

[72] Inventors **Gerhard Hesse;**
Wolfgang Reimann, Jena, Germany
 [21] Appl. No. **755,757**
 [22] Filed **Aug. 27, 1968**
 [45] Patented **June 1, 1971**
 [73] Assignee **VEB Carl Zeiss Jena**
Jena, Germany

1,104,856 3/1968 Great Britain..... 356/112
 Primary Examiner—Ronald L. Wilbert
 Assistant Examiner—T. Mavor

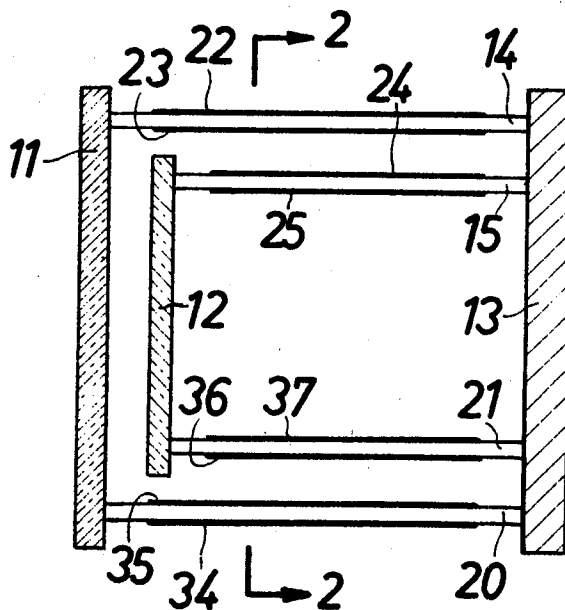
[54] **FABRY-PEROT RESONATORS**
8 Claims, 8 Drawing Figs.

[52] U.S. Cl..... 356/112
 [51] Int. Cl..... G01b 9/02
 [50] Field of Search..... 356/112;
 331/94.5

[56] **References Cited**

UNITED STATES PATENTS
 3,229,224 1/1966 Waly et al..... 356/112
FOREIGN PATENTS
 1,068,054 5/1967 Great Britain..... 356/112

ABSTRACT: A Fabry-Perot resonator comprises two plate which are displaceable relatively to each other by means of concentric series of electrostrictive rods, the number of rods being the same in each series. The rods of the consecutive series are arranged along radii which enclose given angles. The consecutive rods are interconnected in meanderlike fashion. Two opposite surfaces of each rod bear electrically conductive linings, so that applied voltage produces an electric field between these linings. Differential influences on two radially consecutive rods produce changes in the distance apart of, or the angle between, the plates. Equality in the dimensions and thermal properties of the rods renders the resonator insensitive to thermal influence. Suitable coordination of the plate carriers relative to each other permits relatively great changes in the distances of the plates from each other and at the same time excludes thermal influence.



