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[54] DOMES FOR ELECTRIC BELLS

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[30] Foreign Application Priority Data

March 28, 1969 Great Britain.....16,521/69

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84/407, 340/396

[51] Int. Cl.G10k 1/00

[58] Field of Search.....116/148, 152, 160, 163;
84/406, 407, 408; 340/396, 392, 393; 72/1,
2.3; 29/169.5, 407

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[57] ABSTRACT

A bell member for an electric bell, in which the thickness of the bell member varies from place to place in accord with the desired total characteristics of the bell. Variations in the vibrational mode of the bell with variations in the thickness of the base and skirt are particularly considered.

6 Claims, 9 Drawing Figures

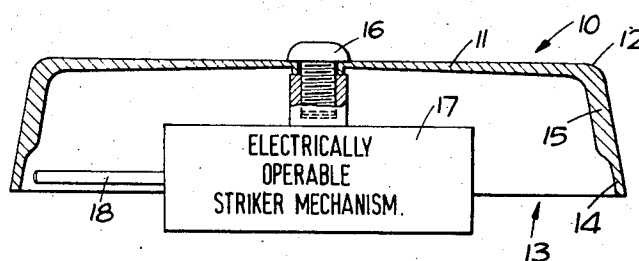


Fig. 1.

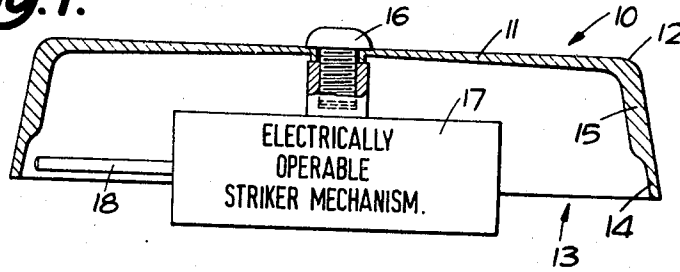


Fig. 2.

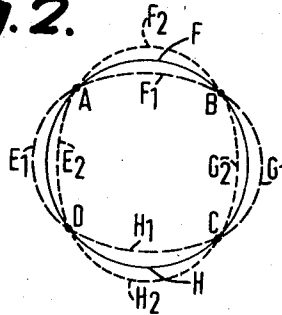


Fig. 3.

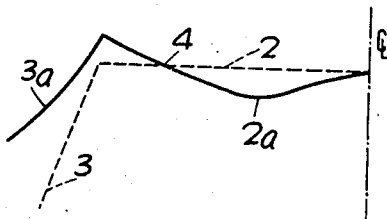
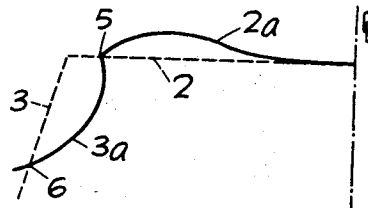
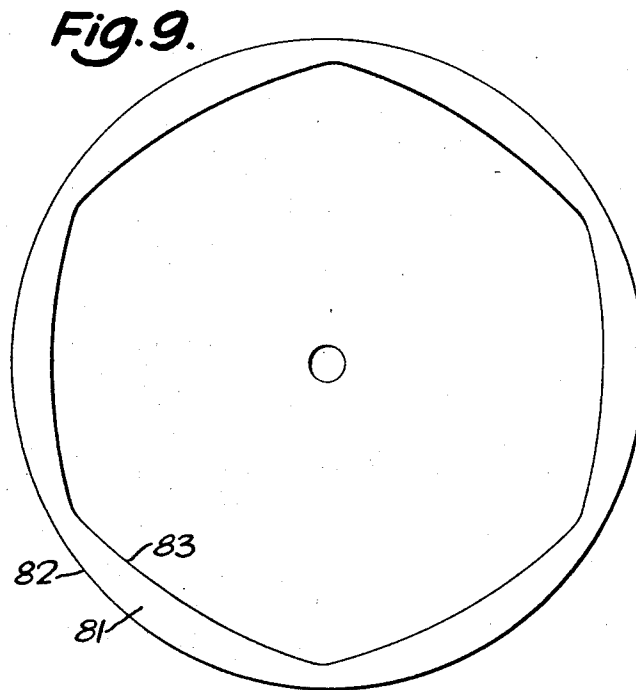
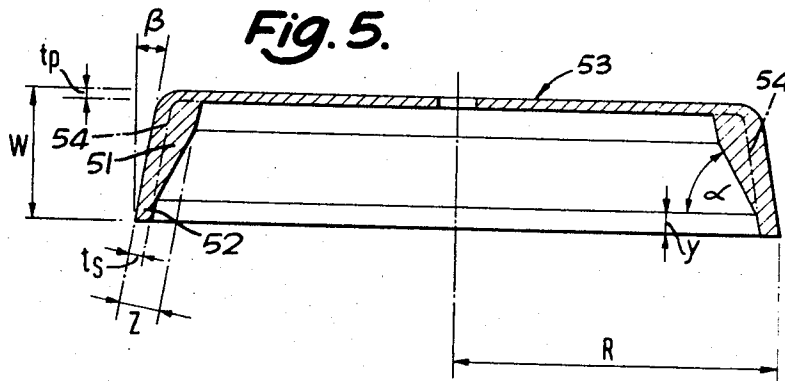


