

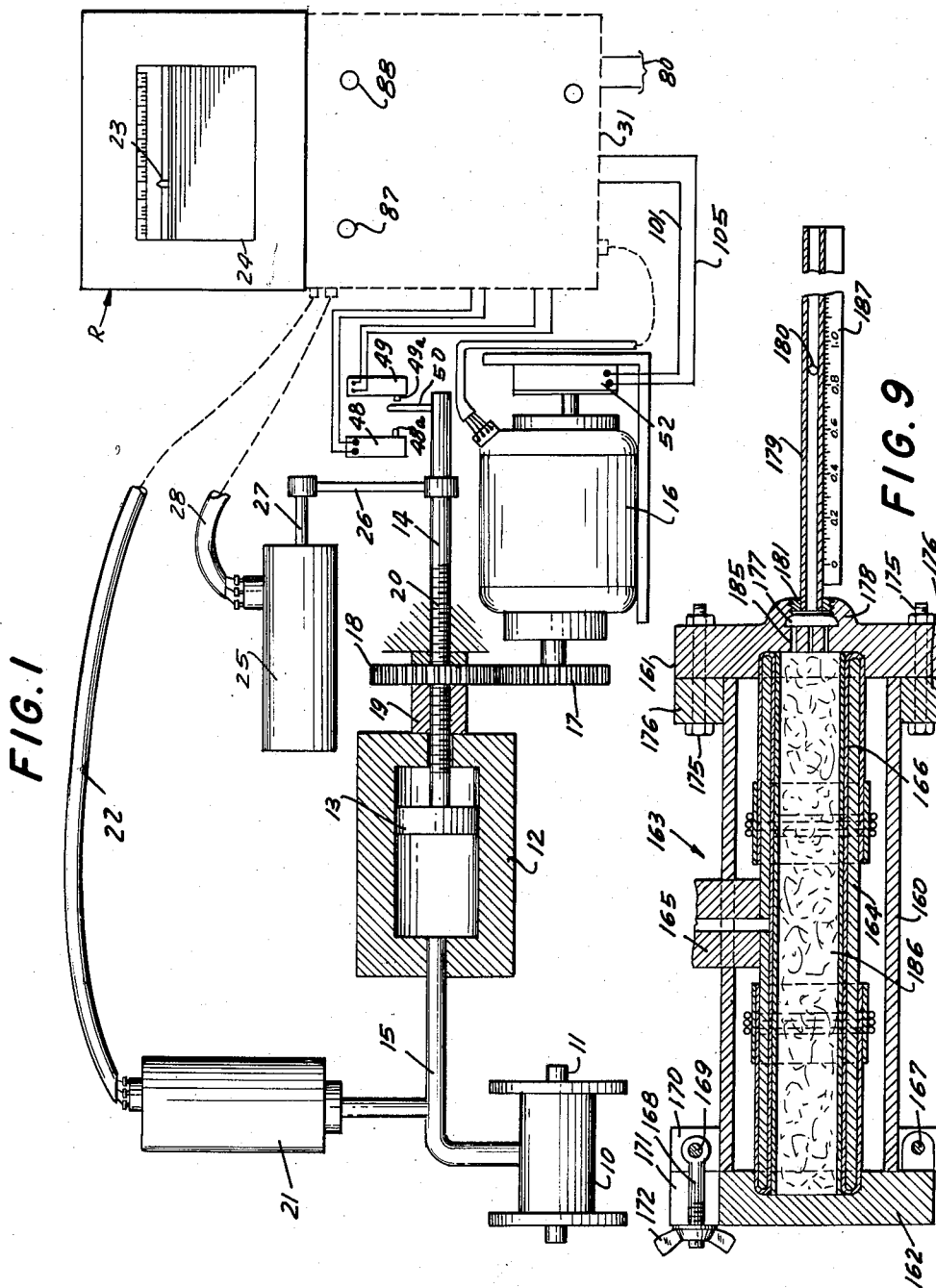
Dec. 31, 1963

A. E. O'KEEFFE ETAL
APPARATUS AND METHOD FOR MEASURING THE
COMPRESSIBILITY OF DEFORMABLE OBJECTS

3,115,772

Filed Nov. 4, 1958

4 Sheets-Sheet 1



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FIG. 5

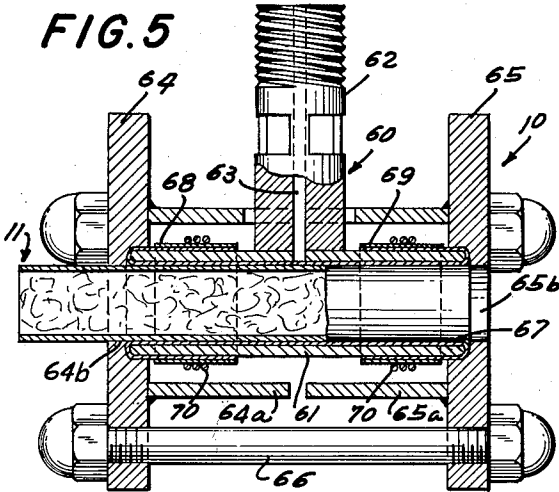


FIG. 6

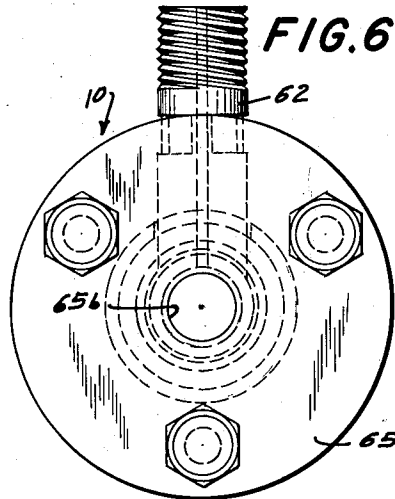
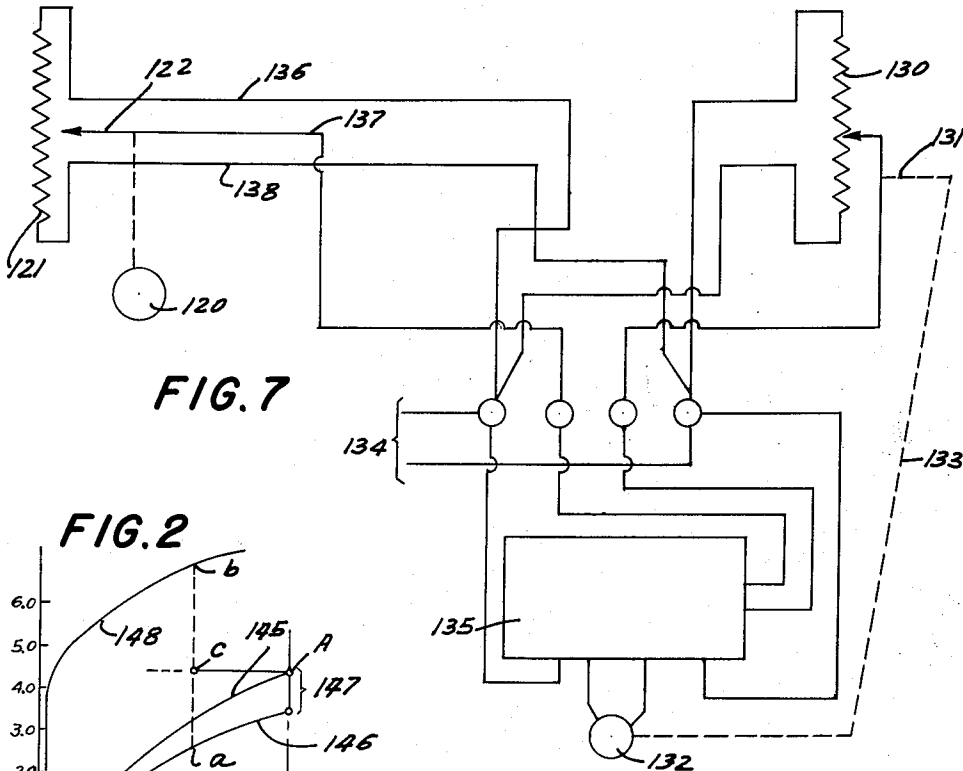
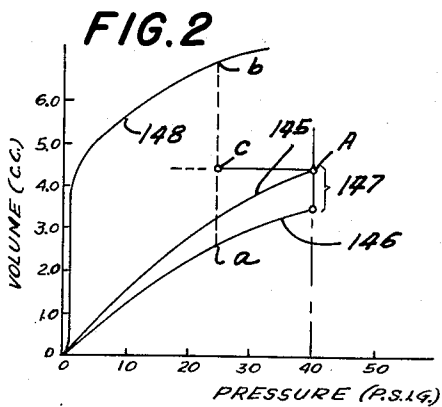