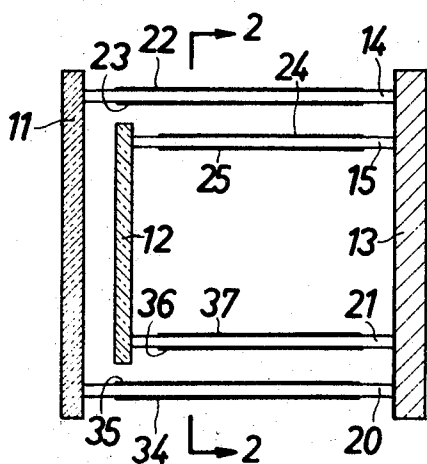


Fig. 1

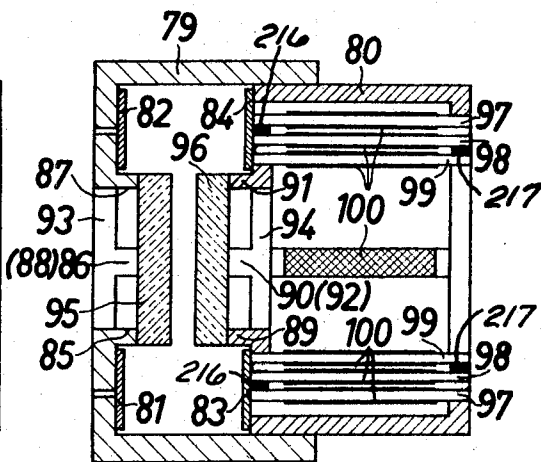


Fig. 3

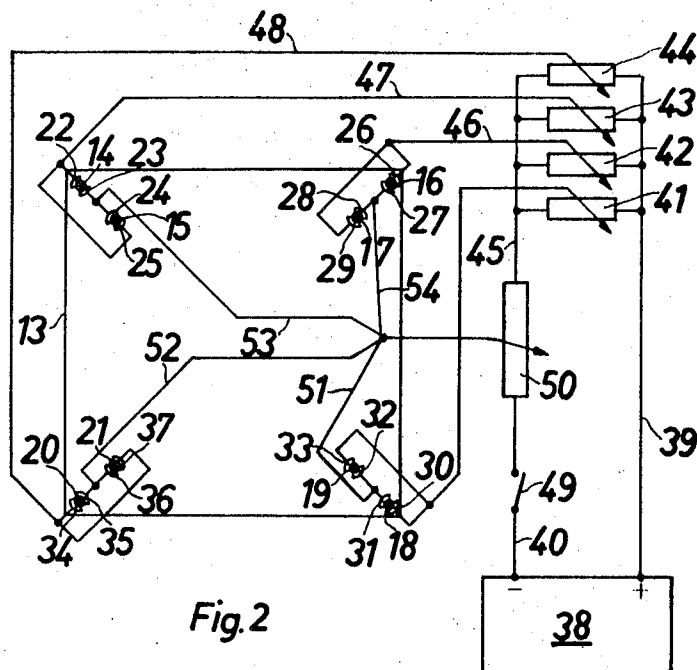


Fig. 2

INVENTORS
for hard name
 BY *Wolfgang Raimann*
 ATTORNEY

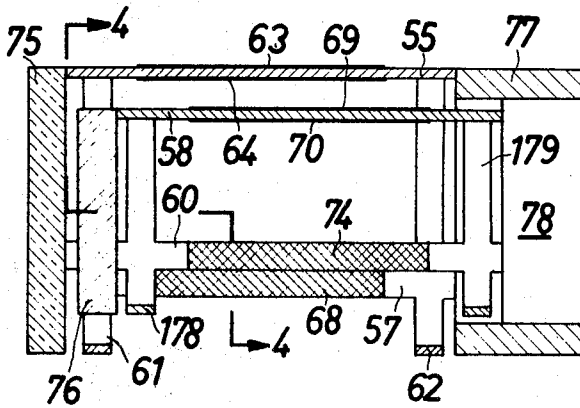


Fig. 4

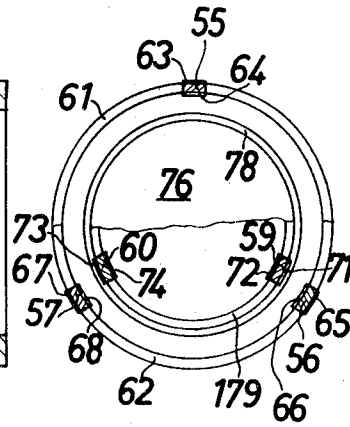


Fig. 5

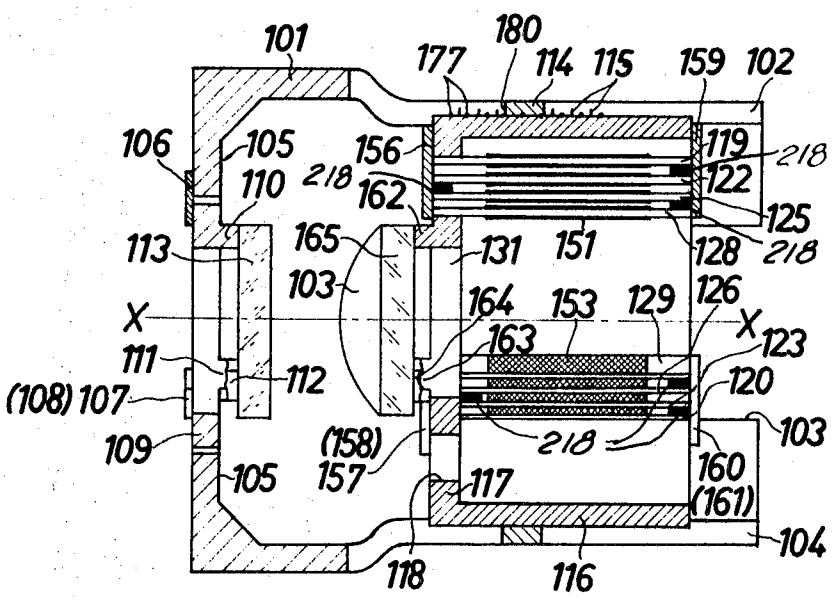
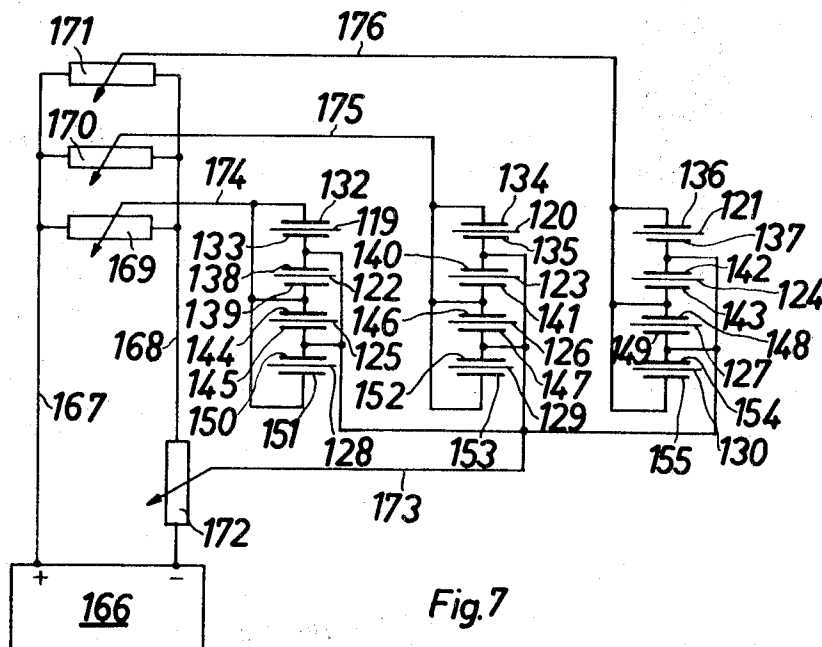
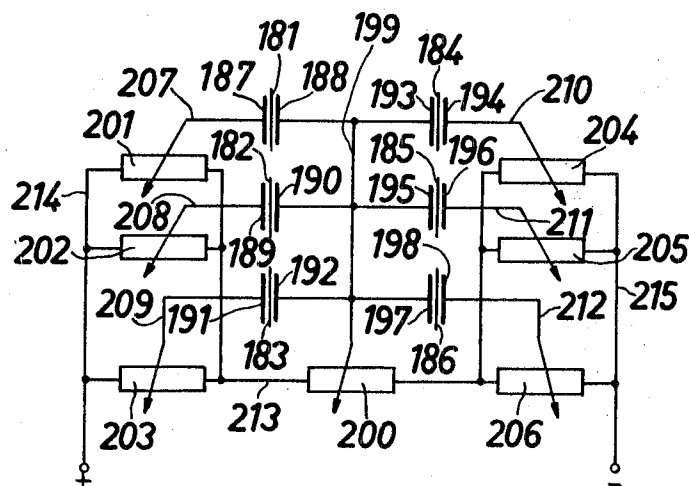


Fig. 6

INVENTORS
Edward Kern.
 BY *Rolfgang Reinmann*
 ATTORNEY



INVENTORS

forward. Here.

BY

Hilfgang Reimann
ATTORNEY

FABRY-PEROT RESONATORS

This invention relates to Fabry-Perot resonators comprising two optical plates and a plurality of rods of electrostrictive material which are located at right angles between the peripheries of these plates and each of which bears electrically conductive linings on two opposite sides, these linings producing an electric field. The rods are attached to the plates either direct or by means of carriers.

In known electrostrictively controlled Fabry-Perot interferometers at least one plate is mounted on webs or rods bearing electric linings on their inner and outer sides, the linings of one of these sides being short-circuited. The magnitude of an electrostrictively effected change of the space between, or the angle enclosed by, these plates is a function of the voltages to be applied to the linings. Great changes in these parameters require great potential differences between the inner and the outer linings. The dielectricity constants and the thicknesses of the rods do not however permit these potential differences to be increased indefinitely. This disadvantage can be obviated by increasing the lengths of the webs or rods and applying corresponding linings. Such an increase is however restricted by considerations of manufacture, methodology and applicability, especially because Fabry-Perot interferometers are often used for example as filters or resonators where small dimensions are indispensable.

