Dec. 29, 1953 F. E. REED, JR 2,664,527

ADJUSTABLE ELECTROMAGNET AND COOLING MEANS THEREFOR

Filed Dec. 8, 1951

11 Sheets-Sheet 1

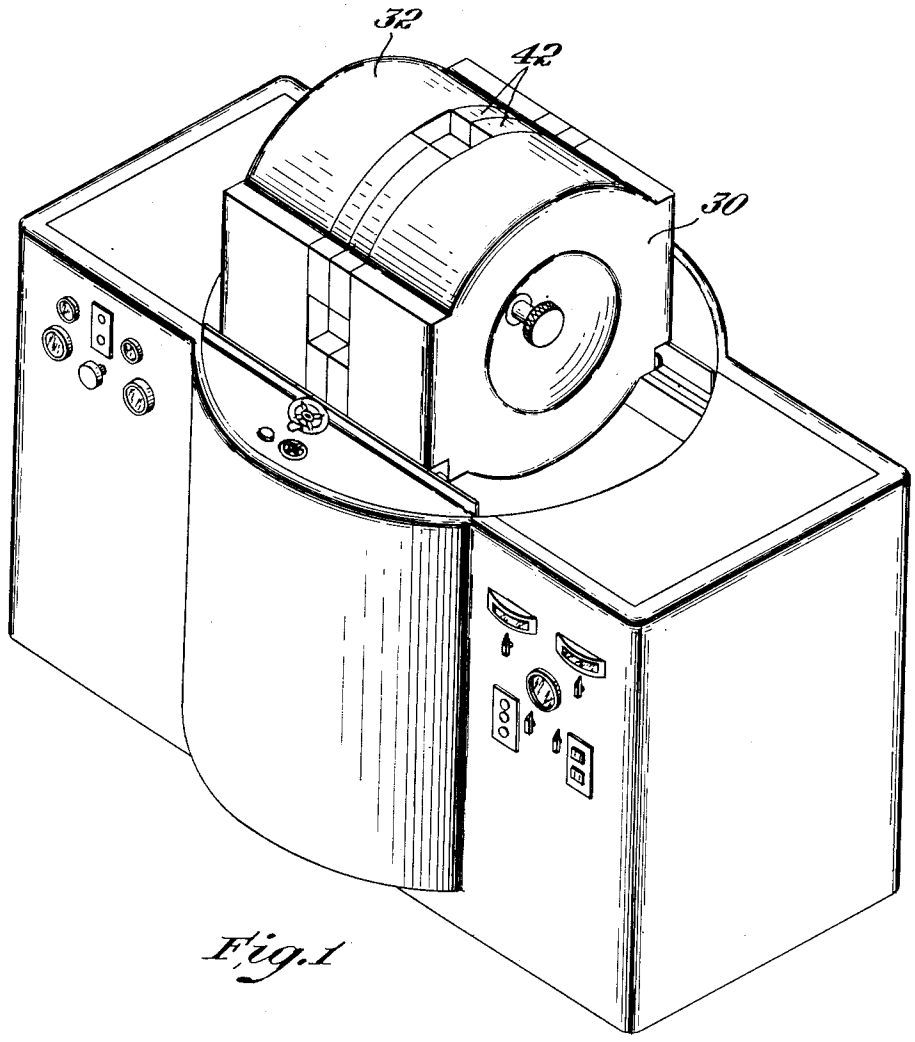


Fig. 1

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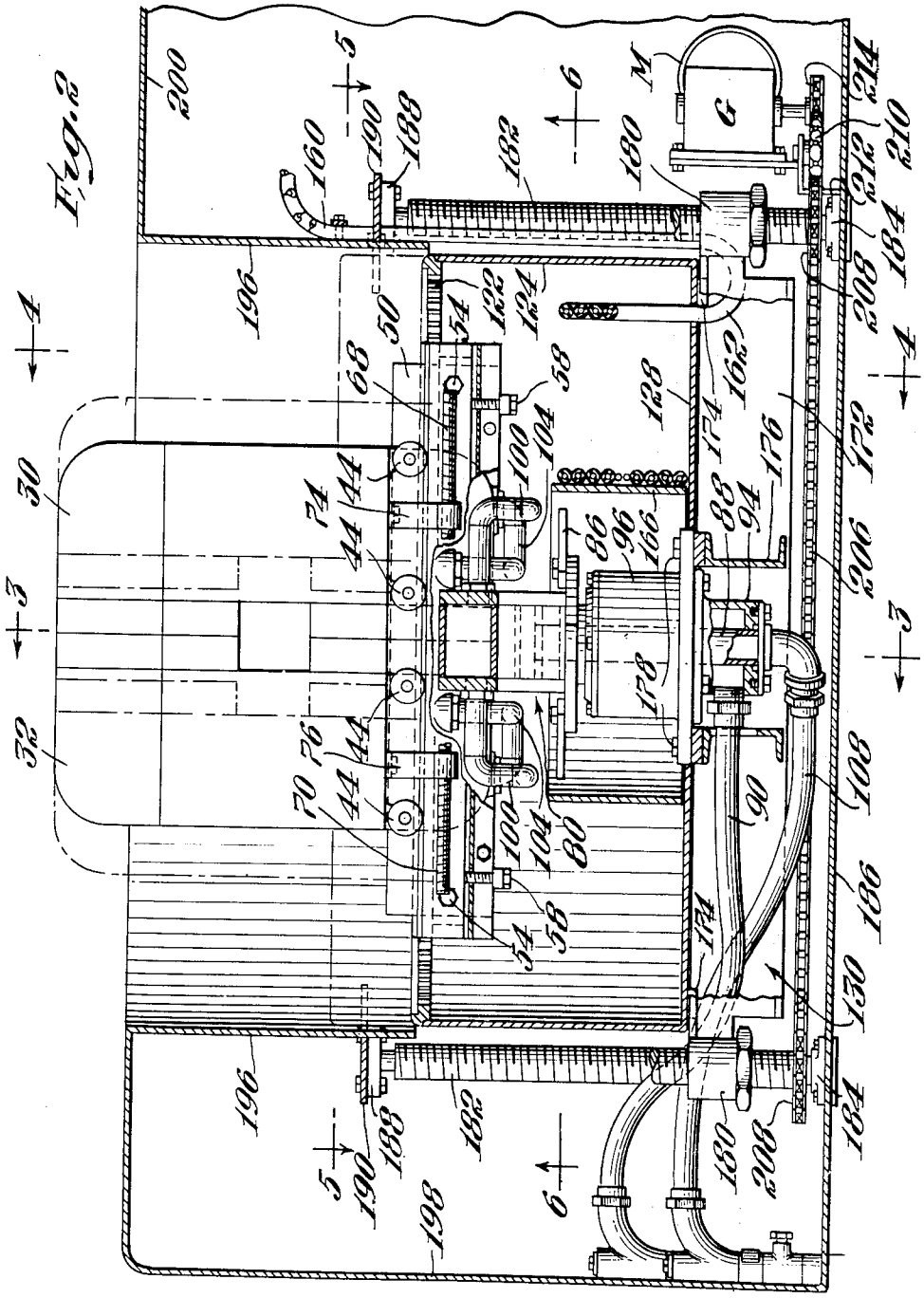
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11 Sheets-Sheet 2

