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Dyck

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[54] **GRAIN MOISTURE TESTER**

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[51] **Int. Cl.** **G01n 25/56;** G01n 3/08

[58] **Field of Search** 73/94, 73, 76; 100/295, 100/211

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[57] **ABSTRACT**

Methods and apparatus for determining the compressibility and/or moisture content of particulate materials are provided. The apparatus generally consists of a closed compression chamber, a piston in the compression chamber and a transducer for sensing the pressure generated within the compression chamber. In one aspect the piston is multi-part and has a concave face. The volume of the chamber is varied by varying the concavity of the piston face. In another aspect the peripheral wall of the chamber consists of a plurality of relatively movable wall sections which slide relative to one another when the volume of the chamber is varied. Also disclosed are methods of compressing particulate material and determining their compressibility and/or moisture content using the apparatus.

2 Claims, 8 Drawing Figures

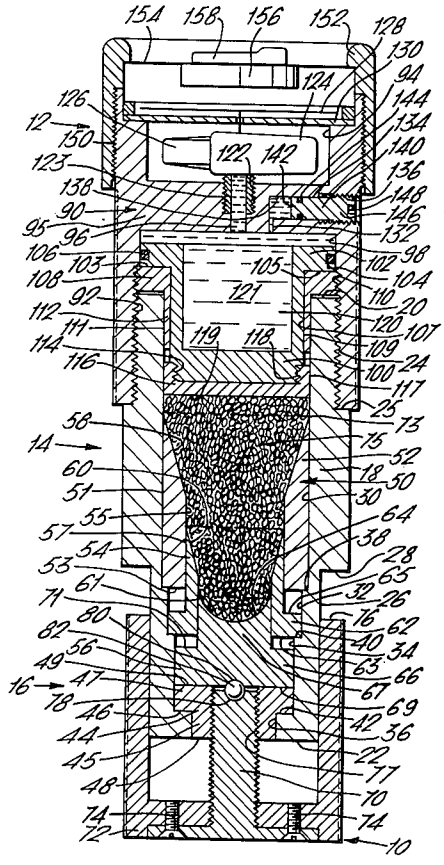


FIG. 1.

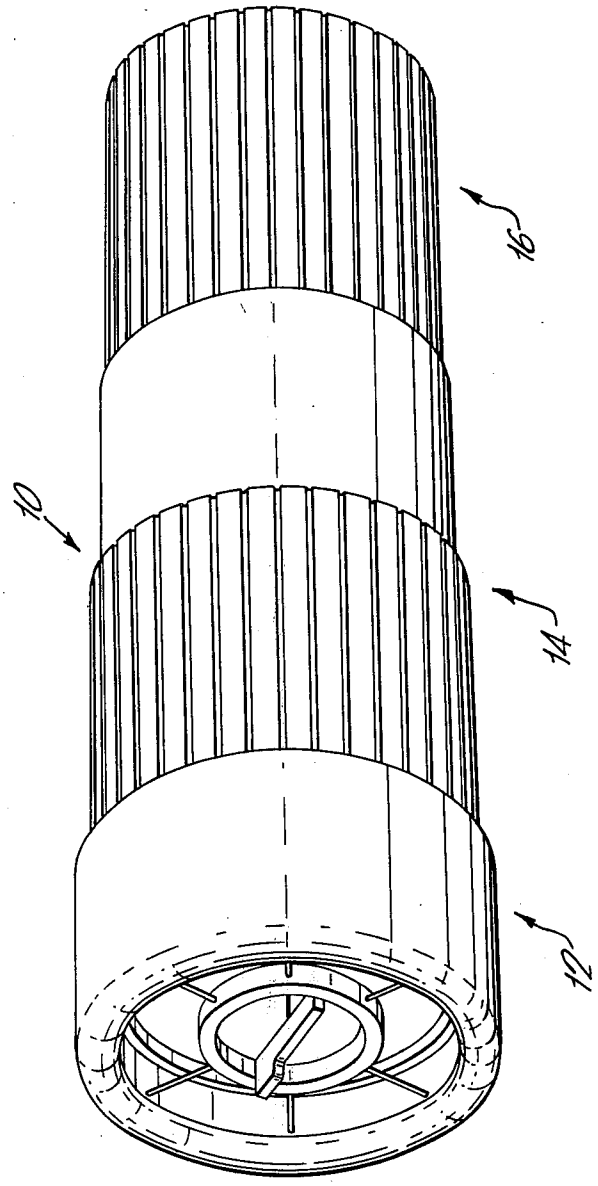


FIG. 2.