The present invention aims at overcoming the foregoing disadvantages in Fabry-Perot resonators by restricting as much as possible the dimensions and the potential differences applied for changing the space or angle between the plates or, alternatively, by providing that this space or angle can be increased at option where great dimensions and potential differences are concerned.

To this end the invention consists in a Fabry-Perot interferometer of the foregoing kind wherein the rods are arranged in at least two equal series in radial succession to each other, and wherein those rods of the several series which succeed each other at one place in the periphery are interconnected in the fashion of a line called "embattled" in heraldry and wherein a connecting means is provided between the plates. In the electric field, the polarization devices of two neighboring series can be rectified or inversely rectified. The arrangement and form of the rods enables one and the same voltage to create, relatively to a series of rods, an at least twofold change of the distance or angle between the plates, provided that the rods are all of the same length and provided with linings of the same form and size. The greater the number of rod series employed, the more will the change in the distance or angle between the plates be multiplied, on the condition of course that the potential differences applied are the same. The rods may be connected with the plates or carriers in a detachable manner, which offers the advantage that also rods of other dimensions can be inserted in Fabry-Perot resonators. The rods of each series are either separate from each other or they are interconnected at their same ends and, with a view to increasing the stability of the resonator, may be integral with the interconnecting means. A series may comprise any desired number of rods. However, to obtain a highly satisfactory Fabry-Perot resonator at the lowest possible expense, it is advantageous to make a series consist of three rods staggered by 120° or four rods staggered by 90°.

Opposite polarization of two neighboring series of rods in an electric field can be achieved in different ways. If, in the process of manufacture, the rods are all polarized in the same sense, it is advantageous to apply the same electric potentials to the linings on the interfacing sides of the rods of two neighboring series, so that the potentials at the linings on the other sides are opposite. Accordingly, the rods of two neighboring series change their lengths in directions opposite to each other, the rods of the one series expanding while those of the other series contract.

Apart from a magnification of the space or angle between the Fabry-Perot plates, the invention permits the temperature influence on the relative positions of the plates to be neutral-

ized by arranging the rods in an even number of equal series and providing that every two of these series have the same thermal properties. Preferably, the rods have all the same coefficient of expansion and the same dimensions. If every two similar series of rods are connected with one another in a suitable manner, or the two series carrying a plate are appropriately connected with the other plate, temperature influences will not in any way effect the reciprocal positions of the plates. The connection may be either permanent or detachable, so that the space between the Fabry-Perot plates can be changed, if desired, by amounts greater than electrostriction permits. In a preferred embodiment of the invention, the rod series are of equal lengths and the connecting means is made up of two telescoping bodies of different materials which contact each other at least in a circumferential line and from this line extend with different lengths parallel to the rods, the coefficients of expansion of the two bodies being such that a change of temperature causes both bodies to expand by the same amount away from the line of contact. It is thus possible by the use of rods of the same lengths to compensate the influence of the thermal expansion of the connecting means on the space between the plates. If the two bodies of the connecting means are displaceable relatively to each other, the position of the line of contact relative to both bodies can be changed as a function of the displacements of these bodies and the ratio of their coefficients of expansion. If only two series of rods are employed, each body may carry one series extending along the same direction, or one of the bodies may carry both series.

The invention hereinbefore set forth refers substantially to Fabry-Perot interferometers, but can be used wherever small deformations in extension or angular variations take place, as for example in interference comparators, adjusting tables and the like.

In order that the invention may be more readily understood, reference is made to the accompanying drawings which illustrate diagrammatically and by way of example four embodiments thereof, and in which:

FIG. 1 is a longitudinal section through an embodiment comprising two series of rods;

FIG. 2 is a top view of the embodiment of FIG. 1 and the respective circuit arrangement;

FIG. 3 is a longitudinal section through another embodiment, which comprises three series of rods;

FIG. 4 is a longitudinal section through a third embodiment, which comprises two integral series of rods;

FIG. 5 is a top view of the embodiment of FIG. 4;

FIG. 6 is a section along the axis of a fourth embodiment which comprises four series of rods;

FIG. 7 is the circuit arrangement of the embodiment of FIG. 6, and

FIG. 8 is a circuit arrangement in which the series of rods are polarized in the electric field in the same direction.