Fig. 2



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11 Sheets-Sheet 3

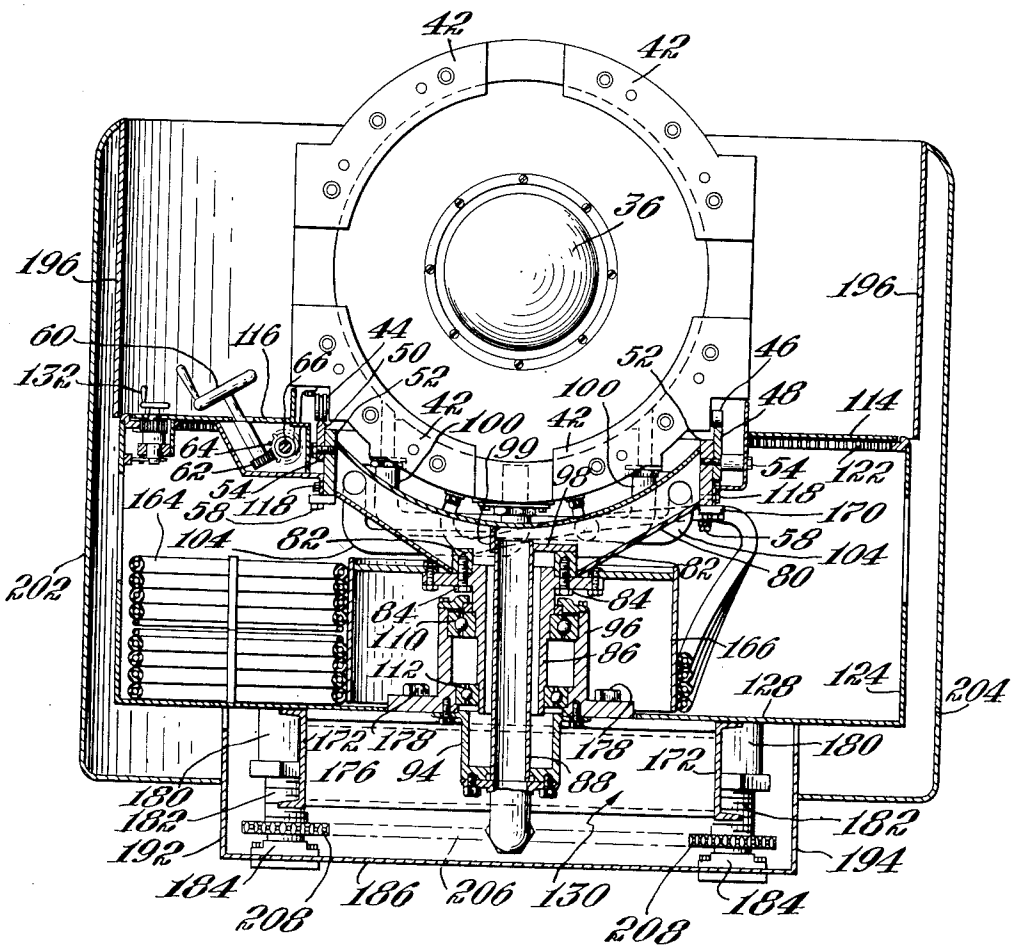


Fig. 3

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11 Sheets-Sheet 4

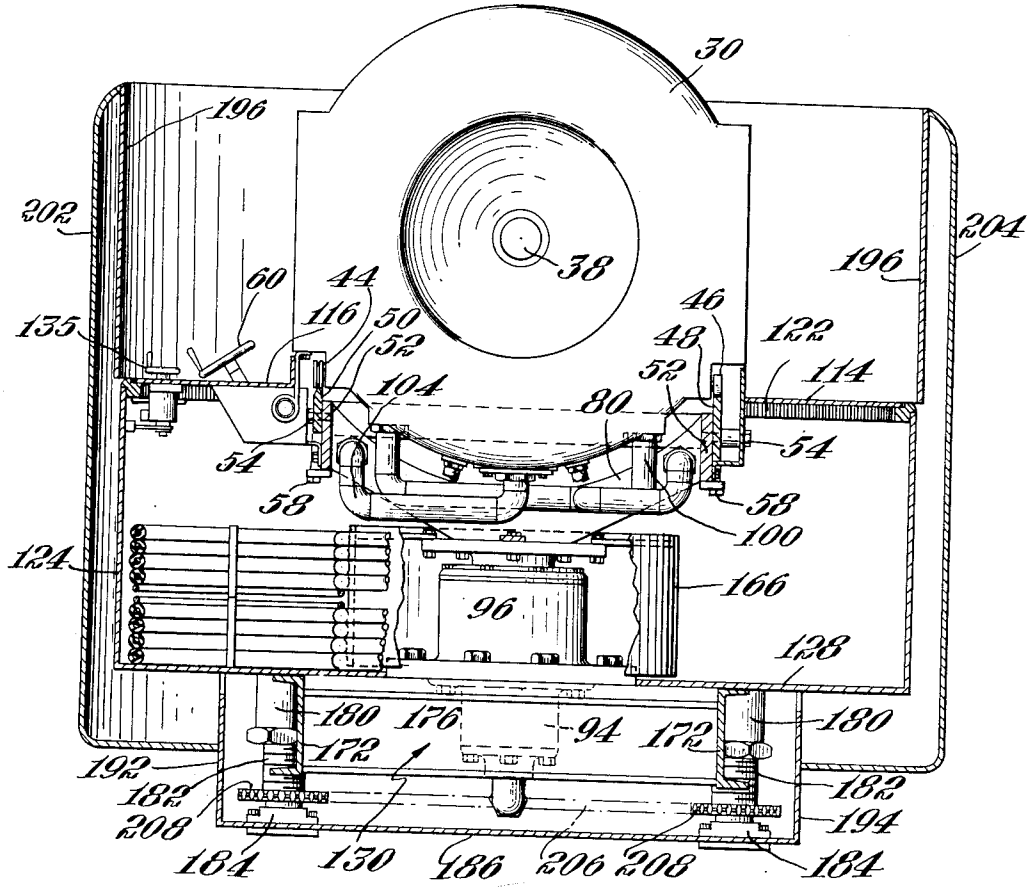


Fig. 4

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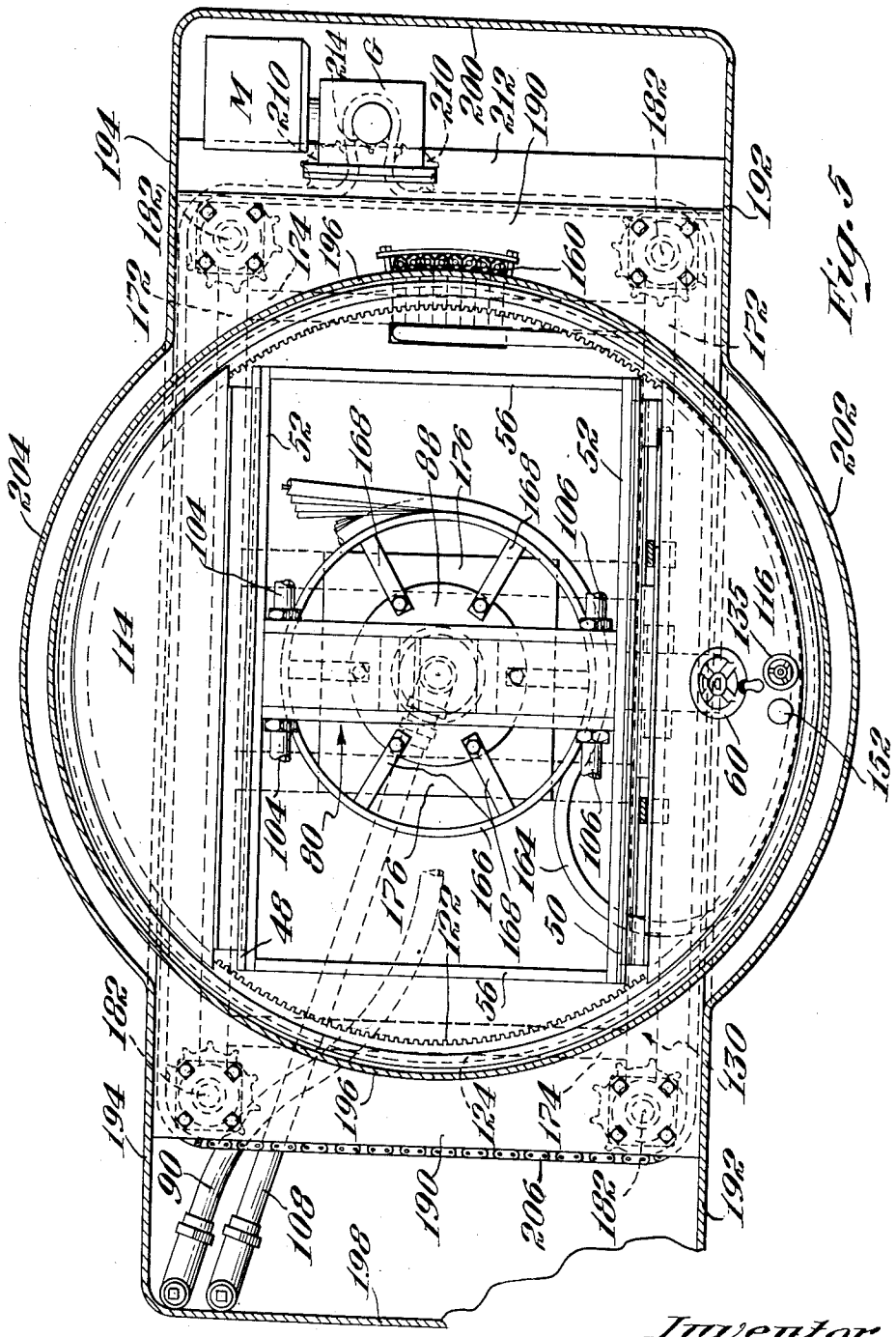


