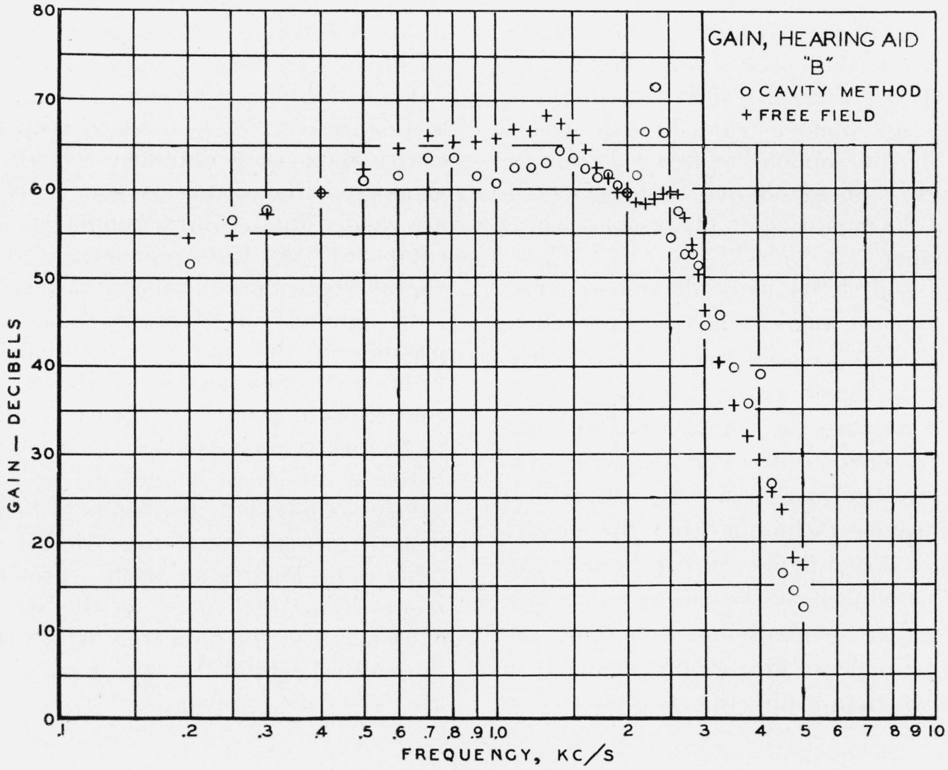

FIGURE 5. *Gains of commercial hearing aid on which both free-field and cavity data were obtained.*

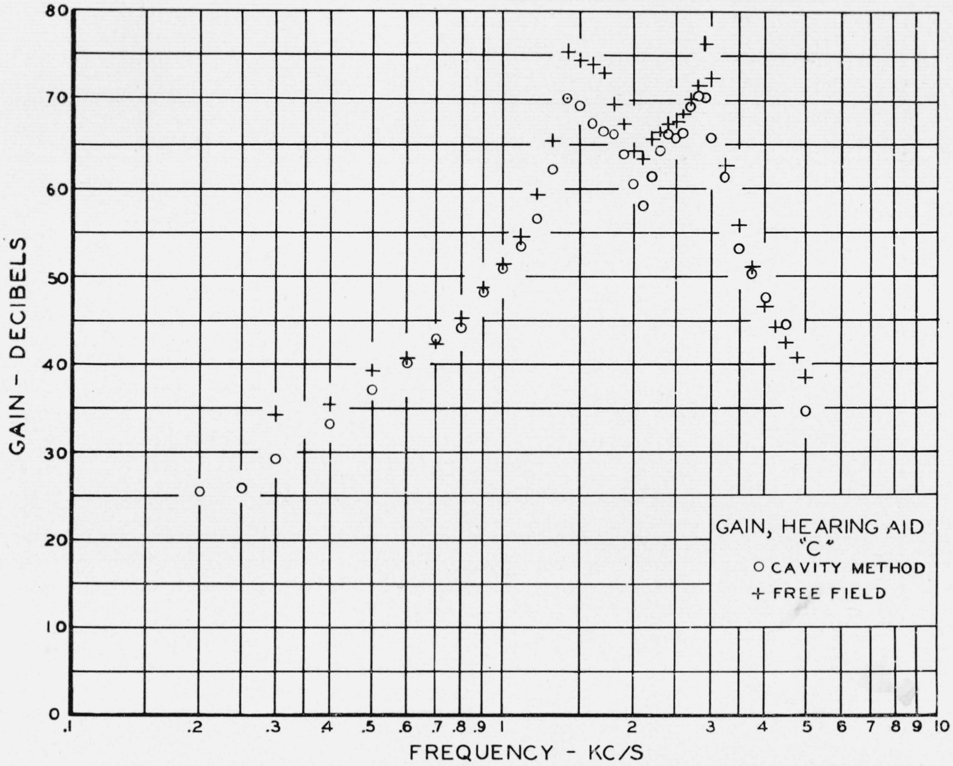

FIGURE 6. *Gains of commercial hearing aid on which both free-field and cavity data were obtained.*

V. Summary

The gain of a hearing aid can be measured by a cavity-pressure technique. The chief advantages of the method are its compactness and simplicity. Results of measurements are equal in validity to those obtained by the more familiar free-field method. A study of the properties of the method shows that a pressure gain measurement is approached (see fig. 3). This property may prove to be valuable in permitting the specification of an inherent pressure gain for a hearing aid. The effects of external conditions, such as the geometry of the case, the size of the body baffle, and filtering through clothing, may be determined by separate investigations. These generally applicable data might be incorporated in the specification for pressure gain. It should not be necessary to measure them for each instrument, as they are the same for all hearing aids. The separation of the problem of determining the actual gain of a hearing aid as worn into a pressure-gain measurement, objectively reproducible, and a study of body diffraction and ear impedance, which are independent of the intrinsic properties of the aid, appears to be desirable and useful.

WASHINGTON, September 15, 1947.

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