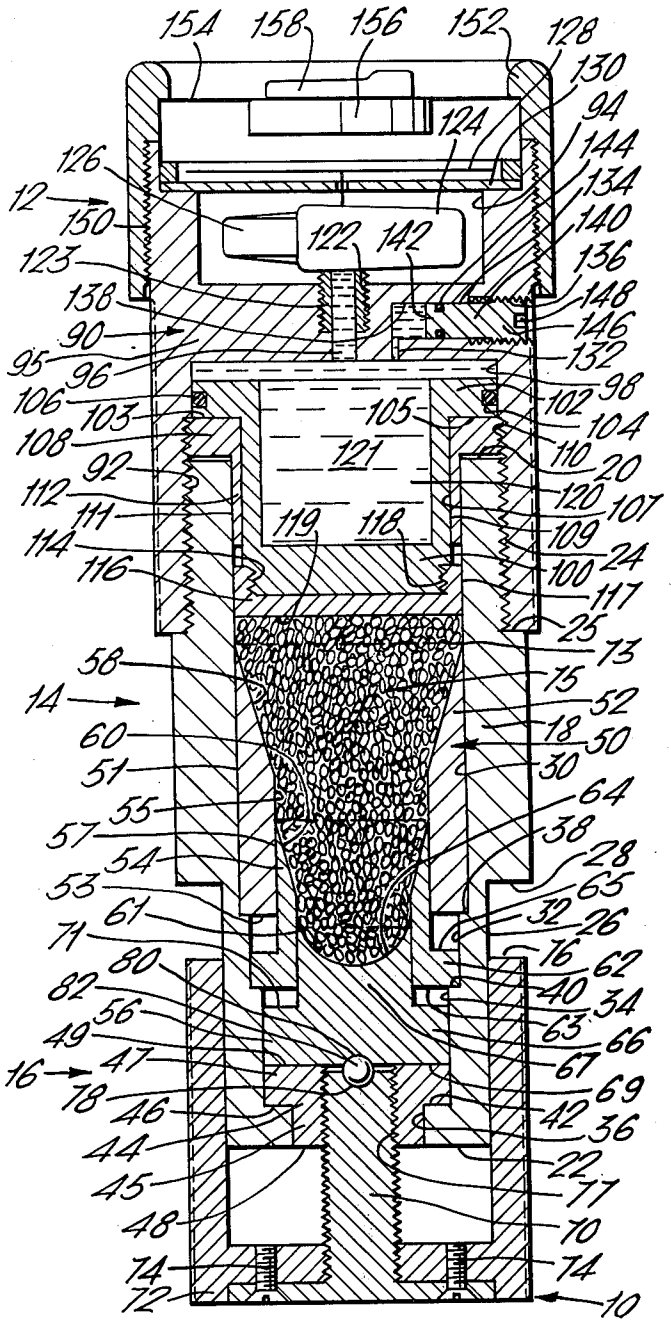
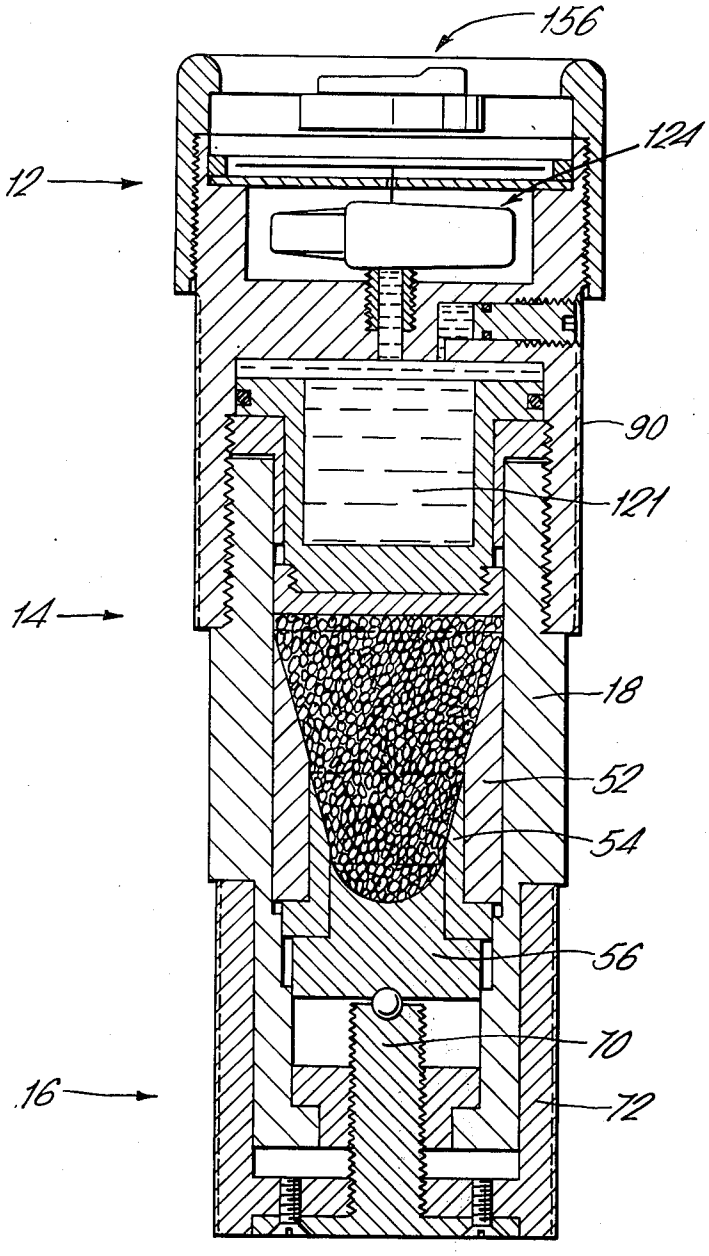