Fig. 4.



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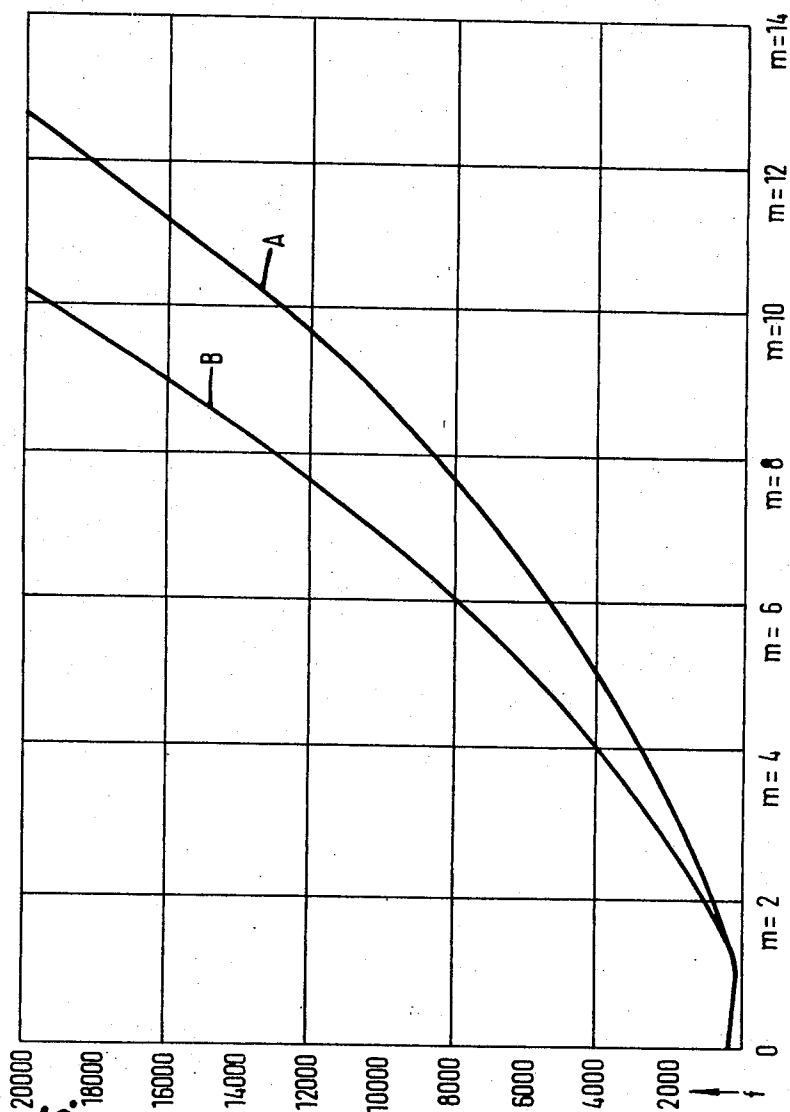
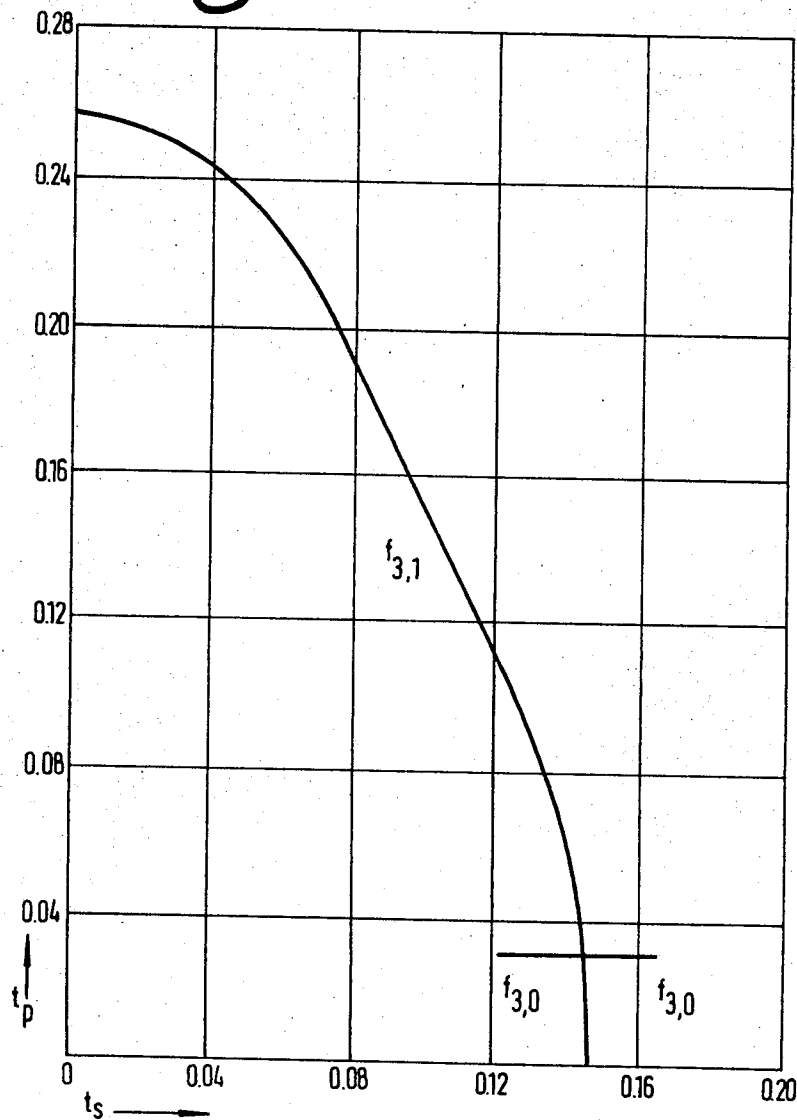