In FIGS. 1 and 2, an optical plate 11 is attached to a connecting means 13 by rods 14, 16, 18, 20, and an optical plate 12 is attached to the connecting means 13 by rods 15, 17, 19, 21. Two opposite sides of the rod 14 respectively bear linings 22 and 23. Analogously, two opposite sides of the rods 15 to 21 are provided with linings 24/25, 26/27, 28/29, 30/31, 32/33, 34/35 and 36/37. The rods are arranged in a series 14, 16, 18, 20 and a series 15, 17, 19, 21. The two series are slightly different from each other in length and size of lining. The two linings of each rod are electrically insulated from each other and act as a condenser. The linings 23/24, 27/28, 31/32 and 35/36, which face each other, are electrically interconnected, as are the linings remote from each other 22/25, 26/29, 30/33 and 34/37. For potentiometers 41, 42, 43, 44 are connected in parallel between wires 39 and 40 which respectively contact the positive and the negative pole of a voltage source 38. The potentiometers 41, 42, 43 and 44 are respectively connected by wires 45, 46, 47 and 48 with two electrically interconnected linings 30/33, 26/29, 22/25 and 34/37 on those sides of the rods 14 to 21 which are remote from each

other. The wire 40 contains a switch 49 and a potentiometer 50. The potentiometer 50 by means of branch wires 51, 52, 53, 54 is respectively connected with the linings 31/32, 35/36, 23/24, and 27/28 on those sides of the rods 14 to 21 which face each other.

If the potentiometers 41 to 44 are all adjusted alike, closing the switch 49 will cause the same voltage to be produced between the two linings of each rod, this voltage depending solely on the adjustment of the potentiometer 50. Accordingly, an electric field is created between the linings of each rod of the series 14, 16, 18, 20. This electric field is antiparallel to that between the linings of each rod of the series 15, 17, 19, 21 and, owing to the difference in the sizes of the linings, of different magnitude. As the rods have all been given the same direction of polarization in the process of manufacture, the electric fields cause the rods of the one series to expand and those of the other to contract. The small variations in the sizes of the linings of the two series entail slight differences in the absolute values of the changes in the lengths of the rods of the two series. These two values are inversely equal if the spaces between and the lengths of the linings are equal.

A variation in the adjustment of the potentiometer 50 produces uniform changes in the lengths of the rods 14, 16, 18, 20 and 15, 17, 19, 21, the result being inverse changes in the positions of the plates 11 and 12 parallel to their original positions. Variations in opposite senses of the adjustments of two of the potentiometers 41 to 44, for example of 41 and 43, which are connected by diagonally arranged rods (18, 19, 14, 15) change also the voltages applied between the linings 30/31, 32/33, 22/23, 24/25 and, accordingly, the respective electric fields, so that the plates 11 and 12 are tilted about parallel axes which are at right angles to the diagonal containing the rods 18, 19, 14, 15. Thus the angle enclosed by the optical plates 11 and 12 is changed with a high degree of accuracy.

In FIG. 3, a hollow cylinder 79 envelops part of a hollow cylinder 80. A carrier 93 holding an optical plate 95 by means of four feet 85, 86, 87, 88 is connected by springs 81, 82 with the hollow cylinder 79. A carrier 94 holding an optical plate 96 by means of four feet 89, 90, 91, 92 is connected by springs 83, 84 with the hollow cylinder 80. These spring connections are such that the plates 95 and 96 can be displaced only parallel to the common geometrical axis of the cylinders 79 and 80. The numerals 88 and 92 in parentheses denote the feet outside the plane of the drawing. Three rod series 97, 98, 99 of electrostrictive material are arranged in radial sequence between the hollow cylinder 80 and the carrier 94. In consistency with the arrangement and number of the feet, each of these series is made up of four rods with electrically conductive linings 100 on two opposite sides. The outer diagonally arranged rods of the three series, which are not themselves electrically conductive, are secured with their one ends to the hollow cylinder 80 or the carrier 94, so that the connections of every two sequential rods are alternately at the one and the other ends of these rods. The rods 97 and 98 are connected by an element 216; and the rods 98 and 99, by an element 217. The other free ends of these rods are connected with the rod located between them, so that the points of connection of the rods are disposed meander-fashion.

If the electrically conductive linings 100 on the radially juxtaposed rods of the series 97, 98, 99 are so interconnected that the neighboring rods are submitted by the applied voltage to oppositely equal length variations, and if the circuit arrangement is similar to that shown in FIGS. 1 and 2, the variation of the distance between the plates 95 and 96 or the variation of the tilting angle enclosed by these plates is three times as great as it would be if only one series of rods were used. In all other respects the mode of operation is the same as that described with reference to FIGS. 1 and 2.