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FIG. 3.



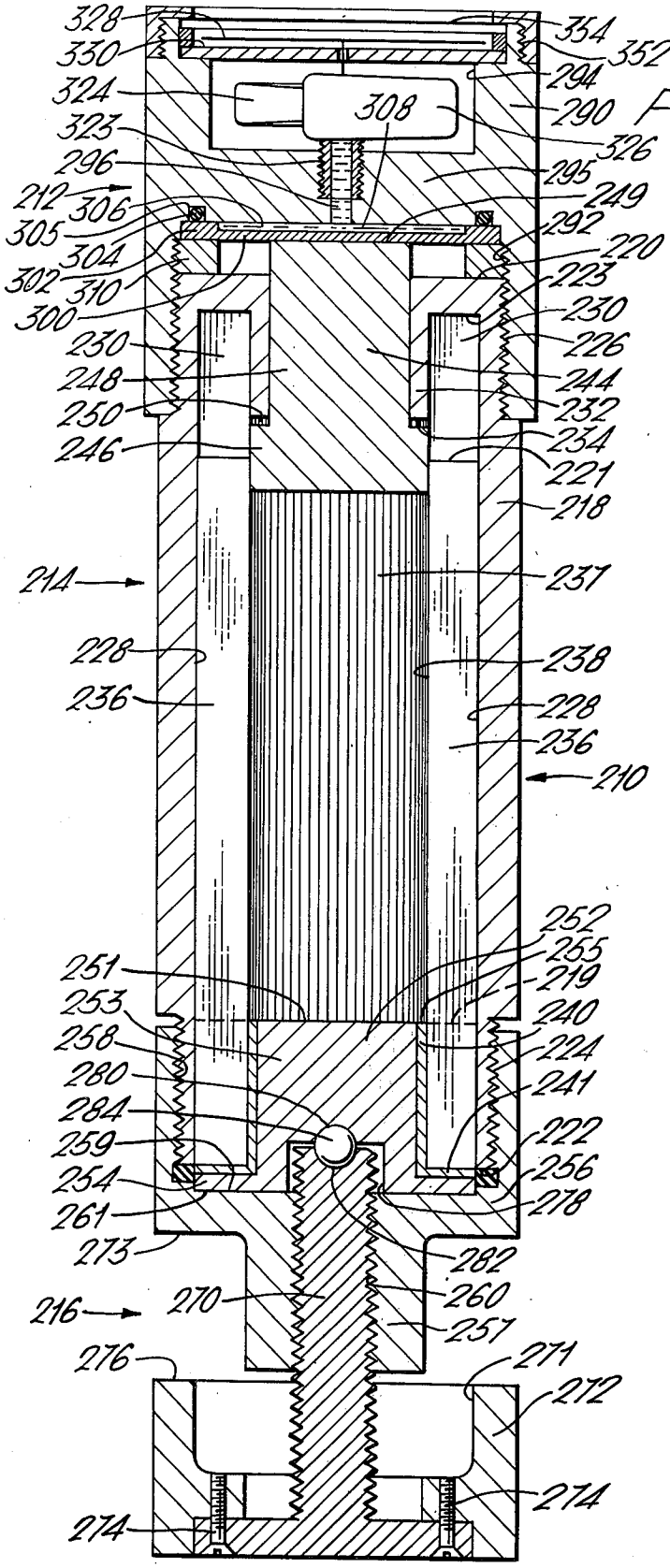