Fig. 6.

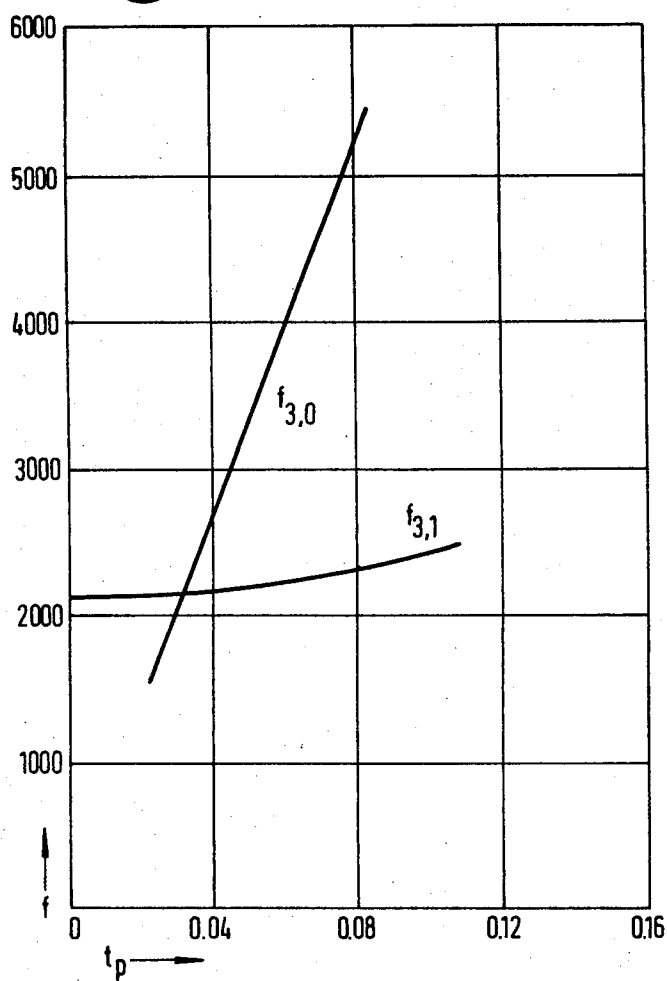
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Fig. 7.



