AD-A068 570 NAVAL RESEARCH LAB WASHINGTON D C F/G 9/1
DEMONSTRATION OF A NEW LOUDSPEAKER, I (VORFUEHRUNG EINES NEUEN --ETC(U)
MAY 79 W SCHOTTKY
UNCLASSIFIED NRL-TRANS-1300 NL

| OF |
AD
A068570

END
DATE
FILMED
6-79
DDC

NRL Translation 1300
7 May 1979

DEMONSTRATION OF A NEW LOUDSPEAKER, I

(Vorfuehrung eines neuen Lautspreachers, I)

by W. Schottky

Translated from: Physikalische Zeitschrift, Vol. 25, 1924, pp. 672-675.

A complete translation from the German, by [redacted] Pieter S. Dubbelday. (Underwater Sound Reference Detachment).

NAVAL RESEARCH LABORATORY
Washington, D.C. 20375

Translation - Sep 78

by

Dr. Pieter S. Dubbelday, Code 8275

from

Physik. Zeitschr. XXV, 1924, 672-675

W. Schottky (Rostock), Demonstration of a new loudspeaker, I.

(Presented in shortened version)

The apparatus which we want to demonstrate to you is the so-called ribbon loudspeaker which was developed by Mr. E. Gerlach and me in the Central Laboratory of the Werner plant of Siemens & Halske, Inc. Allow me to report first on the train of thought which led us to this construction, Mr. Gerlach will later give some information on the more difficult part of our road, the practical implementation of the apparatus.

The general idea from which we proceeded at the start of our experiments, in the fall of 1920, was that of an "air-light" * diaphragm; a diaphragm that would work essentially on air only, in which therefore the elastic forces as well as the inertial mass would be smaller than the reaction forces exerted on the diaphragm by the moving air (in free sound propagation). At the time, this requirement really was not imposed for the first time; we hear, for instance, that already during the war an electroacoustic loudspeaker was constructed according to this principle by Prof. Gerdien, and this requirement follows in the same way from the investigations of Hahnemann and Hecht, which were first performed for

* (Note by translator) Literal translation of "luftleicht."

hydroacoustic equipment. What led us at the time to experiments in this direction were, above all, the bad experiences we had with heavy diaphragms; whether we excited these diaphragms directly or by application of transformers, sounding boards, various tunings, we had always to fight with strong selectivities, reverberation, overtones, that are even more unpleasantly noticeable in the freely emitting loudspeaker than in the telephone when it is pressed against the ear.

For the realization of the principle of the light diaphragm two roads were available that combined the advantage of simplicity with that of a completely uniform action of the diaphragm force. Diaphragm weights of a few mg per cm^2 were required - we come back to this later - which means thicknesses of the order of magnitude of 5-10 μ, using metal foils. Such foils could be entered into a strong electrostatic field and moved back and forth by an alternating positive and negative charge (electrostatic telephone) or they could be suspended in a strong magnetic field and a uniform alternating current could flow in them across the direction of the lines of force. Computation and experiment under readily obtainable conditions resulted in a poorer efficiency and smaller sound intensity for the first method than for the second; consequently we were led to the principle of the ribbon speaker by a sort of negative selection process; this principle proved to be useable thanks to the development efforts of Mr. Gerlach.

When I turn now to the theory of the current carrying ribbon in a magnetic field, the theory of the ribbon speaker and the ribbon microphone, I should mention there too the earlier experiments in that area, which came to our attention during our development of the apparatus. Above all, M. Reinganum in Freiburg should be mentioned, who already describes a "foil telephone" in the "Physikalische Zeitschrift" of 1910, which consists of a thin current-carrying aluminum leaf which was glued all around on a frame and entered into a strong magnetic field. Shortly before the war, Messrs. H. Herrmann and W. Kunze in Halle worked with the principle for physiological experiments independently of Reinganum and they applied for a patent based on the connection in series of several current-carrying ribbons[1]; the most important merits of the ribbon speaker (smooth operation and lack of pronounced natural vibrations) have been recognized already by Reinganum and these authors. The good efficiency of the ribbon speaker and ribbon microphone is connected with conditions, ~~through~~ The, which are by no means related only to the progress in amplifier technology achieved since that time. I would like to describe to you now, in short, those conditions that have, in some respects, significance over and beyond our specific apparatus.