Whereas the embodiments of FIGS. 1 to 3 concern chiefly a multiplication of the range of the displacement or tilting of the optical plates, the embodiments hereinafter described with reference to FIGS. 4 to 7 not only multiply the plate displacement but permit temperature influence to be compensated.

In FIGS. 4 and 5 a series of three rods 55, 56, 57 and a series of three rods 58, 59, 60 are each staggered by 120°. The rods 55, 56, 57 are interconnected by rings 61 and 62, and the rods 58, 59, 60 by rings 178 and 179. The rods all project from the rings interconnecting them. The rods 55, 56, 57 and the rings 61, 62 form part of and are integral with a hollow body. The rods 58, 59, 60 and the rings 178, 179 form part of and are integral with another hollow body. The rod 55 has a lining 63 on one side and a lining 64 on the opposite side. Likewise, the rods 56 to 60 have, respectively, linings 65/66, 67/68, 69/70, 71/72, and 73/74. The linings 63 to 74 are all electrically conductive and of the same dimensions. The two linings of each of the rods 55 to 60 are insulated from each other. The linings are all connected with a voltage source in a manner described hereinafter.

Optical plates 75 and 76 are respectively sprung on the one ends of the rods 55, 56, 57 and 58, 59, 60 which project from the rings 61, 62 and 178, 179. On the other ends of these rods are sprung a connecting means comprising parts 77 and 78 in the form of cylindrical tubes, the longer part 77 enveloping the shorter part 78. The coefficients of expansion of the parts 77 and 78 are such that a change in temperature causes the lengths of these parts to vary by the same magnitude.

If, in a manner described hereinafter, lining 63 is electrically connected with lining 70, 64 with 72, 67 with 74, 64 with 69, 66 with 71 and 68 with 73, and these linings are all connected with a voltage source (not shown), an application of the same voltage to all rods will shorten the rods 55, 56 and 57 by the same amount as it will lengthen the rods 58, 59 and 60, or vice versa. Owing to the constructional conformity of the rods and the exact reciprocity of the parts 77 and 78 of the connecting means, a change in temperature will not influence the positions of the plates 75 and 76 relative to each other.

FIG. 6 shows a cylindrical hollow body 101 having recesses 102, 103, 104 and a further recess which is not illustrated in the sectional drawing. These four recesses are staggered by 90°. One end of the hollow body 101 bears an annular flange 105 to which an annular carrier 109 is attached by means of three springs 106, 107, 108 staggered by 120°. The body 101, the flange 105 and the carrier 109 have a common axis X-X. As the spring 108 is not shown in the drawing, its reference numeral is included in parentheses. The carrier 109 has three feet 110, 111, 112 staggered by 120°. An optical plate 113 is sprung on the free ends of these feet. In FIG. 6 of the drawing, the feet 111 and 112 are visible only in part, and the plate 113 is shown in sectional view. In the hollow body 101, a ring 114 is displaceable along the axis X-X, the magnitude of the displacement being indicated on a scale 115 on a face of the recess 102. The ring 114 contains a hollow body 116 which has a flange 117 and is likewise displaceable along the axis X-X, the magnitude of the displacement of the body 116 relative to the ring 114 being indicated on a scale 177 on the body 116.

The one ends of a first series of rods 119, 120, 121 (FIG. 7) of electrostrictive material are fast with the face 118 of the flange 117. With the free ends of the rods of the first series are connected the one ends of a second series of rods 122, 123, 124 (FIG. 7) which is antiparallel to the first series. With the free ends of the second series are connected the one ends of a third series of rods 125, 126, 127 (FIG. 7) which is antiparallel to the second series. With the free ends of the third series are connected the one ends of a fourth series of rods 128, 129, 130 (FIG. 7). The other ends of the rods of the fourth series are fast with an annular carrier 131 coaxial with X-X. There are three sequels of rods, namely 119, 122, 125, 128; 120, 123, 126, 129; and 121, 124, 127, 130. In each of these sequels the rods are interconnected by elements 218. Each of the four series comprises three rods staggered by 120°, the lengths of the rods being equal at least in pairs. Only two of every three rods are shown in FIG. 6. Those rods of the four series which are coordinated to one place in the periphery are arranged radially. The rods 119 and 130 respectively bear on two opposite sides electrically conductive linings 132/133, 134/135, 136/137, 138/139, 140/141, 142/143, 144/145,