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FIG. 4.

FIG. 5.

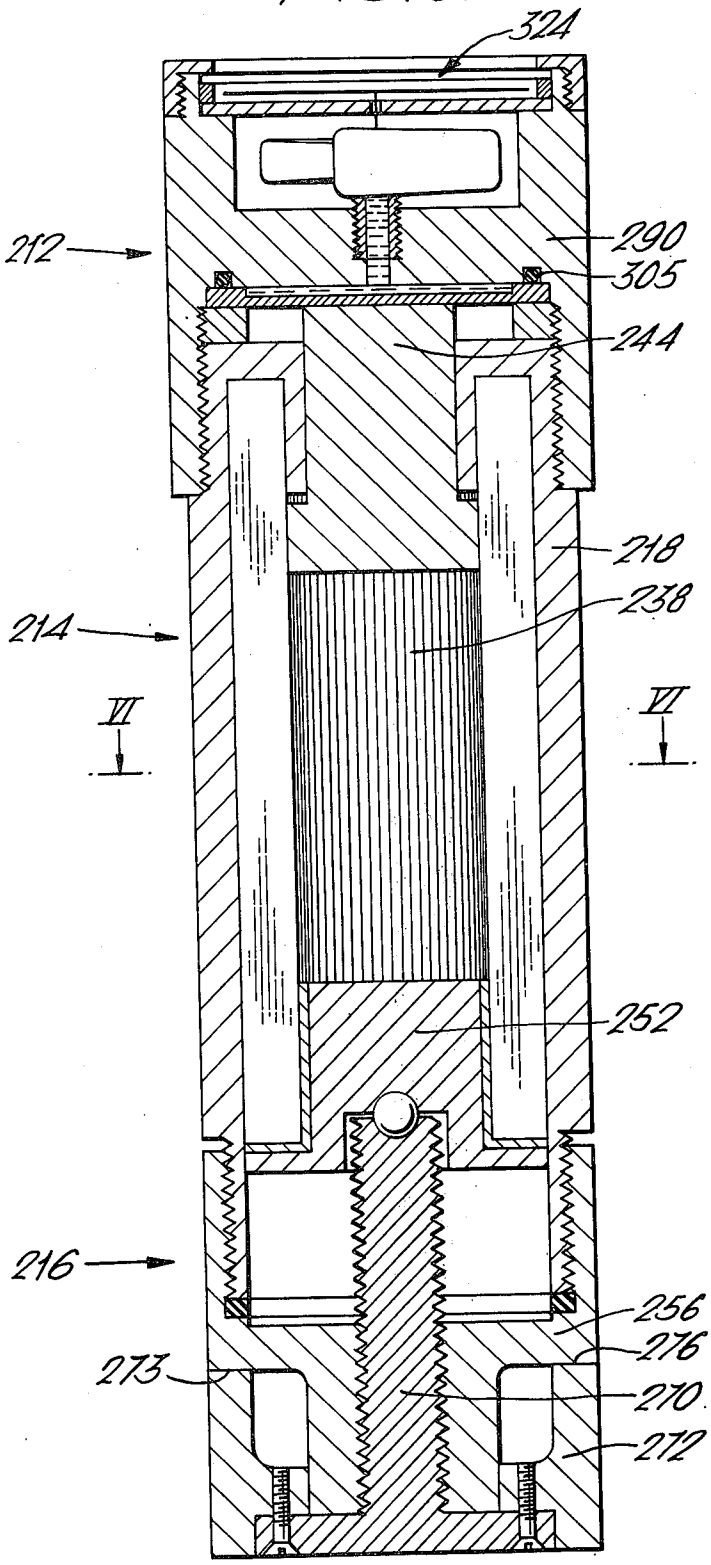


FIG. 6.