Fig. 5

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11 Sheets-Sheet 6

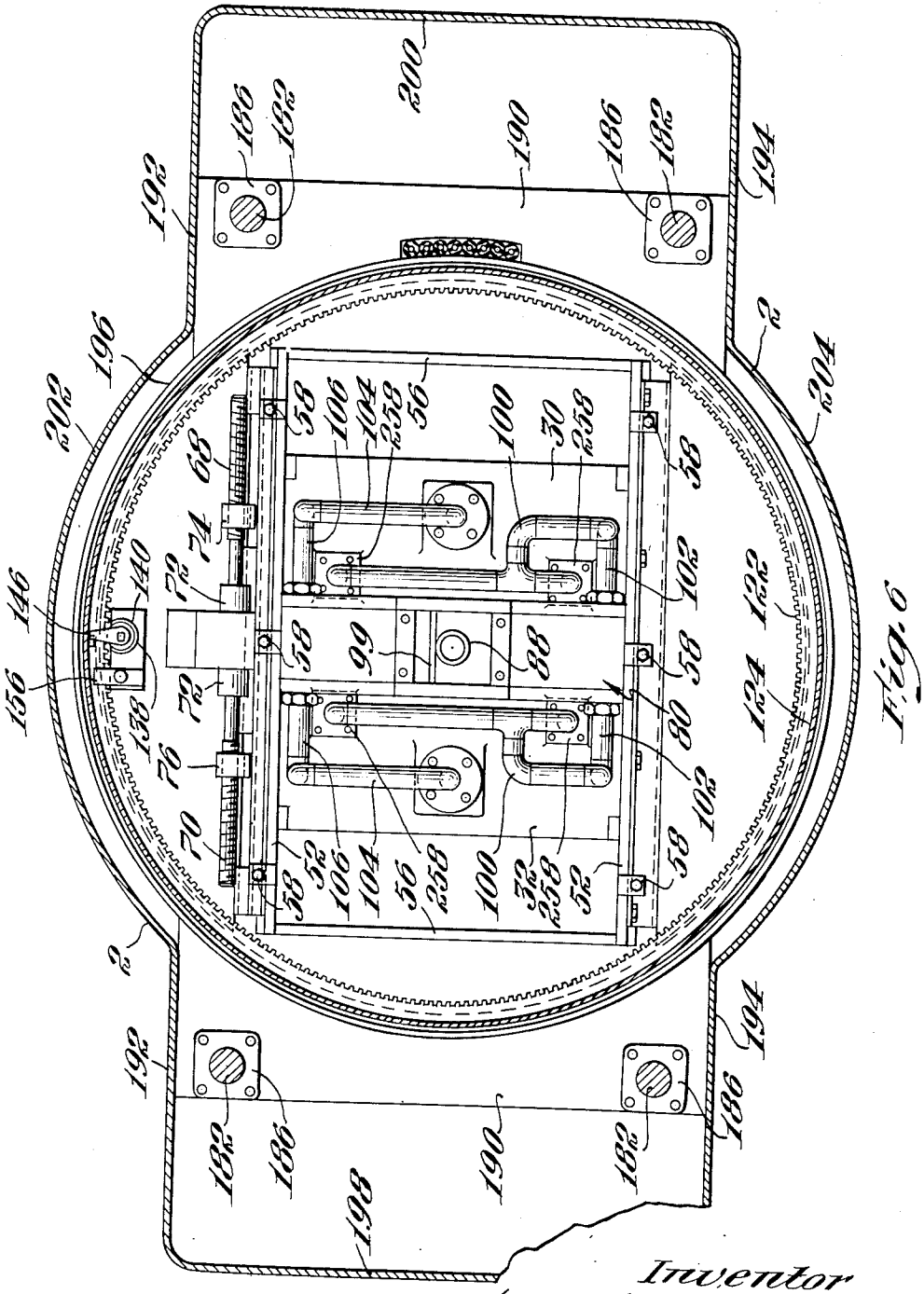


Fig. 6

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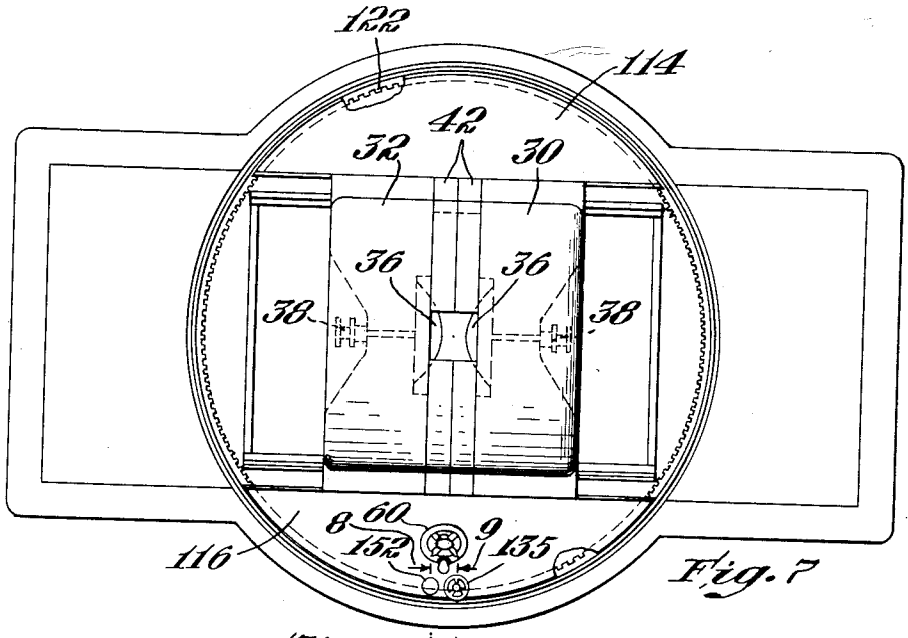


Fig. 7

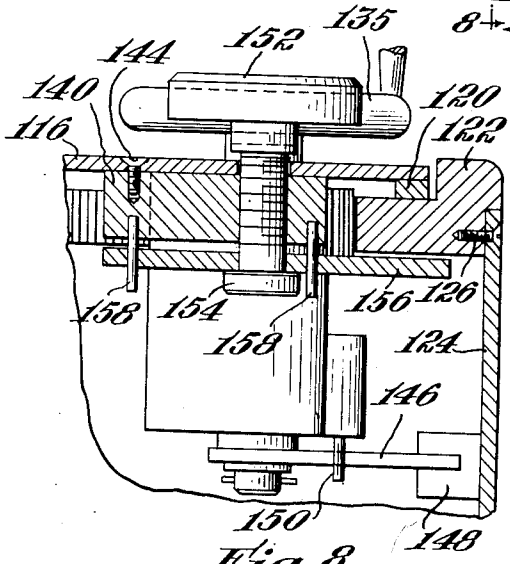


Fig. 8

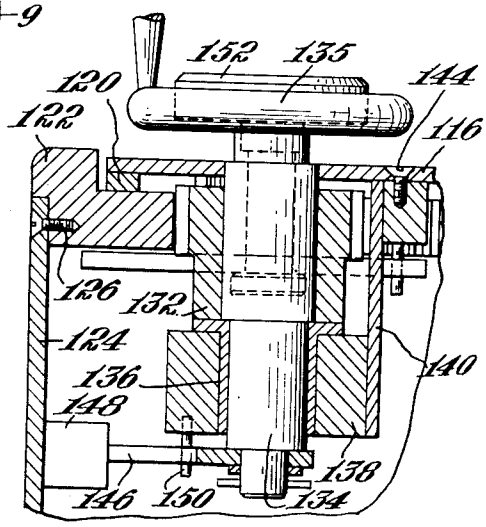


Fig. 9

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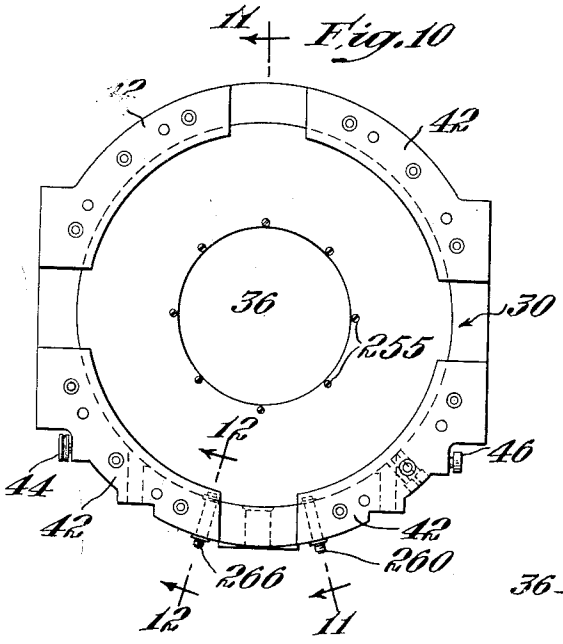