It was already mentioned that it is necessary, in order to obtain an efficiency as good and uniform as possible, to make the electric forces as well as the inertial mass of the diaphragm used as small as possible with respect to the reaction forces in the moving air. Therefore, it is not sufficient to choose the fundamental vibration of the diaphragm as low as possible and thereby to work with relatively heavy masses; one should rather work with very light masses and nevertheless choose the elastic constants and the tension of the diaphragm so small that the natural vibration lies at low frequency. This can be achieved by the proper expedients (compare the following address by Mr. E. Gerlach);

---

[1] Mr. Dr. Herrmann in Innsbruck has referred to this work during the discussion

therefore we can simplify the problem if we just ignore the elastic forces and only consider the inertia of the diaphragm. Then an upper and lower limit obtains for the frequency region in which the diaphragm shows a good efficiency, either one depending on quite different factors.

The upper limit for good efficiency is in fact determined by the mass of the diaphragm. The most graphic expression for the role of the diaphragm mass is obtained when one expresses this diaphragm mass per unit of area in terms of the height of an equivalent air column imagined above the diaphragm. Since 1 cm^3 of air weighs 1.3 mg the equivalent air-column length ℓ_o of a diaphragm is given by

$$\ell_o = \frac{sd}{1.3x10^{-3}} \text{ cm}$$

where s is the specific weight and d is the thickness of the diaphragm. For an aluminum diaphragm of 5-μ thickness (s = 2.9; d = $5x10^{-4}$cm), for instance,

$$\ell_o = \frac{(2.9)(5)10^{-4}}{(1.3)10^{-3}} = 1.1 \text{ cm};$$

for a steel diaphragm of the usual telephone one finds an equivalent length of about 83 cm, for that of the usual magnet loudspeaker even a length of about 250 cm. Now this length ℓ_o should be compared with the wave-length, divided by 2π, of the frequency to be transmitted, which we want to designate as the "phase length" of the pertinent wave, because it approximately represents the region in which the amplitude of the propagating wave can be considered still in phase. For this phase length, indicated by ℓ, we have therefore;

$$\ell = \frac{\lambda}{2\pi}$$

The rule which limits the efficiency of a diaphragm speaker upwards is now simply this, that the apparatus begins to give out for frequencies for which $\ell > \ell_o$. Now the frequency n is connected with the phase length ℓ by the relation:

$$n = \frac{a}{2\pi\ell} \text{ (a is the sound speed) } = \frac{5460}{\ell} .$$

Therefore the upper limits of good efficiency for a free diaphragm are found from the equivalent lengths to be about n = 6000, n = 650, and n = 200 Hz. From this simple consideration it follows that high tones, consonants, and sibilants can only be transmitted in natural proportions to the lower tones by means of "air - light" diaphragms.[2]

The lower limit to the efficiency of a freely emitting speaking apparatus depends on quite a different quantity, which we might characterize as the divergent radius of the wave directly over the diaphragm. The introduction of this measure rests on the comparison of the sound propagation issuing from the diaphragm with that of a spherical wave which issues from a pulsating spherical diaphragm. In both cases, one can investigate how the cross section relevant to the sound propagation increases with the distance from the diaphragm, and if, within a distance of a phase length away from the diaphragm, this propagation law is not too

---

[2] The constriction in the horn right in front of the diaphragm as applied to heavy diaphragms is able to offset the heaviness of the diaghragm to a certain extent, to be sure. This way, though, the efficiency is decreased in other ranges, the applicable horns narrowed down, lengthened, etc. The absolute optimum for a large frequency region lies with the light diaphragm.

irregular, then one may characterize it by a single constant, namely, just the radius of the sphere which would emit a wave with an equal divergence.