FIG. 7

FIG. 2



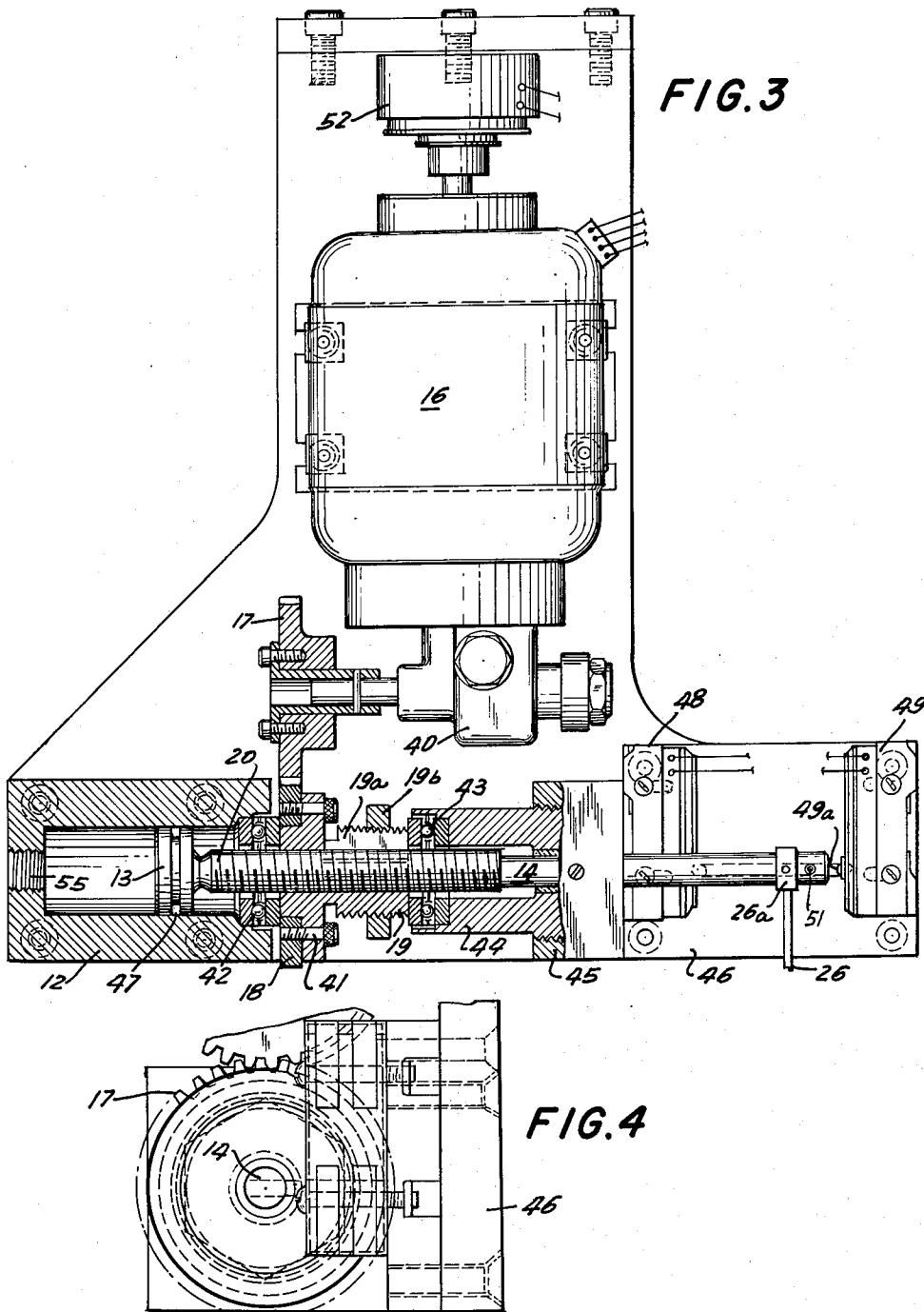
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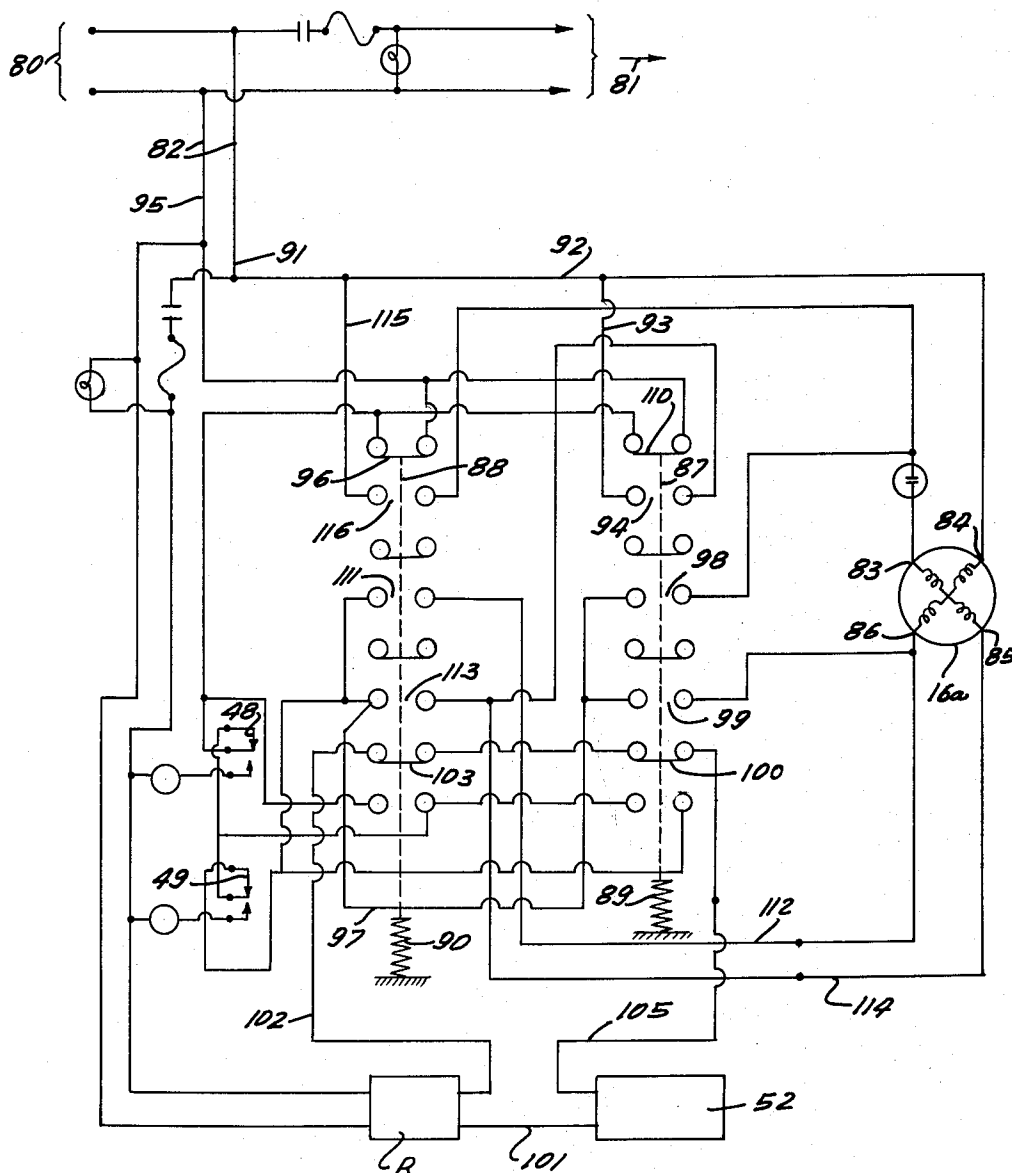
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FIG. 8



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APPARATUS AND METHOD FOR MEASURING THE COMPRESSIBILITY OF DEFORMABLE OBJECTS

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9 Claims. (Cl. 73-94)

The present invention is concerned with an apparatus and method for measuring the compressibility of deformable objects. It is of importance to determine the compressibility of certain articles at times and to relate the data to some standard of measurement. This is particularly so in the case of cigarettes where the compressibility is also commonly referred to as the firmness of the cigarette. The characteristic of firmness in cigarettes is closely related to other factors or properties. A particularly important one is the feel of the cigarette in the hands of the smoker and its ability to retain its shape under various conditions to which the cigarettes may be subjected. From the manufacturing standpoint the firmness is affected by many factors such as the kinds and blend of the tobacco, the treatment thereof, the size of the tobacco particles or cuts, the crispness or flexibility of the tobacco shreds and the content of moisture and other additives such as flavoring materials. The firmness of a cigarette is particularly affected by the degree to which the tobacco is compressed in forming the cigarette rod. The manufacturer, of course, also is interested in relating the firmness of the cigarette to its draw characteristics and the weight of the tobacco which goes into the cigarette, and therefore in measuring the firmness as such other factors are varied.