Fig. 10

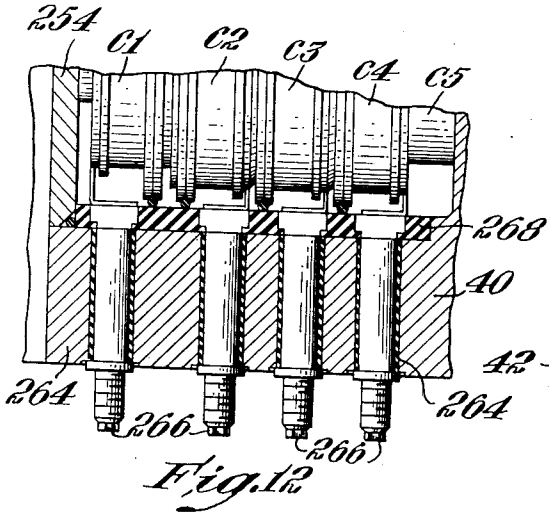


Fig. 12

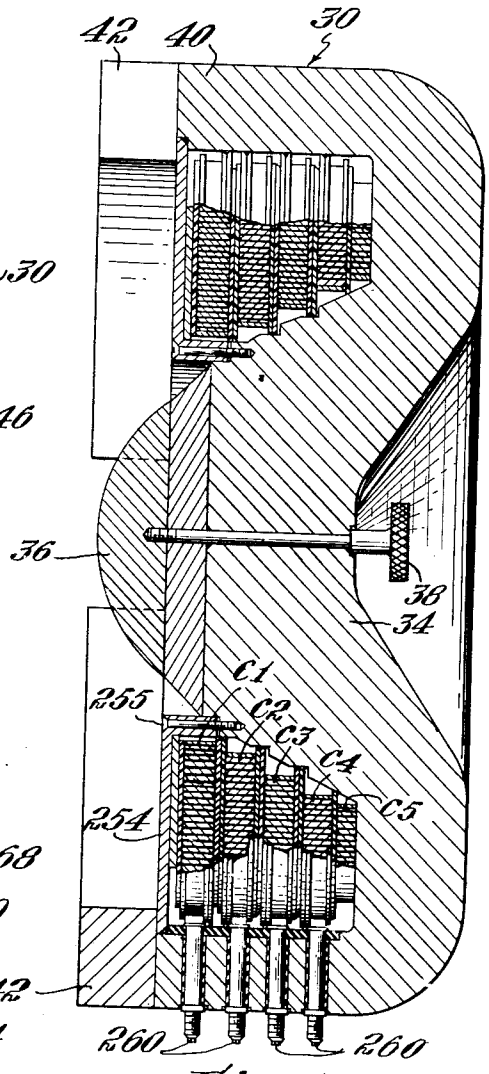


Fig. 11

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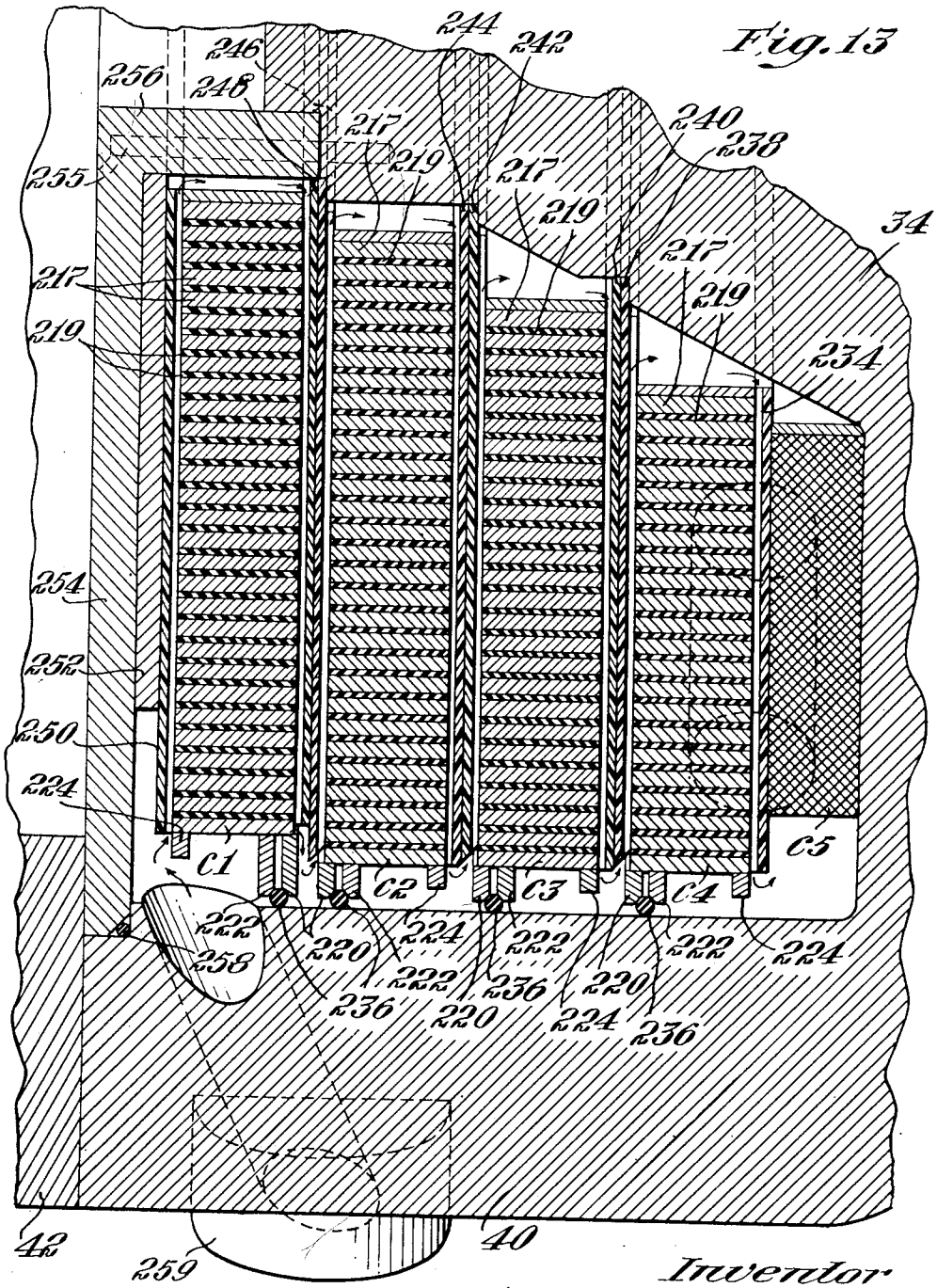
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ADJUSTABLE ELECTROMAGNET AND COOLING MEANS THEREFOR

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11 Sheets-Sheet 9

Fig. 13



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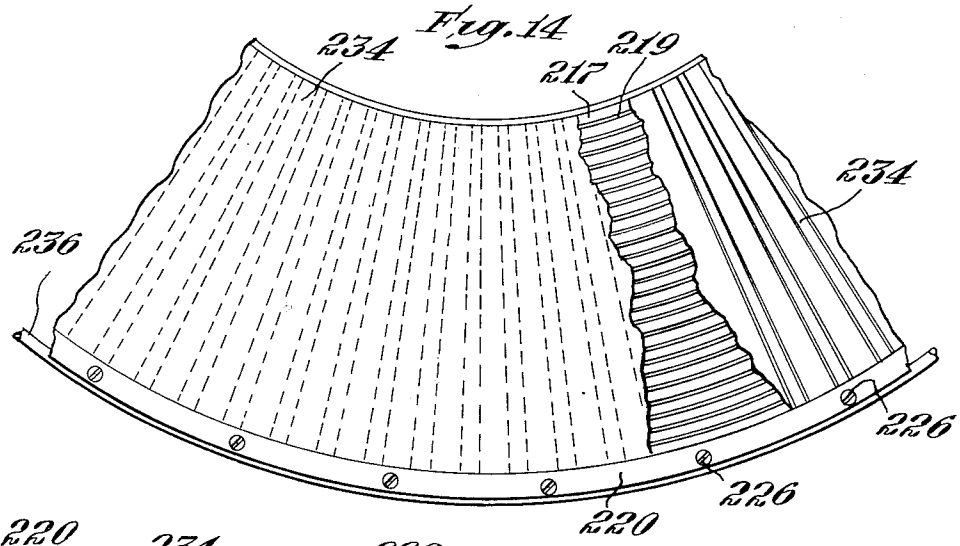
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ADJUSTABLE ELECTROMAGNET AND COOLING MEANS THEREFOR