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Fig. 8.



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DOMES FOR ELECTRIC BELLS

This invention relates to electrical bells. Bells of this type have a bell member and an electrically operable striker.

It has hitherto been the practice to form the bell member from pressed sheet metal although metal castings have sometimes been used. Other materials such as glass and wood have occasionally been employed for making the bell member. Although cast bell members are not always of completely uniform thickness, the variations in thickness have been incidental.

The present invention is directed to improving the tonal quality of an electric bell. It has now been found that if the thickness of the bell member is varied from place to place it is possible not only to obtain a louder sound from the bell member than that obtained from a uniformly thick bell member, of the same diameter, for the same striking force but that the subjective quality of the sound is enhanced. It is possible to vary the thickness of the bell member to give prominence to harmonics which give either a pleasing or strident tone as required.

Although the present invention bears some analogy to the technique of making a church bell, in general the geometry and arrangement of an electric bell is quite different from that of a church bell and in practice there is no analogy between measures adopted to improve the quality of the sound of a church bell and the measures taken to improve the quality of an electric bell by varying the thickness of the bell member. This may be illustrated by the following. A typical church bell would have a height about three-quarters of the diameter at the mouth of the bell and a diameter at its shoulder of one half the diameter at the mouth; the height of a typical bell member for an electric bell is less than half that of the diameter of the mouth, and is preferably between one fifth and one third of the diameter of its mouth. Also the diameter at the shoulder would normally be rather more than half the diameter at the mouth. It is therefore apparent that in general quite different considerations apply in determining the manner in which the thickness of the bell member should vary.

Moreover, as will be more particularly explained hereinafter, it is much more possible in the case of electric bells to project for the bell member an idealized structure which can be analyzed, as far as its possible modes of vibration are concerned, by a finite-element method of analysis. This analytic method can be used to determine the natural frequencies and mode shapes of vibrations in a structure and by considering the effect on the vibration mode of varying the thicknesses of predetermined parts of the bell a particular variation in the thickness of the bell member can be selected.

According to the invention therefore, an electric bell comprises an electrically operable striker and a bell member of which the thickness varies in a predetermined manner from place to place in accord with desired tonal characteristics of the bell. In general, it would be preferable for the thicknesses of selected parts of the member to be predetermined in accord with a desired vibration mode of resonant frequency $f_{m,n}$ where m is the number of circumferential waves and n is the number of nodal circles in the vibration

mode. These terms will be more particularly described hereinafter.

Particular types of variation of the thickness of the bell member are advantageous owing to the ease with which variations from idealized and therefore more easily analyzed structures can be incorporated. In a preferred form of the invention the bell member comprises principally a base and a surrounding skirt, in which the thickness of the base and the thickness of the skirt are predetermined in accord with a desired vibration mode of the bell member.

In one particular construction resulting from the invention the bell member comprises a generally flat base joined by a shoulder to a surrounding skirt, wherein the bell member is thinner in a region at the edge of the skirt forming a mouth for the bell than it is at the shoulder. The thickness of the base of the bell member may increase towards the shoulder. The striker may be arranged to strike the bell member in the said thinner region.

According to another aspect of the invention the thickness of the bell member may vary circumferentially. This variation may be cyclic. One possibility is an arrangement in which the outside dimension of the section through the bell member is circular but the inside dimension corresponds to a regular polygon.