Various devices have been employed heretofore in attempts to measure and regulate the firmness of cigarettes such as devices for measuring the indentation in linear units of a cigarette by a pressure element or the application in its manufacture of a pressure finger which rides on the cigarette rod in the manufacturing operation. Such devices, however, have not proven adequate nor very accurate in their results and are usually not reproducible within a desired range.

The present invention is particularly useful and advantageous in that it enables the firmness or compressibility to be quickly measured and related to a definite standard. The measurements and results are reproducible to an adequately close degree and afford a definite and dependable indication and basis for comparison with standards which may be readily established. The invention includes as a major feature the application to the cigarette of a fluid pressure uniformly distributed circumferentially about the cylindrical section of the cigarette which flexibly compresses and contracts a predetermined cylindrical section. The contraction is volumetric rather than linear. Different fluid pressures produce different volumetric changes and by relating the volume change to pressure an indication of the firmness is obtained over any desired range and the properties or physical characteristics more fully analyzed.

The complete apparatus embodies various other advantageous features associated with the above including a unique system and apparatus for applying the fluid pressure to the cigarette or other test object and an electric recording system which enables the variable pressures and volumes to be recorded and combined on a chart which may be used as a permanent record and readily compared with other records or standards.

The power apparatus comprises a piston type pump which is electrically driven and especially efficient in slowly and progressively applying the liquid through a reduc-

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tion transmission employing a nut and screw drive. The electrical controls may be easily operated by unskilled or non-technical persons without concern as to the reliability of the results. Included is an electrically controlled brake which automatically becomes effective to hold the power drive and the conditions static when the desired degree of a pressure or volumetric contraction has been achieved and the manual control is released.

Different pressure applying units adapted to receive different kinds or sizes of test objects may be readily substituted in the system and the apparatus as a whole quickly and economically altered to test different objects.

Various other constructional and functional features both as to the system as a whole and the components thereof will be made apparent from the embodiment described hereinafter, and the invention comprises the several steps and relation of one or more of such steps to each of the others and the apparatus embodying features of construction, combination of elements and arrangement of parts which are adapted to effect such steps, all as exemplified in the following detailed disclosure.

Reference should be had to the accompanying drawings in connection with the description in which drawings,

FIG. 1 is a generally diagrammatic showing of the system as a whole;

FIG. 2 is a representative chart of a recorded test;

FIG. 3 is a plan view of the fluid pump and its power drive for supplying liquid to the test apparatus;

FIG. 4 is a partial side elevation looking from the right in FIG. 3;

FIG. 5 is a cross sectional view of the component part in which the object, such as a cigarette in the present case, is inserted and subjected to the hydraulic pressure;

FIG. 6 is an end view looking from the right of FIG. 5.

FIG. 7 is a wiring diagram showing the electrical potentiometer system for recording the derived pressure and which system is also employed for recording the volume;

FIG. 8 is a wiring diagram showing the electrical system for controlling the electric drive motor and its brake; and

FIG. 9 is a cross-sectional view of a modified form of device for measuring the fluid volume.

Referring particularly to FIG. 1 for the general features of the apparatus the component parts include the pressure device 10 in which is axially insertable a cigarette as indicated at 11, a pump including a cylinder 12 and its reciprocative piston 13 secured to piston rod 14 adapted to deliver fluid under pressure to the test device 10 through conduit 15. The piston is moved in forward or reverse direction by the reversible electric motor 16 which, as somewhat diagrammatically indicated in FIG. 1, drives through spur gear 17 a spur gear 18 fixed on a nut 19 having a threaded engagement with the screw 20 on the piston rod 14. Connected into the fluid conduit 15 is a pressure transducer 21 which includes a potentiometer operable in response to variations in pressure in the line 15 and adapted through suitable connections 22 and an electrical system to control the movement of pen 23 across the chart 24 in the recorder R.

The position of the piston 13 in its cylinder and correspondingly the volume of liquid delivered through conduit 15 is also measured and recorded through a motion transducer 25 which includes a potentiometer controlled by a sliding contact movable with the piston rod 14 through the medium of an arm 26 secured to the piston rod, the arm 26 carrying a bar 27 which in turn carries the sliding contact. The potentiometer 25 is electrically connected to the recorder R through the cable 28 and suitable electric circuitry means which will be further described hereinafter. For the present it is noted that

the electrical system controlled by potentiometer 25 serves to control a motor for advancing the chart 24, the advance or feed of the chart being in proportion to the movement of the piston rod 14.

In the system as actually constructed the various elements shown in diagrammatic form in FIG. 1, except for the device 10, are normally mounted in a cabinet portion such as that indicated at 31 by broken lines below the visual recording part R and it will be understood that the diagrammatic showing in FIG. 1 is for the purpose of clarity. The device 10 is located in a suitable position such as on the front of the cabinet 31 where it is readily accessible for the insertion and removal of the test objects.

The structural details of the pump and its drive motor are shown more fully in FIGS. 3 and 4. As there indicated the drive from the motor 16 to the spur gear 17 may if desired include a reduction gearing 40. The driven spur gear 18 is integral with or rigidly bolted to the sleeve nut 19 through bolts 41. The nut 19 is supported between a thrust bearing 42 mounted in the rear end of the cylinder 12 and an opposed thrust bearing 43 mounted in a rigid sleeve 44 which is adjustably threaded into and supported in a bracket 45 mounted on the base 46. It is important that the drive be free of lost motion and the nut 19 has radial slots 19a for a portion of its length and the external threads are tapered whereby axial adjustment thereon of the nut 19b effects a tightening in the screw 20. The piston 13 is provided with suitable packing as indicated at 47. As described in connection with FIG. 1 potentiometer sliding contact rod 27 is made movable with the piston rod by any suitable means such as through the arm 26 having a sleeve part 26a secured by a set screw to the piston rod 14 at the desired adjusted position.