146/147, 148/149, 150/151, 152/153, and 154/155 (FIG. 7). The annular carrier 131 by means of springs 156, 157, 158 (158 not shown) is so attached to the hollow body 116 as to be displaceable only parallel to the axis X-X. Springs 159, 160, 161 (161 not shown) fast with the remote end of the hollow body 116 from the carrier 131, secure the rods 119 to 130 against lateral displacement, but do not interfere with changes in the lengths of these rods. In consistency with the staggering of the springs and rods by 120°, the carrier 131 has three feet 162, 163, 164 on which is sprung an optical plate 165. The feet 163 and 164 are shown only in part.

The circuit arrangement in FIG. 7 shows not only the electrically conductive linings of FIG. 6 and the rods separating them, but a floating voltage source 166 which is electronically stabilized and feeds electric wires 167 and 168 between which three potentiometers 169, 170, 171 are connected in parallel, the wire 168 being also connected with a potentiometer 172. The linings 133, 138, 145, 150, 135, 140, 147, 159, 137, 142, 149, 154, by means of a branching electric wire 173 are in connection with the tap of the potentiometer 172. An electric branch 174 connects the potentiometer 169 and the linings 132, 139, 144, 151; an electric branch 175 connects the potentiometer 170 and the linings 134, 141, 146, 153; and an electric branch 176 connects the potentiometer 171 and the linings 136, 143, 148, 155. Within each radial row of rods of the various series, the linings on the sides facing each other, for example the interfacing linings 133/138, 139/144, 145/150 of the rods 119, 122, 125, 128, have the same potential, whereas the two linings of one and the same rod, for example the linings 132/133 of the rod 119, 138/139 of the rod 122, 144/145 of the rod 125, 150/151 of the rod 128, have different potentials.

If the potentiometers 169, 170, 171 assume the same tap positions, there exist between the linings of the rods 119, 120, 121, 125, 126, 127 potential differences which are equal to those of the linings of the rods 122, 123, 124, 128, 129, 130, but have opposite directions and are accordingly antiparallel. Consequently, the electric fields produced by the potential differences are equal, but opposite to each other, and the changes in the lengths of the rods 119, 120, 121, 125, 126, 127 are oppositely equal to the changes in the lengths of the rods 122, 123, 124, 128, 129, 130. Owing to the meanderlike interconnection of the radially arranged rods and the application of the same voltages, the distance apart of the plates 113 and 165 is changed fourfold as compared with the use of one series of rods at the same voltage. If the taps of the potentiometers 169, 170, 171 are adjusted differently, further voltages are created and are superposed on the voltage due to the adjustment of the potentiometer 172. Accordingly, the voltage differences of the radial rows of rods vary from each other, the electric fields are absolutely equal only within one row of rods, and the plate 165 is tilted relatively to the plate 113. Naturally, the rod-length changes which cause this tilting are also four times as great as they would be if only one rod were used.

By means of the piezoelectric rods 119 and 130, the plates 113 and 165 can be displaced relatively to each other only by small amounts up to the order of some microns. To enable greater distances to be adjusted between the plates, the hollow bodies 101 and 116 and the ring 114 are measurably displaceable relatively to each other. To this end, the two hollow bodies 101 and 116 have the scales 115 and 117 working against each other. Both scales bear the same numbers, but their division lines are spaced differently. For adjusting a definite distance between the plates 113 and 165, the ring 114 with the hollow body 116 is set on the desired value on the scale 115, and the body 116 relatively to the ring 114 is set on the same value on the scale 177. The distance thus adjusted is not changed by temperature influences because the coefficients of expansion of the hollow bodies 101 and 116 and the supports 109 and 131 are such that to a setting of one and the same magnitude on both scales correspond equal changes in the lengths of both hollow bodies, these changes extending

away from the face 180 of the ring 114, which is conjugate to the plates 113 and 165 and serves as reading mark. The use of an even number of rod series between the hollow body 116 and the support 131 is likewise instrumental in maintaining temperature stability.

The motion of the ring 114 in the hollow body 101 and that of the hollow body 116 in the ring 114, which in the embodiment of FIG. 6 takes place in friction bearings, may alternatively be effected by screw threads.