Reference will hereinafter be made to the accompanying drawings, in which:

FIG. 1 illustrates an electric bell;

FIG. 2 is a diagram illustrating the effect of circumferential waves on a bell dome;

FIGS. 3 and 4 illustrate the significance of nodal circles in a vibrating dome;

FIG. 5 illustrates two shapes of a bell member or dome, one shape being optimised, the other being selected for analysis;

FIG. 6 is a graph showing the variation of the fundamental natural frequencies of the analyzed bell dome of FIG. 5 with the number of circumferential waves;

FIG. 7 is a further graph illustrating the relation between the thicknesses of the base and skirt of the analyzed bell dome of FIG. 5;

FIG. 8 is a graph illustrating the effect of plate thickness on the natural frequency of the analyzed bell dome of FIG. 5; and

FIG. 9 illustrates a bell member of which the thickness varies circumferentially.

It is convenient to mention at this point a typical construction for an electrical bell. Such a construction is shown in FIG. 1 which shows a generally circular section bell member 10 in the form of a flattened dome having a base 11. The mouth 13 of the dome is formed at the outer extremity of the rim 14 on an outwardly flared skirt 15 joined by a shoulder 12 to the base 11.

The base 11 is attached at the center of its base by means of a screw 16 to the housing of an electrically operable striker mechanism 17 operating a striker 18 to strike the dome on the rim 14.

When a bell member or dome is struck at its mouth, it is caused to vibrate in a complex mode containing both nodes and anti-nodes. Two systems of nodal lines are generally recognized. One is a system of meridians which run up and down the bell at different azimuths and the other is a system of circles which lie at different diameters. The former are called nodal meridians, the latter are called nodal circles.

Referring now to FIG. 2, there is shown a circle 1 denoting the rim of the skirt of a bell dome. If the rim is struck at a point H, the point vibrates in and out between points H1 and H2. Nodal points are formed at four points A, B, C and D while quadrantal points of which point H is one oscillate between points E1 and E2; F1 and F2; G1 and G2; and H1 and H2 respectively. It will be apparent that the displacement of the rim from the rest position is sinusoidal around the rim and accordingly one cycle of inward and outward deflection is conveniently called a circumferential wave. FIG. 2 illustrates a mode of vibration containing two such waves.

Any mode of vibration will also be associated with a particular number of nodal circles. FIGS. 3 and 4 show an idealized half-section of a bell dome having a flat base 2 and a skirt 3. Also shown greatly exaggerated is the vibration of the small element of the dome represented by the Figures, the position of the skirt and base in vibration being denoted 2a and 3a respectively. In FIG. 3 the vibration of the element has a node at the point 4. The locus of the node as successive elements of the bell member are considered is a circle centered on the axis of the dome. For this reason it may be termed a nodal circle. In FIG. 4 there are two nodes 5 and 6 associated with a respective one of two nodal circles at different diameters of the dome.

It follows that any vibration mode may be described by a resonant frequency $f_{m,n}$ where f is the frequency of vibration, m is the number of circumferential waves and n is the number of nodal circles.

A complete analysis of the vibration of shells of revolution has only been obtained for a few highly idealized shells as infinitely long cylinders. Approximate solutions for relatively simple shells such as cylinders of finite length have been obtained by applying what is known as the Rayleigh-Ritz method. However, even this approach usually requires a programmed digital calculator to solve a determinantal frequency equation. Such methods have accordingly not been applied to relatively complex geometry such as truncated cones and non-spherical shells.

However, in the last decade a very powerful technique known as the finite element method has been developed for the static and dynamic analysis of structures. This method requires that the structure be divided into a number of finite elements, the stiffness and mass matrices which can be determined in local co-ordinates. From these matrices the stiffness and mass matrices for the complete structure can be determined.

The natural frequencies and mode shape can then be calculated by solution of an appropriate eigenvalue problem.