Mounted on the base 46 in offset relation to the piston rod 14 are forward limit switch 48 and reverse limit switch 49 operable by any suitable means such as the finger 50 secured to the piston rod by set screw 51, the finger 50 being adapted to contact the switch buttons 48a or 49a respectively, as indicated more clearly in FIG. 1, in the event that the piston under the manual control to be described should over-run the normally permissible extreme position in either direction. The rear end of the motor shaft has associated therewith an electrically controlled brake 52 automatically effective when the circuit to the motor is open as will be described hereinafter.

The forward end of the pump cylinder 12 is provided with a tapped opening 55 in which is screwed a fluid conduit such as that indicated at 15 in FIG. 1. The dimensions and capacity of the pump and related parts will, of course, vary in accordance with the conditions and desired usages but for the purposes of testing the compressibility of cigarettes the dimensions will be relatively small. The inner diameter for example of the pump cylinder may be in the neighborhood of about 1 inch. As will be discussed hereinafter, it is necessary that the hydraulic circuit be tight and free from leakages and that the passages preferably be relatively small. For example the conduit 15 shown in FIG. 1 including the connection with the pressure transducer 21 has a bore in the range of about $\frac{1}{32}$ to $\frac{1}{16}$ inch diameter. The system is charged with a suitable hydraulic fluid and should be free of all voids or gas pockets. The travel of the piston 13 is relatively slow. As will be more fully discussed hereinafter the normal cycle, controlled by manual switches, comprises a slow forward fluid delivering stroke, with a pause if desired at the end of the delivering stroke, and then through separate manual manipulation of the switches a slow reverse movement of the piston in which the fluid is retracted from the pressure device 10 back into the pump cylinder.

An important feature of the invention is the character of the pressure applying device, the details of which are

shown more fully in FIGS. 5 and 6. The test object support 10 includes a T-shaped member 60 which has a cylindrical sleeve part 61 and a radial nipple part 62 to which is adapted to be connected the hydraulic line 15 the nipple part 62 having a small bore 63 leading to the interior of the sleeve portion 61. The T-member 60 is mounted between two end plate members 64 and 65 each having integral therewith or secured thereto a short sleeve section 64a and 65a respectively. Complementary cut-out portions in the sleeves 64a and 65a are provided to receive the nipple part 62. The opposed surfaces of the end plates 64 and 65 are recessed to receive the respective end of the sleeve 61 and the sleeve is clamped therein between the two end plates by spaced clamping bolts 66. Secured within the sleeve 61 is a flexible tubular sleeve 67 which may be made of any appropriate elastic material adapted to flex under fluid pressure applied thereto. It has been found, however, that a high grade of surgical rubber is particularly effective for the purpose. The sleeve 67 is of considerably greater length initially than the supporting rigid sleeve 61 and in assembled position includes portions 68 and 69 flexed backwardly over the respective ends of the sleeve 61. The portions 68 and 69 are each clamped securely to the sleeve 61 by any suitable means such as the wire wrappings 70.

In addition the rubber sleeve 67 is clamped against the respective ends of the sleeve 61 by means of the end plates 64 and 65 under the compression of the clamping bolts 66. In this respect it is noted that the ends of the sleeve 61 are rounded off and the recesses in the plates 64 and 65 have a corresponding radius to insure against any sharp cutting edges. The sleeve 67 has a normal inner diameter when relaxed against the supporting sleeve 61 which is slightly larger than the diameter of the cigarette to be inserted therein so that there is a minimum of lost space, but the cigarette is freely slidable axially through the opening. The end plates 64 and 65 are also provided with openings 64b and 65b respectively, concentric with the sleeve 61, the openings being substantially of the same diameter as the inner diameter of the sleeve 61, making allowance for the thickness of the rubber liner sleeve 67. As will now be apparent upon the delivery of liquid from the pump through the bore 63 of the nipple 62 the liquid is forced throughout the annular closed space between the sleeve 61 into flexible liner 67 and as more liquid is delivered and the pressure increases the sleeve 67 expands against the cigarette throughout the circumferential extent of the portion of the cigarette within the sleeve 61 causing generally uniform contraction in volume of that section of the cigarette. As indicated above, the rubber sleeve 67 is normally substantially collapsed against the surface of the bore of the rigid sleeve 61 when no fluid pressure is applied from the pump, and when in the description and in the claims reference is made to the annular fluid chamber in the test device there is meant the space, actual or potential, between the two sleeves 61 and 67.

The electric circuitry for controlling the operation of the pump is shown in FIG. 8. It includes a source of alternating current 80 having branches 81 leading to the recorder and branches 82 leading to the motor control system including the brake. The reversible electric motor is indicated at 16a corresponding to motor 16 of FIGS. 1 and 3. In accordance with A.C. motors of a standard reversible type motor 16a has four leads indicated at 83, 84, 85 and 86. The circuit also includes the forward limit switch 48 and the reverse limit switch 49 shown generally in FIGS. 1 and 3. The electrically controlled brake 52 is indicated diagrammatically in FIG. 8 and the electric current source includes a rectifier R. The circuit is controlled by manually operable switches 87 and 88, indicated generally as in the front of the cabinet in FIG. 1 and diagrammatically in FIG. 8. Each of these is preferably of the pressure button gang switch type normally spring biased to the motor circuit deenergized positions

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shown in FIG. 8. Such spring biasing means is shown at 89 for switch 87 and at 90 for switch 88.