This divergence radius now is extraordinarily small for diaphragms of which the size is small with respect to the wavelengths to be rendered, and which are not built in walls or horns . With a piston diaphragm of medium size built in a rigid baffle the divergence radius depends on the frequency; it shows irregular variations for wavelengths comparable with the size of the diaphragm to become constant for still lower frequencies. With diaphragms that are small relative to the transmitted wavelengths the only way to arrive at frequency-independent and sufficiently large divergence radii is the use of funnel-shaped attachments; the diaphragm should vibrate at the base of a horn in very close contact with its side if the divergence of the wave is not to become too large nor the divergence radius too small.

According to this "transformation to spherical waves" the importance of the divergence radius for the efficiency of a sound apparatus at low frequency can be deduced without further ado from the theory of the spherical wave as it was formulated by Hahnemann and Hecht in 1916[3]. The efficiency of a spherical diaphragm begins to give out at frequencies at which the phase length ℓ becomes larger than the divergence radius. Divergence radii of 3-5 cm are easily obtainable with short horns, radii of 30 cm and over with horns of meters' length; freely suspended ribbons of 1-cm width, on the other hand, would have divergence radii of fractions of a cm only, insofar as it is at all possible there to speak of sphere-like propagation.

---

[3] I may comment that we have been much furthered in our grasp on the decisive acoustic conditions by correspondence with Prof. Aigner-Wien.

Thus we see the range in which a loudspeaker can display a good efficiency threatened from two sides; at the low frequencies it is the Scylla of the divergence radius, at the high frequencies the Charybdis of the equivalent phase length of the diaphragm. The loudspeaker reproduces the region $R>\ell>\ell_o$ well and uniformly - under otherwise correctly chosen conditions - above and below that it starts to break down, albeit not too fast at first. Therefore the number of well reproduced octaves is given by the ratio R/ℓ_o; if we add an octave on both sides we obtain

$$p = \frac{\log R/\ell_o}{\log 2} + 2$$

octaves, reproduced approximately uniformly[4]. With the ribbon one can reach $\ell_o = 1$ cm, $R = 10$ cm thus here at least p = about 5.5.

I will not talk here about the difficulties in mechanical respect presented by the application of very thin diaphragms, which have not yet been completely overcome, and just as little about the problem how to reduce sufficiently the elastic restraints of such a diaphragm; about the measures taken in our apparatus especially, Mr. Gerlach will give some information. I would like to say yet something, in short, about the theoretically computed efficiencies. Of course these do not only depend on the conversion of the force acting on the diaphragm into acoustic motion but also on the degree to which one succeeds to transform a given electric AC energy into useful force action on the diaphragm. Here, fortunately, the conditions are theoretically completely understood; one

[4] The value of p can be improved a little for heavy diaphragms, where in essence generally $R<<\ell_o$, by means of the above-mentioned constriction in the horn.

finds that it is essentially the resistance of the ribbon and the strength of the magnetic field that determine the efficiency. Since the mass of the ribbon increases with the thickness, while, on the other hand, the resistance decreases, an optimum exists for the thickness of the ribbon. If one chooses that optimum, we obtain, neglecting friction losses, efficiencies of 40%, 62% linear for ω 5000, and linear efficiencies of 33% for ω 50,000, 45% for ω = 270, for our large electromagnet apparatus (H = 10,000 gauss)*. With magnetic fields of 3000 gauss, as we hope to reach in the smaller apparatus' with permanent magnets, one computes an optimum efficiency of about 25% linear; for higher frequencies the linear efficiency drops to about 10%. If one would succeed to come close to these theoretically possible values, then the ribbon loudspeaker with permanent magnet would be able to compete effectively with the magnetic loudspeaker.

With respect to the application of the ribbon speaker as a receiving apparatus, it may be commented only that we believe to be closer to a final solution here than in the application of the apparatus as a sound producer, since certain difficulties concerning questions of amplitude and durability do not occur here. Theoretical principles allowing one to compare the efficiency of an apparatus as a receiving and as a transmission apparatus as well as a more extensive theory of the ribbon loudspeaker will be discussed in a publication that will appear later.

* (Note by translator) This is a literal translation of this passage; the technical meaning was not clear to translator.