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Fig. 14



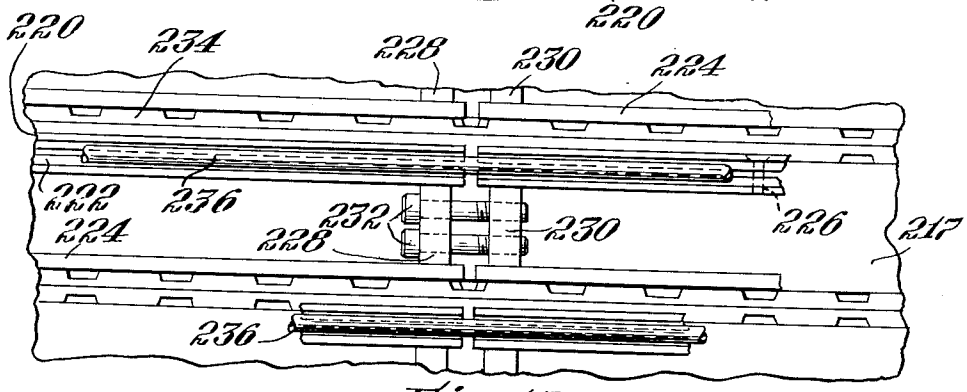


Fig. 15

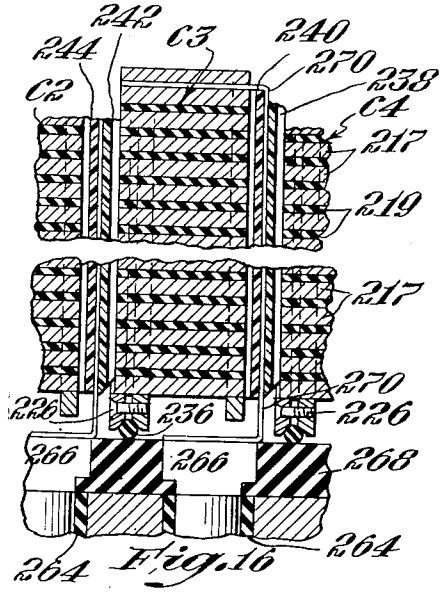


Fig. 16

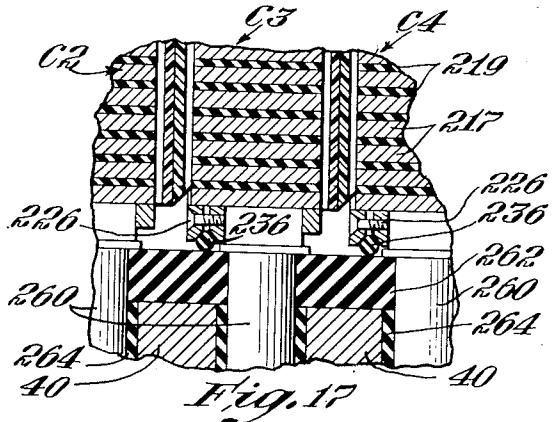


Fig. 17

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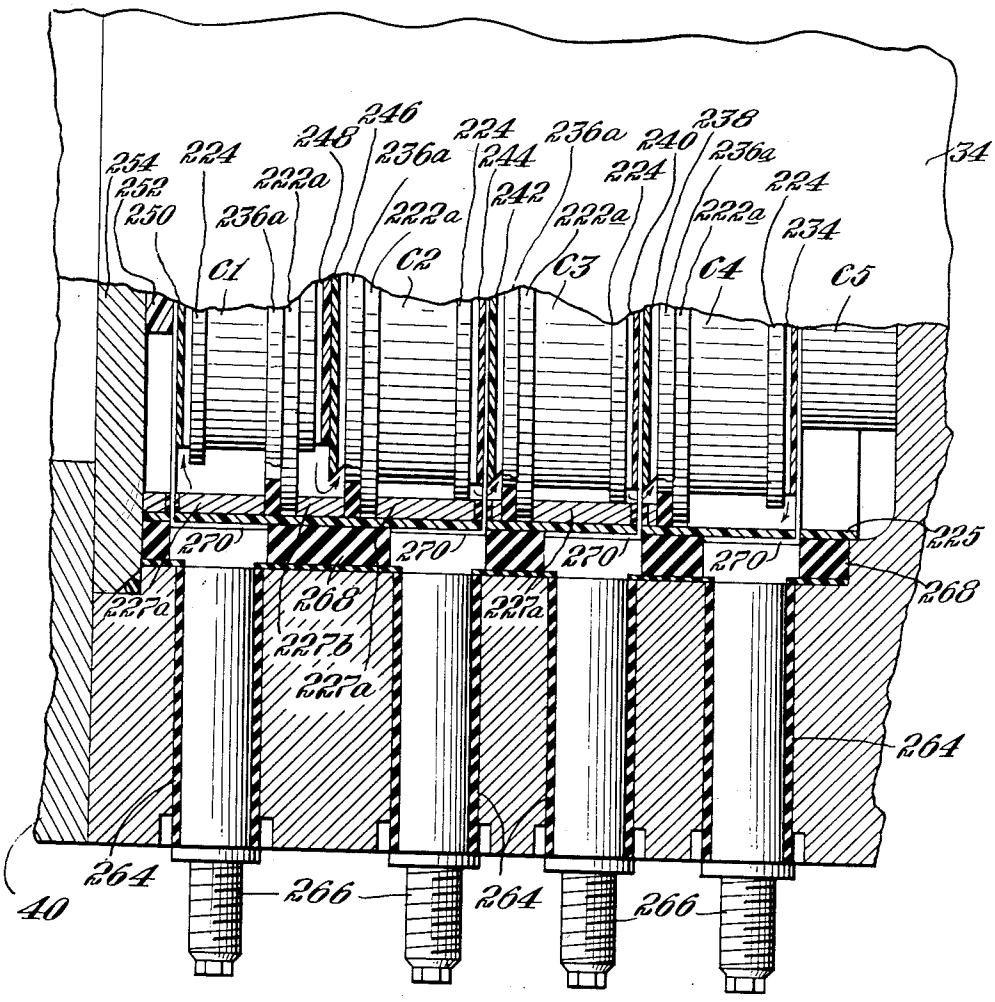


Fig. 16a

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2,664,527

UNITED STATES PATENT OFFICE

2,664,527

ADJUSTABLE ELECTROMAGNET AND COOLING MEANS THEREFOR

Flood Everett Reed, Jr., Belmont, Mass., assignor to Arthur D. Little, Inc., Cambridge, Mass., a corporation of Massachusetts

Application December 8, 1951, Serial No. 260,633

17 Claims. (Cl. 317—158)

1

This invention relates to electromagnets and more particularly to electromagnets of the type having high field strengths suitable for experimental and development applications in physics, biophysics, chemistry and metallurgy.

Objects of this invention are to provide an electromagnet which develops a high flux density, which has a minimum stray electromagnet interference, which is compact, which has accurately controlled air gap which can be readily varied, which can be readily rotated and raised and lowered without disturbing the electrical or cooling fluid connections, which requires a minimum of operational supervision, which is quiet in operation, which has easily interchanged pole pieces to obtain a variety of field patterns, and which advances the art generally.

An electromagnet according to the invention comprises two substantially conical core pieces of a low reluctance material, such as iron, axially arranged with their apexes, which are the pole pieces of the magnet, in spaced relationship to form an air gap. A magnetizing winding is disposed respectively about each of the core pieces and the magnetic circuit completed by two cylindrical pieces one end of each of which is integrally joined with the base portion of a corresponding conical core piece so that the opposite ends of the cylindrical pieces either abut or are adjacent, being separated by shims of a low reluctance material so as not to interrupt the magnetic circuit. The cylindrical pieces are provided with supporting means such as pairs of wheels which engage two spaced rails so that the pieces are separable in an axial direction for example by the conjoint operation of a pair of lead screws. The rails are carried upon a cradle or similar support which is preferably rotatably mounted and movable up and down in a vertical direction so that the position of the air gap is readily adjustable to facilitate the setup of experiments.

The magnetizing windings are preferably fluid cooled and comprising a plurality of coils which are adapted to be electrically interconnected. Each coil includes a strip of low resistance conducting material, such as copper, which is spirally wound to form an annulus. Interposed between adjacent turns of the conducting strip is a second strip of nonconducting material such as a suitable plastic which acts as electrical insulation between the coils. At the end of each coil are means, such as an annular end plate, wherein are disposed passageways for a cooling fluid at least a portion of whose side walls are formed

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by the turns of the conducting strip so that the fluid is in direct contact with the strip.

These and other objects and advantages will be apparent from the following description of what is now believed to be the preferred form which refers to drawings wherein:

Fig. 1 is an isometric view of the electromagnet and its housing;

Fig. 2 is an axial sectional view with portions in elevation;

Fig. 3 is a sectional view on line 3—3 of Fig. 2;

Fig. 4 is a sectional view on line 4—4 of Fig. 2;

Fig. 5 is a sectional view on line 5—5 of Fig. 2;

Fig. 6 is a sectional view on line 6—6 of Fig. 2;

Fig. 7 is a plan view with portions broken away;

Fig. 8 is a fragmentary sectional view on line 8—8 of Fig. 7;

Fig. 9 is a fragmentary sectional view on line 9—9 of Fig. 7;

Fig. 10 is an end view of one of the magnet halves;

Fig. 11 is a sectional view on line 11—11 of Fig. 10;

Fig. 12 is a fragmentary sectional view on line 12—12 of Fig. 10;

Fig. 13 is a partial sectional view showing the passages for the cooling fluid through the coils;

Fig. 14 is a fragmentary plan view with portions broken away of one of the coils;

Fig. 15 is an enlarged fragmentary elevation view showing the details of construction of the coils;

Fig. 16 is an enlarged fragmentary sectional view showing the manner in which the inner end of the coil conductors are connected to their terminals;

Fig. 16a is a sectional view similar to Fig. 16 illustrating an alternate type of coil construction; and

Fig. 17 is an enlarged fragmentary sectional view showing the manner in which the outer end of the coil conductors are connected to their terminals.

In the particular embodiment of the invention chosen for the purpose of illustration, the electromagnet comprises two identical halves or sections 30 and 32 respectively supported, as will be described in detail hereinafter, so as to be axially separable. As is best shown in Fig. 11, the section 30 consists of truncated conical portion 34 of a low reluctance material such as pure iron whose vertex portion is completed by a removable pole piece 36 which is secured in position by means of bolt 38 extending through an axial aperture in the conical portion. The base of the

conical portion 34 is cast integrally with one end of a coaxially disposed cylindrical piece 40 so that a plenum chamber is formed therebetween to accommodate several magnetizing windings which will be described in detail hereinafter.

The second section 32 is substantially identical to the section 30, described above, and arranged in axial alignment therewith so that the respective pole pieces 36 are in spaced relationship to form the air gap of the electromagnet as is shown in Fig. 7. The path of the magnetic circuit is completed through the cylindrical pieces 38 of the respective sections 30 and 32 and four shim pieces 42 which are interposed between the ends thereof. Each shim piece 42 occupies less than a full quadrant resulting in four equally spaced apertures which act as hand holes for visibility and access to the air gap when the electromagnet sections 30 and 32 are in their closed positions.