For a forward or pressurizing stroke of the piston 13 the operator depresses switch button 87. This establishes connection from the side 91 of the electric power source through line 92 to motor lead 84 of the motor, and also through branch 93 and contacts 94 to motor lead 85. The other side 95 of the electric power source is connected through contacts 96, closed limit switches 48 and 49, and line 97 and contacts 98 to motor lead 83, and through contacts 99 to motor lead 86. The circuit to the brake 52 is broken at contacts 100 and the brake is released. The operator observes the progressive increase in pressure as indicated by the travel of the pen 23 to the right across the recorder, and the piston 13 continues to advance until the operator releases the button switch 87 when the desired pressure has been reached.

Release of the switch establishes the circuit for energizing the brake 52. The circuit connections in this respect comprise the direct line 101 from one side of the source through the rectifier R, and the connection from the other side through line 102 contacts 103 and 100 and line 105. It may be noted that the brake is immediately applied upon release of the switch and the piston and pressure remain static at the desired established condition at which the operator releases the switch 87. It may also be noted that the brake remains applied at all times when neither button 87 nor 88 is depressed.

To reset the system, which includes the retraction of the piston 13 and release of the pressure at the object in the pressure device 10, the operator depresses button 88 which changes the electric connections at motor 16a to the reverse position. The circuit in such case comprises a connection from the main line 95 through contacts 110, closed limit switches 48 and 49, contacts 111 and line 112 to motor lead 86, and through contacts 113 and branch line 114 to motor lead 85. The other side 91 of the main line is connected directly to motor lead 84, and through branch 115 and contacts 116 to the motor lead 83. The circuit to the brake is broken at contact 103 and the brake released. The piston continues to retract and to withdraw liquid from the pressure device 10 back into the pump cylinder so long as the operator maintains switch 88 depressed which normally is until the original condition is established and the cigarette is fully released from pressure.

In either of the forward or reverse operations if the piston over-runs the normal desired range the corresponding limit switch 48 or 49 is opened breaking the connection to the motor through the line 95.

As has been mentioned in a general way the system embodies means for continuously measuring and indicating, as by a strip chart recorder means, the pressure of the liquid applied to the test piece and the volume of liquid delivered and utilized in contracting the test piece portion including the net volume of liquid occupying the space resulting from contraction of the test piece or in other words the amount of reduction in volume of the test piece. The present system embodies means for simultaneously recording these two variable factors in a single graph on rectangular coordinates. This is accomplished in a recorder by advancing a chart in accordance with one variable and moving a recording pen across the chart in accordance with the other variable. The operation may be effected by two Selsyn system type mechanisms in which one Selsyn system operates a motor to advance the chart in timed relation and in proportion with for example the advance of the piston, and the other Selsyn system, which has an element responsive to the fluid pressure, operates a motor which moves the pen across the chart in timed relation and in proportion to the pressure change.

In the present system the initial controls comprise the pressure transducer 21 and the motion or linear movement transducer 25. As is well known a transducer

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functions to respond to variations in the condition with which it is associated and to translate the variation into electrical values which may be impressed upon an electrical system operable to record the variations. Transducers of various types are commonly known in the art and require no disclosure as to details herein. The patents to Barnes, Jr., et. al. 2,466,071 and Clason 2,790,043 disclose the general principles and construction of a pressure transducer device adapted for the purpose. It is sufficient to point out here that in general the transducer embodies a diaphragm or other functionally comparable element responsive to pressure variation and adapted to operate a sliding contact over a potentiometer to vary electrical values in a control system. Such a transducer is indicated diagrammatically at 120 in FIG. 7 and includes a potentiometer 121 having a sliding contact 122 operable as to position in accordance with pressure variations. The patent to Linahan 2,749,754 is representative of another type of transducer employing instead of a mechanical sliding contact, a column of liquid in contact with a resistance element, the height varying with the liquid pressure.

As has been described a transducer is also associated with the piston rod 14 as indicated generally at 25 in FIG. 1. In this case, however, the response is proportional to the linear position of the piston, the slidable potentiometer contact being attached to the piston rod radial arm 26. Transducers of such type and character are well known in the art and since the particular details thereof form no part of the present invention they are omitted in the interest of simplicity.

The transducers operable from the mechanical system shown diagrammatically in FIG. 1 are elements of the recorder system heretofore mentioned, the graph and pen recording part being indicated generally at 24 in FIG. 1. Function plotters or recorders for simultaneously recording two conditions on rectangular coordinates are well known in the art and it is unnecessary for the purposes of the present invention to encumber the record with the details thereof. Such recorders are disclosed for example in patents to Barnes, Jr. 2,527,207 and Ruhland 2,625,458. They are also referred to in the art as X-Y recorders, see in that respect the patent to Ross 2,721,109. In some cases two or more variables are imposed upon the movement of one element, and in others, as in the present case, one variable condition determines the transverse position of the pen 23 or other marking element and another variable condition determines the advance and position of the chart 24.

The present system of that type embodies a potentiometer network wherein an element varies as to position in accordance with the variation in the condition to which it is applied which causes an electrical unbalance in the network and operation of the corresponding motor in the recorder to a position where the balance is restored. FIG. 7 shows the electrical system for effecting the above function. It will be described first in connection with the pressure condition. The system embodies a pressure transducer, indicated at 21 in FIG. 1, and diagrammatically in FIG. 7 including a potentiometer 121 having a sliding contact 122 movable from the pressure responsive device 120. The circuitry also includes a potentiometer 130 at the recorder having a sliding contact 131 movable as to position by the pen operating motor 132 through the connection indicated diagrammatically at 133. The source of alternating current is indicated at 134. Motor 132 is controlled through the amplifier 135. Variation in liquid pressure at transducer 120 as the pump piston moves to the left will move the sliding contact 122 in proportion producing an unbalance in the network through lines 136, 137 and 138 causing motor 132 to operate and move sliding contact 131 to a position to restore the electrical balance. The recorder pen driven from the motor 132 will therefore move to a

position corresponding to the portion of the contact element 122 and to the liquid pressure in the system.