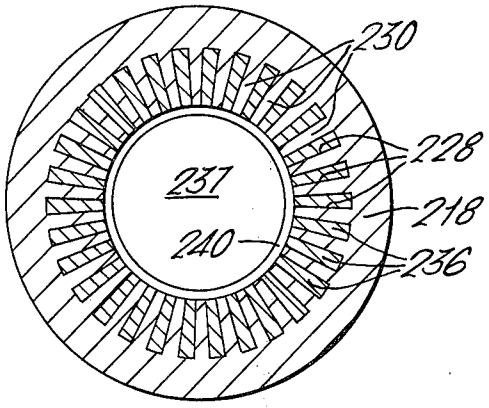


FIG. 7.

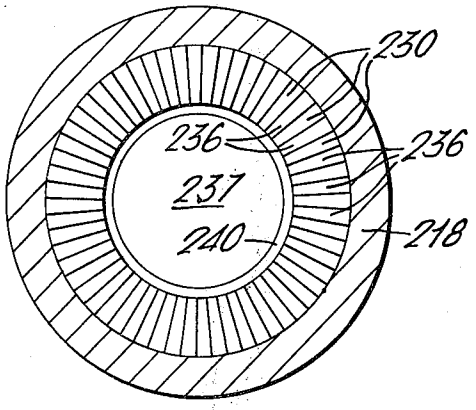
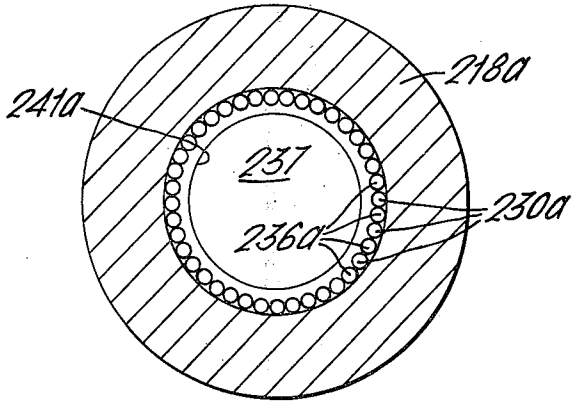


FIG. 8.



GRAIN MOISTURE TESTER

BACKGROUND OF THE INVENTION

The present invention relates to methods and apparatus for determining the compressibility and/or moisture content of particulate materials. More particularly, it relates to such methods and apparatus for determining the moisture content of grain.

Most commercially available grain moisture testers are not suitable for use by the average farmer. Those that have, in the past, provided satisfactory results generally require electric power, are not portable to the extent that they may be transported into the field, and are expensive.

To overcome the difficulties of this prior art, attempts have been made to determine the moisture content of grain by the compression method. Since it is known that the hardness of grain and many other compressible materials varies substantially in inverse proportion to the moisture content of the material, it was postulated that, by obtaining a measure of the compressibility of that material, one could obtain a measure of the moisture content. The apparatus used heretofore for determining the compressibility usually consisted of straight cylinders provided with a compressing piston. With such an arrangement the grain was not, however, uniformly compressed in that the grain adjacent the piston was overly compressed whereas the grain further from the piston was hardly compressed at all. This resulted from the large frictional forces exerted on the grain by the cylinder wall. Additionally, the previous apparatus of this kind were of a type wherein a predetermined force was exerted on the grain by the piston and the resulting deflection of the piston, i.e., the reduction in volume of the cylinder, was taken as an indication of the compressibility and therefore moisture content of the grain. With such an arrangement the deflection of the piston with respect to the cylinder was usually read directly from a mechanical scale arrangement so that the accuracy of the reading was limited by the accuracy and readability of the scale arrangement. The accuracy of any reading with such a device depended on the magnitude of the indicated value when compared with the possible error in reading the scale. Thus, the accuracy was inherently poor when the grain was very dry and hard such that the amount of deflection of the piston was small. Additionally, the calibration of any such tester was extremely difficult since it was difficult to ensure that the cylinder was filled with grain to precisely the same desired level prior to each test. Thus, the scale would rarely and randomly be at "zero" at the beginning of any given test.