Accordingly, it is theoretically possible to investigate the vibration of characteristics of the bell dome theoretically by a finite element method and to construct a computer program for the calculation of frequencies, mode shapes and circumferential waves produced by a specified dome shape. It is therefore possible to invert such a program and provide it with a self-optimizing program with constraints relating to a desired frequency and vibration mode to obtain a profile required to maximize the amplitude of vibration in the specified mode and hence maximize the sound output. It is also possible to specify the ratio required between a series of frequencies in order that a pleasant or strident note be produced. However, although such programs are of importance to the designer, they are mentioned here only to demonstrate the theoretical basis of the present invention. The present invention is concerned with the practical application of the knowledge that selective variation in thickness of the dome can be used to improve the vibrational characteristics of the dome. Moreover, such programs are in the general case extremely complex and from the point of view of the designer it is convenient to assume an idealized shape such as a truncated cone for the bell member or dome, to examine how the vibrational characteristics of such a dome vary with change of thickness of selected parts of the dome and then to choose those thicknesses in accord with the desired frequency and sound output of the dome.

For example, one shape of dome that can readily be adopted is shown in FIG. 5. This shows a dome 51 having a skirt 52 and a base 53. The base has a thickness t_b , the skirt has an initial thickness of Z and tapers to a thickness t_s , the inner angle of the taper being α and the outer cone angle being β . The height of the skirt is W , the length of the rim is y and the radius of the dome is R . The thicknesses t_b and t_s are selected as variable parameters, the other dimensions, in inches being $W=1.2$, $R=3$, $Z=0.4$, $y=0.2$, α being 60° and β being 10° .

The shape of dome just described is an optimized shape, in which the thickness of the skirt is not constant. Table 1 refers to the results of varying t_b and t_s . Also shown in FIG. 5 is a shape of dome selected for analysis, in which the skirt is of constant thickness t_s , as shown by the lines 54. The results of analyzing the latter shape of dome are shown in Tables 2A to 2D.

TABLE 1

	$f_{2,1}(\text{Hz})$	dBA	$f_{3,1}$	dBA	$f_{4,1}$	dBA	$f_{5,1}$	dBA	$f_{6,1}$	dBA
(a)..... Constant thickness.....	1,180	74	2,660	80	4,250	92	5,900	84	7,850	85
(b)..... Optimised shape.....	1,670	76	4,260	99	7,000	80	10,000	79	13,000	73
(c)..... $t_s=0.2$	1,750	77	4,460	92	7,200	89	10,500	74	14,000	71
(d)..... $t_s=0.1$	1,590	84	3,900	92	6,300	80	9,000	72	11,000	66

TABLE 2A

m	0	1	2	3	4	6
$f(\text{Hz.})$	377	170	782	1,804	2,859	5,355
Mode.....	Ms0, Np0	Ms0, Np0	Ns0, Ms0, Np0	Ns0, Ms0, Np1	Ns0, Ms0, Np1	Ns0, Ts, 1.
$f(\text{Hz.})$	895	2,934	>3,000	>3,000	8,018	13,658
Mode.....	Ts0, Tp0	Np1, Ms0, Ns0			Np0, Ns2	Np2, Ns2
$f(\text{Hz.})$	2,834	>3,000			15,880	19,468
Mode.....	Np1, Ms0, Ns0				Np2, Ns1	Ns1, Np3
$f(\text{Hz.})$	>3,000				18,788	>20,000
Mode.....					Np2, Ns1	

TABLE 2B

<i>m</i>	0	1	2	3	4	5
<i>f</i> (Hz.)	347	149	979	2,416	3,994	7,822
Mode	Ms0, Np0	Ms0, Np0	Ns0, Ms0, Np0	Ns0, Ms0, Np1	Ns0, Ms0, Np1	Ns0, Ts1
<i>f</i> (Hz.)	788	3,106	>4,000	>4,000	8,643	14,717
Mode	Ts0, Tp0	Np1, Ns0, Ms0			Np0, Ns2, Ms0	Np3, Ns2
<i>f</i> (Hz.)	2,994	>4,000			17,250	>20,000
Mode	Np1, Ms0, Ns0				Np3, Ms0, Ns2	
<i>f</i> (Hz.)	>4,000				>20,000	
Mode						

TABLE 2C

<i>m</i>	0	1	2	3
<i>f</i> (Hz.)	287	125	697	1,671
Mode	Ms0, Np0	Ms0, Np0	Ns0, Ms0, Np0	Ns0, Ms0, Np1
<i>m</i> =0				
<i>f</i> (Hz.)	825	2,445	3,344	4,857
Mode	Ts0, Tp0	Np1, Ms0, Ns0	Np1, Ns0	
<i>f</i> (Hz.)	2,336	4,600	7,550	
Mode	Np1, Ms0	Ns0, Ts0, Tp0	Np1, Ns1, Ms0	
<i>f</i> (Hz.)	6,429	6,955	9,083	
Mode	Np2, Ms0	Np2	Np2, Ms0, Ns0	