An identical electrical system is associated with the transducer 25 controlled by the position of the pump piston and effective to control the operation of the chart advancing motor. In other words as the sliding contact bar 27 associated with the piston moves over its potentiometer, similar to potentiometer 121 in FIG. 7, it creates an unbalance which operates the chart advancing motor, corresponding to motor 132, and moves its sliding contact, corresponding to contact 131, to restore and maintain the balance. The advance of the chart, therefore, is proportional to the advance of the piston 13 and to the volume of liquid delivered.

In the operation therefore the chart is slowly advanced in accordance with and in proportion to the advance of the pump piston, and simultaneously the pen advances across the chart in accordance with and in proportion to pressure change in the liquid. Added liquid from the pump into the closed system compresses the cigarette a progressively greater amount but, due to increased resistance to deformation as the cigarette is compacted more, the pressure necessarily increases progressively. The result is a continuous curve such as is indicated at 145 in FIG. 2. In FIG. 2 the horizontal scale represents pressure in pounds per sq. in. gauge; and the vertical scale represents volume in cubic centimeters. The construction and proportions of the system and the values involved may be varied in accordance with conditions and the objects to be tested. In the case of cigarettes it has been found that a practical range for the pressure is up to about 50 p.s.i.g. and a suitable volume of liquid is in the range of 1 to 2 cubic inches or about 16 to 32 cubic centimeters.

It will be appreciated that the volumes of liquid involved are relatively small, and that certain amounts thereof are expended in compensating for expansions of the parts slight though they may be. In particular it is impossible as a practical matter to operate a device responsive to pressure such as the pressure transducer 21 without consuming some liquid in flexing the diaphragm or like displaceable part. Accordingly for a true measure of the net volume of liquid which goes to replace the contracted volume of the cigarette it is necessary to operate first the apparatus with a rigid non-deformable standard test piece inserted in the pressure device 10 and thereby obtain a base curve such as the curve 146 shown in FIG. 2. In the case of testing cigarettes the standard for deriving the base curve will comprise a solid mandrel of substantially the size of the cigarettes. The chart is then moved back to place the pen at the same zero point at the bottom left and the operation repeated obtaining a curve such as that indicated at 145 extending over substantially the same pressure range but resulting in delivery of a greater volume of liquid at any particular pressure. The contraction or change in volume in the cigarette at any particular pressure selected is the differential in volume indicated by the difference in value on the ordinate scale. For example the reduction in volume at the pressure 40 lbs. is represented by the increment 147 on the ordinate scale.

For purposes of standardization and convenience further observations and evaluations may be employed. Curve 148 represents an object of zero firmness, that is the hypothetical curve that would be drawn if the device were operated with nothing in the support device to offer appreciable resistance. As the curve indicates the volume increases for a considerable period without substantial increase in pressure and then levels off as the added volume is consumed in expansion of the parts. As a further phenomenon in testing an article such as a cigarette the initial pressure-volume curve will be substantially like that shown at 145, but if the pump is stopped and held at some volume point such as indicated at A on curve 145 the cigarette will gradually lose some of its resilient resistance and the pressure will decrease at constant volume along

a line such as that indicated at AC. As time goes on the rate of decrease in pressure becomes less and less and for practical purposes it is sufficient to permit it to continue for some reasonable time such as an arbitrarily chosen period of two minutes. At such time the recorded pressure will be some value represented by the point C. Curve 146 represents an object having substantially no compressibility and for purposes of comparison is assigned an arbitrary firmness value of 100. The vertical distance *ab* through point C from curve 146 to curve 148 is defined as the scale of firmness and enables obtaining a figure representing the relative firmness of the object tested. Such firmness figure is determined from the formula:

$$F = \frac{V_f}{V_o} \times 100$$

where,

F =firmness.

V_o =volume of the object portion before compression.

V_f =volume of the object portion after compression.

The value V_o is of course directly determined by measurement and computation; and V_f is determined by subtracting the value *ab* from V_o .

For measurements involving the use of the recorder system described it is of course desirable to employ a substantially non-compressible fluid. Certain principles and features of the invention, however, can also be employed using a gaseous fluid, and particularly the device of FIGS. 5 and 6 is so usable. For example when a gas is delivered at a selected pressure through the connection 62 of FIG. 5 to the interior of the rubber sleeve the volume of gas at that pressure can be determined and likewise the added volume of gas at that pressure utilized to contract the object and accordingly the volume of contraction of the object.

FIG. 9 shows a modified form of device and system for measuring the firmness or compressibility of an object particularly a cigarette or generally similar object. As in the system described in connection with FIG. 5 the basic principle involved is the measurement of fluid volumes under selected pressures.

The physical structure of the test object support device of FIG. 9 comprises a main cylindrical part 160 having end plates 161 and 162 within which is mounted a T-shaped member 163 having a cylindrical part 164 and a radial nipple part 165 to which is connected a source of fluid under pressure. This may be a source of compressible gas or a hydraulic fluid and in the latter case may be like that heretofore described and shown diagrammatically in FIG. 1. The inner sleeve 164 has secured therein a flexible sleeve 166 similar to the sleeve 67 described in connection with FIG. 5.

The end plate 162 is made removable from the left end of sleeve 164 in any suitable manner as by means of being hinged at 167 to sleeve 160 and releasably secured in closed position by an eye bolt 168 pivoted at 169 to a lug 170 on sleeve 160 and adapted to be swung into a slot 171 in cover 162 and the cover then clamped to the sleeve by thumb nut 172. The cover 162 has a recess to receive the end of tube 164 over which is folded the rubber tube 166 and drawing up thumb nut 172 forms a fluid tight seal at that end.