As is best shown in Figs. 3 and 4 each of the sections 30 and 32 is supported by four wheels 44 and 46 arranged in two pairs on opposite sides of the respective sections. The rear pair of wheels 46 rest upon the top of a plane track 48. The front pair of wheels 44 are grooved to engage a V-shaped track 50 to prevent transverse movement which might result in the wheels leaving the tracks. The tracks 48 and 50 are attached respectively to two opposed side members 52 of a supporting cradle by means of the bolts 54. The opposite ends of the side members 52 are interconnected by respective end members 56 (Fig. 5). The tracks 48 and 50 are leveled by means of jack screws 58.

The sectionals 30 and 32 are moved relatively to each other along the tracks 48 and 50 by means of a hand wheel 60 (Fig. 3) which is carried upon one end of a shaft whose other end is fastened to a pinion 62. The pinion meshes with a worm 64 upon a shaft 66 so that operation of the wheel 60 conjointly rotates two lead screws 68 and 70 (Fig. 6) which are connected to the opposite ends of the shaft by couplings 72. The lead screws 68 and 70 engage threaded apertures in brackets 74 and 76 respectively which are bolted to the sections 30 and 32, the hand of the threads upon the lead screws being such that the sections are moved to and from each other as the hand wheel 60 is rotated.

The cradle is carried by a yoke 80 consisting of two spaced arcuate members whose ends are welded or otherwise attached to the central portions of the respective cradle side members 52. At the bottom of the yoke 80 are two transverse strips 82 (Fig. 3) which are provided with threaded apertures for receiving the bolts 84 securing the yoke to the integral flange of a hollow shaft 86. Coaxially disposed with respect to the shaft 86 is a conduit such as the nipple 88 so that the space therebetween forms a cavity which can be used to introduce a cooling fluid for example oil into the winding of the electromagnet as will now be described. To this end oil from a supply tank (not shown) is brought in through a flexible conduit such as the hose 90 (Fig. 2) connecting into the side wall of a thimble 94 which is bolted to the bottom of a bearing housing 96 beneath the lower end of the shaft 86. The upper end of the cavity between the shaft 86 and the nipple 88 connects with a chamber formed by the arcuate yoke members and two baffles 98 and 99 (Fig. 3). From this chamber, the cooling oil flows into two opposed manifolds 100 (also see Fig. 6) which interconnects the yoke 80 and the corresponding inlets of the two core sections 30 and 32. The

manifolds 100 are each supplied with a sliding joint 102 so as not to interfere with the movement of the core sections along the rails 48 and 50 described heretofore.

The cooling oil is removed from the bottom of the respective core sections 30 and 32 through two drain conduits 104 having sliding joints 106 which interconnect with the second chamber formed in the yoke by the baffles 98 and 99. The upper end of the nipple 88 opens into this second chamber so that oil therefrom is discharged through the nipple 88 into the flexible drain conduit 103 (Fig. 3).

The shaft 86 is journaled in two ball bearings 110 and 112 (Fig. 3) whose outer races are secured in the bearing housing 96, mentioned above, so that the core sections 30 and 32 and their supporting cradle and yoke 80 can be revolved as a unit. To this end segmental shaped aprons 114 and 116 (see also Fig. 7) are secured respectively to the opposite sides 52 of the cradle by means of the bolts 118 which engage apertures in the lower ends of upright skirts welded to the edges of the respective skirts disposed adjacent the core sections. The outer edges of the aprons are each supported by means of a respective spacer strip 120 which is fastened to the bottom of the apron as is best shown in Figs. 8 and 9 so that the strip slidably rests upon a shoulder cut in the top face of a relatively stationary ring gear 122. The gear is supported by a cylindrically rolled plate 124 whose upper end is fastened to the gear by means of screws 126. The lower end of the cylinder formed by the plate 124 is closed by a circular plate 128 (Fig. 2) carried upon the top of a frame 130 to which is also bolted the bearing bracket 96 mentioned above.

The internal teeth of the ring gear 122 are engaged by a pinion 132 (Fig. 9) attached to a shaft 134 which is manually rotatable by means of a hand wheel 135. The lower end of the shaft 134 is journaled in a bearing 136 pressed in an aperture in a circular block 138 forming the bottom portion of bracket 140 which extends downwardly from a plate 142 (also see Fig. 6) which is attached to the bottom face of the apron 116 by means of screws 144. To limit the rotation of the apron 116 and the core sections 30 and 32 to 360 degrees, a finger 146 is loosely carried upon the lower end of the shaft 134 which extends below the block 138 so that the end of the finger will come into contact with stop 148 projecting inwardly from the inner wall of the plate 124. The travel of the finger 146 is also limited by one of two spaced pins 150 which extends downwardly from the block 138 so that further movement beyond the position shown in Fig. 9 is prevented.

It is also possible to lock the core sections 30 and 32 in any selected angular position by means of a hand wheel 152 (Fig. 8) attached to the upper end of threaded member 154 which engages a threaded aperture in the plate 140. The lower end of the threaded member 154 is provided with a head which contacts the bottom of a locking piece 156 so that the end of the piece is forced against the bottom face of the ring gear 122 as the hand wheel 152 is turned thereby preventing relative rotation between the gear and the apron 116. Two pins 158 prevent the locking piece 156 from rotating conjointly with the threaded member 154.

As is best shown in Fig. 2, the electrical cables supplying power to the core windings (described below) in the respective core sections 30 and 32 are brought in as at 160 from a power supply such as a motor generator set (not shown) and

thence down to make 180 degree bend as at 162 and come up through an aperture in the circular plate 128. Thence the cables are arranged along the inner face of the cylindrically formed plate 124, as is shown in Fig. 5, and bent back upon themselves to form a bight 164 so as to be against the outer surface of a cable drum 166 which is supported by six equally spaced arms 168 bolted to the flange of the stub shaft 88 to form a spider so that the drum rotates conjointly with the core sections 30 and 32 and aprons 114 and 116. After passing partially around the cable drum 66 the cables rise as indicated in Fig. 3 to be attached to the bottom of the cradle as at 170 and thence to connect with the terminals of the core windings as will be described hereinafter. From the above description of the disposition of the electrical cables, it will be evident that as the core sections 30 and 32 are rotated counterclockwise (as viewed in Fig. 5), the cables are drawn away from the inner surface of the cylindrical plate 124 and reeled upon the cable drum; and conversely as the cable drum is rotated clockwise the cables are unwound from the drum and laid against the inner wall of the cylindrical disposed plate 124 so that the cables do not interfere with the rotation of the core pieces 30 and 32 within the limits determined by the stop 148 mentioned above.

The frame 130 as is shown by dotted lines in Fig. 5 is rectangular in shape comprising two longitudinal channel members 172 in between whose respective ends are welded the end pieces 174. Near the center portion of the channel members 172 are welded two spaced cross pieces such as the channels 176 whereupon is attached the bearing housing 96 by means of bolts 178 (Fig. 3). At each end of each channel member 172 is welded a boss 180 (Fig. 2) having a threaded aperture therein for engaging a corresponding vertical lead screen 182 positioned respectively at each corner of the frame 130. The bottom ends of the lead screws 182 are journaled in correlated bearing blocks 184 which are bolted to a base plate 186. Similar bearing blocks 188 are provided for journaling the upper ends of the lead screws 182. As is best shown in Figs. 2 and 6 the upper bearing blocks 188 are bolted respectively to the bottom of two support plates 190 which extend between two opposed side walls 192 and 194 rising vertically from the opposite sides of the base plate 186. One side of each of the bearing support plates 190 is concave to conform to the outer surface of the plate 196 which is rolled so that its inner surface forms the wall of a cylindrical well for receiving the ring gear 122 and its supporting drum formed by the plate 124. Two end plates 198 and 200, which interconnect with the ends of the walls 192 and 194 extend vertically upwardly from the respective ends of the base plate and are rolled over to form cover plates which connect with the opposite sides of the well plate 196. The center portions of the side wall plates 192 and 194 are cut away so as not to interfere with the cylindrical well plate 196, a bay being formed on either side for the well plate by the arcuate bay plates 202 and 204 respectively. The lower ends of the bay plates are bent under as is shown in Figs. 3 and 4 and welded to the side plates 192 and 194. The upper ends of the bay plates are rolled over and welded to the upper end of the well plate 196.

The lead screws 182 are driven to raise or lower the frame 130 by means of a chain 206 which

engages four sprocket wheels 208 mounted respectively near the bottom of the lead screws adjacent the lower bearing brackets 184. The chain also passes around two idler sprockets 210 (Fig. 5) rotatably attached to a supporting angle piece 212 and a driving sprocket 214 attached to the output shaft of a gear reduction unit G which is also carried by the angle piece. The gear reduction unit G is operated by a reversible electric motor M to raise or lower the cradle and the core sections 30 and 32 supported thereby.

As is shown in Figs. 11 and 13, the magnetizing winding for each of the core sections 30 and 32 is comprised respectively of four main coils *c1*, *c2*, *c3* and *c4* and an auxiliary control coil *c5* which are annular in shape and of progressively lesser diameter so that the coils surround the conical portion 34 and are disposed within the plenum chamber between the conical and cylindrical portions 34 and 40 of the associated core section. Each main coil consists of a strip of conducting material 217 such as copper which is spirally wound to form an annulus. A strip 219 of a non-conducting material, for example silicone impregnated fiberglass, having substantially the same width as the conducting strip 217 is interposed between adjacent turns of the coil to act both as a spacer and to provide electrical insulation between the turns. As is best shown in Fig. 15, each of the coils is bound by means of three split hoops such as the bands 220, 222 and 224. Two bands 220 and 222 lie adjacent one edge of an associated coil and are interconnected by a plurality of screws 226. The band 224 is located near the other edge of the coil and the ends thereof are connected respectively to the corresponding ends of the band 222 by cross pieces 228 and 230. The cross pieces are drawn together by two screws 232 thereby to tension the bands.