TABLE 2D

<i>m</i>	0	1	2	3
<i>f</i> (Hz.)	258	109	919	2,313
Mode	Ms0, Np0	Ms0, Np0	Ns0, Ms0, Np0	Ns0, Ms0, Ts1
				Np1
<i>f</i> (Hz.)	719	2,556	3,555	5,174
Mode	Ts0, Tp0	Np1, Ns0	Np0, Ns1	
<i>f</i> (Hz.)	2,418	4,152	7,681	
Mode	Np1, Ms0	Ns0, Ts0, Tp0	Np1, Ns0, Ms0	
<i>f</i> (Hz.)	6,751	7,256	9,726	
Mode	Np2, Ms0	Np2, Ms0	Np2, Ms0, Ns0	

Table 1 illustrates the resonant frequencies and sound outputs for various modes of vibration of (a) a dome of similar shape but of constant thickness; (b) a dome of the shape in FIG. 5, called optimized shape, wherein $t_p=0.1$ inches and $t_s=0.15$ inches; and two other shapes denoted (c) and (d) where the thickness of the rim t_r is 0.2 inches and 0.1 inches respectively. As can be seen from the Table the variation in the thickness of the rim of the skirt causes substantial variation in the resonant frequencies and sound output of the bell and all cases show a very substantial change from a bell having constant thickness. It will be appreciated that all sound levels are measured in echo-less conditions using the same striker mechanism.

It will be seen from Table 1 therefore one can determine how variations in thickness of selected parts of the bell dome give rise to different vibrational modes and accordingly different resonant frequencies and sound outputs and one feature of the present invention is that these results should be used to select the appropriate sizes of the "variable" parts so as to produce a bell dome giving a desired output. The Table shows that a very considerable change in the sound output is associated with slight changes in the dimensions of the skirt: moreover, it will be apparent that a considerable increase in sound output (92dBA to 99dBA) for no extra input power can be obtained by optimizing the shape and that slight alterations from the optimized shape can lose this advantage.

As a further illustration of how the present invention is put into practice, one may consider the idealized shape of dome of FIG. 5 (having a skirt of constant

thickness) more generally. It will be assumed that the dome should have a resonant frequency $f_{3,1}$ equal to 2,100 Hz. The variables in the design problem may be the thickness of the plate t_p and the thickness of the skirt t_s . It will be appreciated that there would exist a multiplicity of solutions unless some further constraint is imposed such as the minimization of the volume of material in the dome. Reference will be made to Tables 2A, 2B, 2C and 2D to illustrate the various vibrational modes associated with selected values of the base thickness and skirt thickness. Table 2A is associated with base thickness and skirt thickness equal to 0.1 inches, Table 2B with a base thickness of 0.1 inch and a skirt thickness of 0.15 inches, Table 2C with a base thickness of 0.08 inches and a skirt thickness of 0.1 inches and Table 2D with a plate thickness of 0.08 inches and a skirt thickness of 0.15 inches. For each mode the principal features of the mode are indicated by the use of the letters M, N and T which correspond to displacements in the meridional, normal and tangential directions respectively; the appropriate letter (M, N or T) is followed by either the letter p indicating that the largest displacement is in the (base) plate or the letter s indicating that the largest displacement is in the skirt and finally the number after p or s indicates the number of nodal circles associated with displacements in the plate or skirt. It will be noted from the Tables that in certain cases the principal features of vibration include more than one type of displacement. Accordingly the most significant type is listed first, the next most important displacement is listed second and so on. The Tables do not illustrate every type of mode

since this would be a task difficult both experimentally and by calculation and is in any event unnecessary for present purposes.