The other end plate 161 is clamped over the opposite end of sleeve 164 by suitable means such as by bolts 175 extending through the end plate and through holes in an annular ring or lugs 176 integral with sleeve 160. The end plate 161 has a hollow area 177 within a boss 178 in which is secured by a fluid tight joint a precise low-inertia volume meter, such as the glass capillary tube 179 within which moves a drop of liquid 180. The particular volume meter shown comprises a common form of capillary tube open at the outer end to atmospheric pressure. Initially the liquid bubble is set at zero in any suitable manner as by blowing into the outer end. The tube may be made

readily removable for setting purposes as by providing the inner end with a ring 181 threaded into the boss 178. The space 177 communicates with the interior of the rubber sleeve 166 through suitable openings such as the holes 185.

The object to be measured such as a cigarette, or a section of the length of a cigarette, depending upon the length of the sleeve 164 is inserted into the central space by opening end plate 162. A cigarette section so inserted is indicated at 186. In operation the compressibility of the object may then be measured in either one of two ways. It may be by measuring the fluid delivered through nipple 165, as heretofore described, or it may be by measuring the fluid expelled from the compressed cigarette into the volume meter 179, which has associated therewith the scale 187 graduated in the present case in cubic centimeters. For a selected pressure delivered into the rubber sleeve 166 the cigarette section will be compressed by a certain volume which will expel a corresponding volume from the cigarette axially through holes 185 into the bore of the capillary tube, the volume being indicated by the position of the liquid drop 180, and comprising a measure of the compressibility of the cigarettes. In this manner of measurement the applied fluid through nipple 165 can be either a gas or liquid without varying the results or requiring any compensation for the compressibility of a gas since the factors involved are the pressure applied to the exterior of the cigarette and the volume of air at atmospheric pressure expelled into the meter tube 179. As has been heretofore mentioned the compressibility may alternatively be measured through the pressure and volume of the fluid delivered through nipple 165 in the manner described in detail earlier herein in connection with FIG. 1 and the device of FIG. 5.

It will thus be seen that the objects set forth above, among those made apparent from the preceding description, are efficiently attained and, since certain changes in carrying out the above process and in the constructions set forth, which embody the invention may be made without departing from its scope, it is intended that all matter contained in the above description and shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

We claim:

1. An apparatus for measuring the compressibility of an elongated object comprising a support having an opening in which the object is longitudinally insertable, a flexible sleeve extending around said opening and connected to said support to form an annular closed chamber, means for supplying liquid to said chamber under pressure to cause the sleeve to engage and compress the object, and means for measuring the pressure of the liquid and the volume of liquid supplied in compressing the object.

2. An apparatus for measuring the compressibility of a cigarette comprising a support having an opening generally conforming to a cross section of the cigarette in which the cigarette is longitudinally insertable, a flexible sleeve extending around said opening and connected to said support to form an annular closed chamber, means for supplying liquid to said chamber under pressure to cause the sleeve to engage and compress the cigarette, and means for measuring the pressure of the fluid and the volume of liquid supplied at different pressures and thereby the amount of contraction of the cigarette portion under compression at the different pressures.

3. The method of measuring the compressibility of a cigarette comprising positioning the cigarette within a liquid tight annular chamber having a flexible annular wall adapted to engage the surface of a portion of the cigarette, supplying liquid under pressure to the interior of said chamber to cause the said wall to expand and compress the cigarette, and measuring the volume of liquid supplied at particular pressures and thereby the decrease

in volume of the cigarette portion at the respective pressures.

4. In an apparatus for measuring the compressibility of an object, a rigid annular member having an opening therethrough, a sleeve of elastic material within said opening secured to longitudinally spaced portions of said member to form a fluid tight annular chamber between the member and sleeve, and provide an opening through the sleeve in which the test object is freely insertable, said member having an opening arranged for the supply of fluid under pressure to said chamber to expand the sleeve into engagement with and compress the test object, and means for measuring the pressure of the fluid and the volume of fluid supplied in compressing the object.

5. Apparatus for measuring the compressibility of a self-sustaining non-fluid object having in combination a support for the object, an expansible closed liquid receiver having a flexible wall adapted to engage the object when positioned in the support and to flex into and conform to the shape of the object, means for supplying liquid under pressure to said receiver to expand said receiver and contract by compression thereof the volume of the object, the liquid pressure increasing as the supply of liquid and contraction of the object increase, and means for progressively and concurrently indicating the liquid pressure and the amount of contraction in the volume of the object.

6. The method of measuring the compressibility of a deformable object having fluid filled voids comprising the steps of subjecting the object to compression from a flexible element expanded into engagement with the object thereby reducing the bulk volume of the object, and collecting and measuring the volume of fluid expelled from the object by the reduction of its bulk volume at a determined pressure.

7. The method of measuring the compressibility of a deformable object having fluid filled voids comprising the steps of confining the object in a closed space, subjecting the object to compression by pressure applied to the surface of the object thereby reducing the bulk volume of the object, measuring the pressure, and collecting and measuring the volume of the fluid expelled from the object by the reduction of its bulk volume at the selected pressure.

8. Apparatus for measuring the compressibility of an object comprising a rigid closed hollow support, a flexible member comprising therein and having a fluid tight seal and adapted to form with a wall portion of the support a fluid tight chamber, said support having a closable opening for the insertion therein of a test object, means for supplying fluid under pressure to the interior of said chamber to cause said flexible member to expand and compress the test object, and a volume meter connected to said hollow interior and adapted to receive and measure fluid expelled from said object when fluid under pressure is supplied to expand said flexible member.

9. Apparatus for measuring the compressibility of an object comprising a rigid hollow annular member, a sleeve of elastic material secured therein and having a fluid tight seal therewith and adapted to provide an opening to receive therein a test object, said opening conforming substantially to the size and shape of the object, a closable opening at one end of said member for the insertion therein of a test object, a volume meter connected to the other end, and means for supplying fluid under pressure to the space between said member and sleeve to cause the latter to expand and compress the said object and thereby expel fluid into said volume meter, and means for measuring the pressure of the supplied fluid.

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