The circuit arrangement of FIG. 8 comprises a rod series 181, 182, 183 and a rod series 184, 185, 186 and respective linings 187 to 192 and 193 to 198. The linings 188, 190, 192, 193, 195 and 197 by means of a branched wire 199 are connected with a potentiometer 200. The linings 187, 189, 191, 194, 196 and 198 are respectively connected by wires 207 to 212 to potentiometers 201, 202, 203, 204, 205 and 206. The potentiometers 203, 200 and 206 are connected in series in a circuit 213, the voltage source of which is indicated in the drawing by + and -. The potentiometers 201 and 202 in a circuit 214 are connected in parallel with the potentiometer 203, and the potentiometers 204 and 205 in a circuit 215 are connected in parallel with the potentiometer 206.

The taps of the potentiometers conjugated to adjacent rods of different series are so interconnected as always to be displaced the same amounts but in opposite senses. Accordingly, if the variations in the lengths of the rods 181, 182 and 183 are to be opposite to the variations in the lengths of the rods 184, 185 and 186, the taps of the potentiometers 201, 202 and 203 are to be displaced to the left and those of the potentiometers 204, 205 and 206 to the right. The potentiometer 200 ensures equality of the voltage changes between the linings of each of the rods. The potentiometers 201 to 206 produce differential voltages between every two adjacent rods belonging to different series. When voltage is applied, the rods 181 to 186 lie in rectified electric fields. In all other respects the mode of operation of the embodiment of FIG. 8 is similar to that described with reference to FIGS. 1 to 7.

The embodiments of the invention particularly described are presented merely as examples of how the invention may be applied, other embodiments, forms and modifications of the invention falling within the scope of the appended claims will of course suggest themselves to those skilled in the art. Variations are possible for example in the combination of the several features of the embodiments. In the embodiment of FIGS. 1 and 2, the linings 22 to 37 may all be of the same size and dimensions. The Fabry-Perot resonators of FIGS. 1 to 3 may have three rods staggered 120° instead of four rods staggered 90°. The supports 93 and 109 in FIGS. 3 and 6 may be connected, respectively, with the hollow cylinder 79 and the hollow body 101 by means of piezoelectric rods. The parts 77 and 78 in FIG. 4, like the hollow bodies 101 and 116 in FIG. 6, may be displaceable relatively to one another. The embodiments of FIGS. 4 to 8 may have four rods staggered by 90° instead of three rods staggered by 120°. In the embodiment with four rods per series, staggered by 90° (FIGS. 1 and 2), the circuit arrangement may be such that the potentiometers 41, 43 or 42, 44 conjugated to the diametral rods are replaced by one single potentiometer which changes the potentials of the diametrically disposed rods in opposite senses.

We claim:

1. A Fabry-Perot resonator comprising two optical plates at a variable distance from one another, rods of electrostrictive material extending parallel to the distance between said two plates, elements for interconnecting said rods, said rods being arranged in at least two equal series in radial juxtaposition to each other, every such two of said rods as are adjacent to one another along a radius being interconnected alternately at their one ends and their other ends, each of said rods bearing electrically conductive linings along their longitudinal extension on two opposite surfaces for producing an electric field,

each of said linings being connected with a voltage source through at least one voltage control, and mechanical connecting means, said connecting means and said rods connecting said plates with each other.

2. A Fabry-perot resonator as claimed in claim 1, wherein the connections of said rods with said plates or said carriers are detachable.

3. A Fabry-Perot resonator as claimed in claim 2, wherein the same electric potentials are applied to the linings of the interfacing sides of the rods of two neighboring series.

4. A Fabry-Perot resonator as claimed in claim 3, wherein said rods are arranged in an even number of equal series and every two series have the same thermal properties.

5. A Fabry-Perot resonator as claimed in claim 4, wherein the series or rods are all of the same length and the connecting means are made up of two telescoping bodies of different

materials which touch each other along at least one peripheral line of contact and extend in different lengths parallel to the rods and which have such coefficients of expansion that both bodies when exposed to a change of temperature expand by the same amount.

6. A Fabry-Perot resonator as claimed in claim 5, wherein said two bodies are displaceable relatively to one another, one of said bodies carrying a scale and the other of said bodies carrying an index, said scale and said index working against one another for the reading of the displacement.

7. A Fabry-Perot resonator as claimed in claim 6 comprising two series of rods, wherein each of said bodies carries one of said series and both series extend along the same direction.

8. A Fabry-Perot resonator as claimed in claim 6, wherein one of said bodies carries all said series.

20

25

30

35

40

45

50

55

60

65

70

75