The coils *c1* through *c5* are arranged as shown in Fig. 11, the auxiliary control coil *c5*, which is of conventional design consisting of a plurality of turns of insulated copper wire, being positioned in the bottom of the recess and an annular disc such as the end ring 234 (Fig. 13) of a suitable plastic load upon the top thereof so that the radial grooves in the ring (see Fig. 14) are turned up away from the coil. The coil *c4* is positioned abutting the grooved face of the ring 234 so that a plurality of passageways are formed through which a cooling fluid, such as oil, is directed, as will be described hereinafter. The bands 220 and 222 are provided with chamfered inner edges which form a V notch wherein is carried an O ring 236 of a resilient material such as suitable synthetic rubber which bears against the inner wall of the cylindrical section 40 of the core section. The coil *c3* is placed contiguous the end of the coil *c4* opposite the annular ring 234 and two annular end rings 238 and 240 are interposed therebetween. These rings 238 and 240 are generally similar to the ring 234 being provided with radially disposed grooves but have a lesser inner diameter so that the inner edges thereof are supported by a shelf in the conical portion 134 of the core section. The rings 238 and 240 are positioned so that their grooved faces are abutting the edges of the conducting strips 217 of the coils *c4* and *c3* respectively. The coil *c2* is similarly disposed in the plenum chamber between the conical and cylindrical pieces of the core section and separated from the coil *c3* by the grooved annular rings

242 and 244. The coil c1 is positioned adjacent the coil c2 but is turned end for end so that the ends of the respective coils having the O rings 236 are contiguous being separated by the grooved annular rings 246 and 248. A single annular ring 250 is placed with its grooves adjacent the end of the coil c1 and a spacer 252 interposed between the ring and a sealing plate 254. An integral flange 256 extends normally from the inner edge of the plate 254 and is provided with a plurality of equally spaced apertures which accommodate screws 255 for securing the plate to a step in the conical portion of the core section. The corner of the inner face of the sealing plate 254 is chamfered to receive an O ring 256.

From the above described arrangement of the coils c1 through c5, it will be apparent that oil under pressure introduced through the manifold 100 (Fig. 6), as described in detail heretofore, will enter through the apertures in bosses 259 into the cavity between the sealing plate 254 and the coil c1 and thence into the radial grooves in the annular ring 250 as is indicated by the flow direction arrows of Fig. 13. As the end of the coil forms one wall of the radial passageways through which the oil flows, the oil comes into direct contact with the edge of the conducting strip 217 so that maximum heat transfer takes place therebetween. Upon leaving the grooves in the annular ring 250, the oil flows through cavity formed between the inner side of the coil c^1 and the flange 256 and thence through the radial grooves in the annular ring 248 so that the oil is brought into direct contact with the opposite edge of the conducting strip 217 of the coil c1. In similar manner the oil is directed through the grooves of the remaining annular rings as is indicated by the flow direction arrows so that the oil is brought into direct contact with both edges of the strips of each of the coils c1 and c4. Upon discharging from the grooves in the annular ring 234 abutting the coil c4, the oil flows into the cavity between the coil and the wall of the cylindrical portion 40 of the core section and thence out through the drain conduit 106.

Electrical connections to the outer and inner ends of the conducting strips 217 of each of the coils are made respectively through separate terminals. As is shown in Figs. 11 and 17, the outer end of the conducting strip 217 of each coil is brazed or otherwise secured to the end of a respective terminal 260. The inner ends of the terminal 260 are supported in a block 262 of a nonconducting material such as a suitable plastic, which strip is recessed in the cylindrical portion 40 of the core section. The body portions of the respective terminals 260 which extend through apertures in the cylindrical portion 40 are electrically insulated therefrom by the nonconducting sleeves 264.

The inner ends of the strips 217 of the respective coils are connected to terminals 266 which are shorter than the terminals 260 so that the heads thereof are embedded in a nonconducting block 268 with the ends thereof flush with the surface of the block. One leg of a U-shaped strap 270 of an electrically conducting material such as copper is brazed respectively to the flush surface of the head of each of the terminals 266. As is shown in Fig. 16, the other leg of the strap 270 is secured to the inner end of the conductive strip 270 of the respective coil so that the connecting portion of the strap lies in a recess in the face of the annular end ring opposite that in which the oil grooves are disposed. As the ends of each of the coils c1 through c4 are each provided with respective terminals to which the ends of the cables described heretofore are fastened by means of conventional connectors (not shown), the coils can be interconnected electrically in series, parallel, or various series parallel combinations to accommodate different loads and permit power sources having various output voltages to be used. Leads from the auxiliary coil c5 are brought through an aperture (not shown) drilled in the core section which is then plugged to prevent the leakage of cooling fluid therethrough.

An alternate type of construction wherein flat ring gaskets 222a are used to prevent by-passing of the cooling fluid is shown in the embodiment of Fig. 16a wherein the coils c1 through c5 and the end rings 234 through 250 are stacked in the plenum chamber formed between the conical and cylindrical portions 34 and 40 of the associated core section in a manner similar to that described in detail with respect to the embodiment shown in Figs. 11 and 13. The coils c^1 through c^2 used in the embodiment of Fig. 16a are generally similar in construction to the corresponding coils described heretofore with the exception of the clamping means which comprises two spaced bands 222a and 224 for each of the coils. The band 224 is connected to the band 222a by cross-pieces similar to pieces 228 and 230 shown in Fig. 15 and described above. The band 222a is not chamfered and has an external diameter such that it fits within a sleeve 225 of a suitable insulating material which lines the inner wall of the cylindrical portion 40 of the core section. The sleeve 235 has cut away portions to accommodate the oil passages and the terminals for the coils.

On the top of each of the bands 222a is located respectively a gasket 236a of a resilient material such as synthetic rubber the outer diameter of each of which is forced aginst the sleeve 225 by a respective spacer 227a or 227b, as the case may be. Each spacer extends between the gasket 236a of a respective coil and the clamping band 222a of the adjacent coil with the exception of the last spacer which contacts the inner surface of the sealing plate 254 so that the gaskets are compressed to bear against the sleeve 225 to form fluid tight joints between adjacent coils. The flow of cooling fluid through the passages and plates is indicated by the arrows in Fig. 16a being generally similar to that described heretofore in connection with the embodiment shown in Fig. 13.

In operation the core sections 30 and 32 are separated by rotation of the hand wheel 60, as described heretofore, and the test specimen (not shown) to be subjected to the magnetic field placed midway between the pole pieces 36. The exact relative vertical positioning of the specimen can be determined by the raising or lowering of the core sections 30 and 32 by operation of the motor M. The core sections are then returned to their closed position by the reverse rotation of the hand wheel 60. Cooling oil and electrical current are then supplied to the core windings as described heretofore. Fine variations of the magnitude of the resulting magnetic field are obtained by varying the current flow through the auxiliary winding c5. By conjoint rotation of the core sections 30 and 32 by means of the hand wheel 135, the direction of the magnetic

lines through the specimen can be varied if so desired.

It will be evident that the above described electromagnet is a flexible research tool which makes available a strong magnetic field (to 35,000 gauss) whose direction is readily adjjustable for applications such as magnetic moment studies of nuclei, measurement of magnetic anisotropy, magnetic susceptibility experiments on both paramagnetic and diamagnetic salts, microwave absorption in paramagnetic and ferro-magnetic materials, magneto-optics, such as Zeeman Effect studies, magnetic properties of colloids and suspensions, determination of ferromagnetic impurities, determination of the carbon content in steels, adiabatic demagnetization to obtain temperatures below 1° Kelvin, paramagnetic saturation at low temperatures, anti-ferromagnetism, or meta-magnetism at low temperatures, permeability determinations at high flux densities, ferromagnetic saturation, studies of living organisms in magnetic fields as well as other similar studies.

It should be understood that the present disclosure is for the purpose of illustration only and that this invention includes all modifications and equivalents which fall within the scope of the appended claims.

I claim:

1. An electromagnet for research purposes comprising two substantially conical core pieces of a low reluctance material axially arranged with their apexes in spaced relationship to form an air gap, a magnetizing winding disposed respectively about each of the core pieces, the magnetic circuit being completed by two cylindrical pieces, one end of each of which abuts the corresponding end of the other cylindrical piece, the opposite end of each cylindrical piece being integrally joined with the base of a respective conical piece so that the cylindrical piece encloses the associated winding to minimize the stray flux, and means for supporting said cylindrical pieces so that they are separable axially.

2. An electromagnet according to claim 1 wherein are also included one or more shim pieces of a low reluctance material which are selectively interposed between the abutting ends of the cylindrical pieces to change the air gap distance between the apexes of the conical pieces.

3. An electromagnet according to claim 2 wherein each shim piece includes several annular portions having inner and outer diameters corresponding to the diameters of the cylindrical pieces, the ends of adjacent portions being spaced apart to form apertures giving access to the air gap between the conical pieces.