Having found the results shown in the tables, it is readily possible to select the thicknesses of the base and skirt in accord with the required vibrational characteristics of the bell member or dome. For example, it is evident from Table 2A that the lowest natural frequency for the respective type of dome with n equal to 4 is 2,859 Hz. In this case the mode shape is characterized by a normal N displacement of the skirt s with zero nodal circles, meridional displacement of the skirt with zero nodal circles and a normal displacement of the base plate with one nodal circle.

FIG. 6 is a graph illustrating the variation of the natural frequency for the mode with one nodal circle (n equal to 1) as a function of m the number of circumferential waves for the types of dome (A and B) associated with Table 2A and 2B. FIG. 7 shows the required relationship between the thickness of the plate t_p and the thickness of the skirt t_s such that the fundamental mode with three circumferential waves will have a natural frequency of 2,100 Hz as required. For most values of the plate thickness the mode shape is similar to that shown in FIG. 3. However for a plate thickness of about 0.031 inches another mode of vibration occurs as is shown in FIG. 8 which is a graph illustrating resonant frequency against base-plate thickness. This mode has no nodal circle and is a swash mode in which the distortion occurs almost completely in the base with maximum displacement at the skirt. It will be readily apparent that FIG. 7 shows how to select the skirt thickness and plate thickness to give the required shape of bell member. Indeed, the results plotted on FIG. 7 can be used to design a bell with $f_{3,1}$ equal to 2,100 Hz by inspection. However if a constraint such as minimization of total material is imposed then a design can easily be affected by calculating the volume of material in the gong namely by the formula $V = \pi t_p [(R - h \tan 10^\circ)^2 - r^2] + (\pi t_s / \tan 10^\circ) [R^2 - (R^2 - (R - h \tan 10^\circ)^2)]$.

This equation has in this example an explicit form: V is approximately equal to $24.4t_p + 28.8t_s$ cubic inches; superposition of the line corresponding to this equation on FIG. 7 indicates that V is an absolute minimum when the thickness of the base is zero. However if the minimum thickness of the base is specified such as 0.05 inches the minimum value of the volume corresponds to a thickness of the skirt of 0.141 inches and is in fact 5.28 cubic inches.

However, this should not be allowed to obscure the essential fact that from the knowledge of the vibration modes and the variation thereof with the thickness of selected parts of the bell member it is readily possible to determine what the thicknesses of the selected parts should be. It is convenient to assume a fairly idealized shape because this makes both calculation of the reso-

nant frequencies and the choice of thicknesses easier but the method obviously has more general application for other shapes.

FIG. 9 illustrates another type of variation of the thickness of a bell member 81. The outside of a section through the member is a circle 82 whereas the inside is shaped as a regular polygon. The order of the polygon may be selected in accord with the number of desired circumferential circles in the vibration mode.

We claim:

1. An electric bell, comprising: an electrically operable striker; and a bell member of which the thickness varies in a preselected manner from place to place in accord with the desired tonal characteristics of the bell, the thickness of the bell member varying circumferentially, the circumferential variation being cyclic, the outside dimension of a section through the bell member being circular, and the inside dimension of the section corresponding to a regular polygon.

2. A method of making a bell member for an electric bell, comprising: selecting an idealized shape for the bell member; calculating the resonant frequencies associated with different combinations of thicknesses of selected parts of the bell member; determining the thicknesses of those parts in accord with the desired vibrational mode and resonant frequency or frequencies of the bell member; and forming the bell member according to said selected shape and said determined thicknesses.

3. A method according to claim 2 wherein the bell member has a shape approximating a truncated cone and said selected parts are the base of the bell and the skirt thereof.

4. A method according to claim 2 wherein the desired resonant frequency is satisfied by a range of values for the thicknesses of selected parts of the bell member and the actual thicknesses are determined in accord with a constraint on the volume of the bell member.

5. A method of making a bell member for an electric bell, comprising: selecting an idealized shape for the bell member, said shape consisting of geometrically substantially regular parts; calculating the vibration mode of the bell in respect of a plurality of sets of values of thickness of selected parts of the bell member; selecting a particular vibration mode for the bell, thereby predetermining the thicknesses of said parts in accord with said calculations; and forming the bell member according to said selected shape and said determined thicknesses.

6. A method according to claim 5, wherein said shape is a truncated cone, said bell member consisting of a substantially flat base and a truncated conical skirt portion, said selected parts comprising the said base and the said skirt portion.

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