4. An electromagnet for research purposes comprising two substantially conical core pieces of a low reluctance material axially arranged with their apexes in spaced relationship to form an air gap, each of the conical pieces being truncated and the respective vertex portion being a separable piece, a magnetizing winding disposed respectively about each of the core pieces, the magnetic circuit being completed by two cylindrical pieces, one end of each of which abuts the corresponding end of the other cylindrical piece, the opposite end of each cylindrical piece being integrally joined with the base of a respective conical piece so that the cylindrical piece encloses the associated winding to minimize the stray flux, and means for supporting said cylindrical pieces so that they are separable axially.

5. An electromagnet according to claim 4 wherein the truncated conical pieces are provided with respective axially disposed apertures, and including two bolts extending through the apertures to secure the respective vertex portions to the ends of the truncated conical pieces.

6. An electromagnet for research purposes comprising two substantially conical core pieces of a low reluctance material axially arranged with their apexes in spaced relationship to form an air gap, a magnetizing winding disposed respectively about each of the core pieces, the magnetic circuit being completed by two cylindrical pieces, one end of each of which abuts the corresponding end of the other cylindrical piece, the opposite end of each cylindrical piece being integrally joined with the base of a respective conical piece so that the cylindrical piece encloses the associated winding to minimize the stray flux, and means for supporting said cylindrical pieces including two pairs of wheels rotatably attached to the bottom of each of the cylindrical pieces respectively and two spaced rails arranged in a horizontal plane parallel to the axes of the cylindrical pieces for engaging the wheels so that the cylindrical pieces are separable.

7. An electromagnet according to claim 6 wherein are also included two lead screws for moving the respective cylindrical pieces along the rails, and a handwheel for conjointly operating the lead screws concomitantly to move the cylindrical pieces towards and from each other.

8. An electromagnet for research purposes comprising two substantially conical core pieces of a low reluctance material axially arranged with their apexes in spaced relationship to form an air gap, a magnetizing winding disposed respectively about each of the core pieces, the magnetic circuit being completed by two cylindrical pieces, one end of each of which abuts the corresponding end of the other cylindrical piece, the opposite end of each cylindrical piece being integrally joined with the base of a respective conical piece so that the cylindrical piece encloses the associated winding to minimize the stray flux, and a rotatable support for said cylindrical pieces, said cylindrical pieces being movable with respect to said support so that they are separable axially.

9. An electromagnet for research purposes comprising two substantially conical core pieces of a low reluctance material axially arranged with their apexes in spaced relationship to form an air gap, a magnetizing winding disposed respectively about each of the core pieces, the magnetic circuit being completed by two cylindrical pieces, one end of each of which abuts the corresponding end of the other cylindrical piece, the opposite end of each cylindrical piece being integrally joined with the base of a respective conical piece so that the cylindrical piece encloses the associated winding to minimize the stray flux, and means for supporting said cylindrical pieces including a cradle having a centrally disposed pivotal support and two spaced rails carried by said cradle in a horizontal plane parallel to the axes of the cylindrical pieces, said cylindrical pieces each being provided with pairs of wheels for engaging said rails so that the cylindrical pieces are separable axially.

10. An electromagnet for research purposes comprising two substantially conical core pieces of a low reluctance material axially arranged

with their apexes in spaced relationship to form an air gap, a magnetizing winding disposed respectively about each of the core pieces, the magnetic circuit being completed by two cylindrical pieces, one end of each of which abuts the corresponding end of the other cylindrical piece, the opposite end of each cylindrical piece being integrally joined with the base of a respective conical piece so that the cylindrical piece encloses the associated winding to minimize the stray flux, and a support whose height is adjustable for said cylindrical pieces said cylindrical pieces being movable horizontally with respect to said support so that they are separable axially.

11. An electromagnet for research purposes comprising two substantially conical core pieces of a low reluctance material axially arranged with their apexes in spaced relationship to form an air gap, a magnetizing winding disposed respectively about each of the core pieces, the magnetic circuit being completed by two cylindrical pieces, one end of each of which abuts the corresponding end of the other cylindrical piece, the opposite end of each cylindrical piece being integrally joined with the base of a respective conical piece so that the cylindrical piece encloses the associated winding to minimize the stray flux, and means for supporting said cylindrical pieces including a cradle having a centrally disposed pivotal support, two spaced rails carried by said cradle in a horizontal plane parallel to the axes of the cylindrical pieces, said cylindrical pieces each being provided with pairs of wheels for engaging said rails so that the cylindrical pieces are separable axially, a frame to which is attached said cradle support, and a plurality of conjointly operable lead screws for moving said frame in a vertical direction.

12. An electromagnet for research purposes comprising two substantially conical core pieces of a low reluctance material axially arranged with their apexes in spaced relationship to form an air gap, a magnetizing winding disposed respectively about each of the core pieces, the magnetic circuit being completed by two cylindrical pieces, one end of each of which abuts the corresponding end of the other cylindrical piece, the opposite end of each cylindrical piece being integrally joined with the base of a respective conical piece so that the cylindrical piece encloses the associated winding to minimize the stray flux, means for supporting said cylindrical pieces so that they are separable axially, and conduit means for conducting a cooling medium to and from the windings, said conduit means having means to accommodate the axial movement of the cylindrical pieces.

13. In an electromagnet, fluid cooled magnetizing winding comprising a plurality of coils adapted to be interconnected electrically, each coil including a multiplicity of turns of a conductor wound to form an annulus and non-conducting material interposed between adjacent turns of the conducting strip to act as electrical insulation therebetween, means located at either end of the respective coils and provided with passageways through which cooling fluid can be directed, the turns of the conductor forming a portion of the wall defining the pasasgeways so as to bring the fluid into contact therewith, and means for interconnecting the passageways associated with the respective coil so that the fluid will flow therethrough.

14. In an electromagnet, fluid cooled magnetizing winding comprising a plurality of coils adapted to be interconnected electrically, each coil including a multiplicity of turns of a conductor wound to form an annulus and non-conducting material interposed between adjacent turns to act as electrical insulation therebetween, an annular end plate located respectively at each end of each of the coils, the face of each plate abutting the end of the associated coil being provided with a plurality of radially disposed grooves forming passageways through which cooling fluid can be directed to bring the fluid into contact with the conductors, the coils being stacked with the outer faces of the respective plates of adjacent coils in abutment, and means for connecting the passageways in the respective plates in series so that the fluid will flow successively therethrough.

15. In an electromagnet, fluid cooled magnetizing winding comprising a plurality of coils adapted to be interconnected electrically, each coil including a strip of a conduction material spirally wound to form an annulus and a strip of non-conducting material interposed between adjacent turns of the conducting strip to act as electrical insulation therebetween, the width of conducting strip axially with respect to the coil being at least as great as the width of the non-conducting strip so that the ends of the conducting strip are exposed, an annular end plate located respectively at each end of each of the coils, the face of each plate abutting the end of the associated coil being provided with a plurality of radially disposed grooves forming passageways through which cooling fluid can be directed to bring the fluid into contact with the ends of the strips, the coils being stacked with the outer faces of the respective plates of adjacent coils in abutment, and means for connecting the passageways in the respective plates in series so that the fluid will flow successively therethrough.

16. In an electromagnet, fluid cooled magnetizing winding for a magnetic circuit comprising a plurality of coils adapted to be interconnected electrically, each coil including a strip of a conducting material spirally wound to form an annulus and a strip of non-conducting material interposed between adjacent turns of the conducting strip to act as electrical insulation therebetween, the width of conducting strip axially with respect to the coil being at least as great as the width of the non-conducting strip so that the ends of the conducting strip are exposed, a plurality of clamp rings disposed about the periphery of each of the coils, two of the rings being adjacent to form a V-shaped notch, an annular end plate located respectively at each end of each of the coils, the face of each plate abutting the end of the associated coil being provided with a plurality of radially disposed grooves forming passageways through which cooling fluid can be directed to bring the fluid into contact with the ends of the strips, the coils being stacked with the outer faces of the respective plates of adjacent coils in abutment, and a gasket carried respectively in each of the V-notches to contact the adjacent portions of the magnetic circuit thereby to act as baffles so that the fluid will in series flow through the passageways.

17. An electromagnet comprising two substantially conical core pieces of a low reluctance material axially arranged with their apexes in spaced relationship to form an air gap, a fluid cooled magnetizing winding disposed respectively about each of the core pieces, the magnetic circuit being completed by two cylindrical pieces, one end of

each of which abuts the corresponding end of the other cylindrical piece, the opposite end of each cylindrical piece being integrally joined with the base of a respective conical piece so that the cylindrical piece encloses the associated winding to minimize the stray flux, and means for supporting said cylindrical pieces so that they are separable axially, said fluid cooled magnetizing winding comprising a plurality of coils adapted to be interconnected electrically, each coil including a multiplicity of turns of a conductor wound to form an annulus and non-conducting material interposed between adjacent turns of the conducting strip to act as electrical insulation therebetween, means located at either end of the respective coils and provided with passageways

through which cooling fluid can be directed, the turns of the conductor forming a portion of the wall defining the passageways so as to bring the fluid into contact therewith, and means for interconnecting the passageways associated with the respective coil so that the fluid will flow therethrough.

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