SUMMARY OF THE INVENTION

It is an object, then, of one aspect of the present invention to provide improved methods for determining the compressibility, and preferably also the moisture, of particulate material.

It is an object of another aspect of the present invention to provide an apparatus for compressing, and preferably also determining the moisture content of, particulate material.

Accordingly, a method is provided for determining the compressibility of a particulate material. The method comprises first providing a first predetermined volume of the particulate material in an uncompressed condition. Then the particulate material is compressed

to a second predetermined volume which is smaller than the first predetermined volume. Finally the pressure exerted by the compressed particulate material is measured. Preferably, also, that measured pressure is converted to a measure of the moisture content of the particulate material.

As used herein, the term "compressible particulate materials" is to be construed as a generic term indicating all of those materials whose compressibility and/or moisture content can be determined by the present methods and devices. Thus, the methods and apparatus of the present invention have a particular utility in the field of determining the moisture content of cereal grain, as well as for determining the moisture content of other particulate materials such as, for example, soil, peas, sunflowers, saw dust and the like.

By an embodiment of this aspect of this invention, a method is provided for compressing particulate material in a substantially closed compression chamber having a piston with a substantially concave face. The method comprises the first step of filling the chamber with particulate material, and the second step of reducing the volume of the chamber by reducing the concavity of the piston face.

By yet another embodiment of this aspect of this invention, a method is provided for compressing particulate material in a substantially enclosed chamber having first and second axially spaced-apart ends and an axially extending peripheral wall. The method comprises the first step of filling the chamber with uncompressed particulate material; the second step of reducing the axial dimension of the chamber; and the third step of moving axially extending portions of the peripheral wall axially with respect to one another.

By another aspect of this invention, apparatus is provided for testing the compression of particulate material. The apparatus comprises substantially closed chamber means having a volume which is variable between a first predetermined volume and a second predetermined volume smaller than the first predetermined volume. Pressure sensor means are provided for sensing the magnitude of pressure within the chamber. Indicator means are provided which are coupled to the pressure sensor means for indicating the magnitude of such pressure. Preferably, the indicator means may also indicate the moisture content of the particulate material being tested.

By one embodiment of this aspect of this invention, an apparatus is provided for compressing particulate material, the apparatus being of the type having a substantially closed compression chamber and a piston slidable in such chamber. In such apparatus, the piston has a substantially concave face and comprises a plurality of telescopically interengageable members relatively movable with respect to one another. Such movement varies the concavity of the piston face and thereby also the volume of the chamber.

By yet another embodiment of this aspect of this invention, an apparatus is provided for compressing particulate material. The apparatus comprises a plurality of members movably interengageable with one another to define a substantially enclosed variable volume chamber. Such chamber has first and second axially spaced-apart ends and an axially extending peripheral wall. The peripheral wall includes a plurality of axially extending peripheral wall sections which are axially

movable with resepct to one another in response to variation in the volume of such chamber.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings which illustrate embodiments of the present invention,

FIG. 1 is a perspective view of one form of grain moisture tester in accordance with an aspect of the present invention;

FIG. 2 is a cross-sectional view of the compression tester of FIG. 1, assembled and in which the particulate material is in an uncompressed condition;

FIG. 3 is a cross-sectional view of the compression tester of FIG. 1 corresponding to that of FIG. 2, in which the particulate material is in a compressed condition;

FIG. 4 is a cross-sectional view of a grain moisture tester in accordance with another aspect of the present invention in assembled form, in which the particulate material would be in an uncompressed state;

FIG. 5 is a cross-sectional view of the tester of FIG. 4 in which the particulate material would be in a compressed state;

FIG. 6 is a view along line VI—VI of FIG. 5; and

FIGS. 7 and 8 are views similar to FIG. 6 of yet another embodiment of grain moisture tester in accordance with another aspect of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the embodiment of the tester shown in FIGS. 1 through 3, there is illustrated a tester 10 for determining the moisture content of grain. The tester includes a pressure sensor and indicator section 12, a compression chamber section 14, and a piston actuator section 16.

As can be most readily seen from the cross-sectional views of FIGS. 2 and 3, the main body of compression chamber section 14 consists of a cylindrical sleeve 18 having opposite ends, i.e. upper end face 20 and lower end face 22, a reduced diameter, externally threaded upper portion 24 adjacent end face 20 which ends at an annular shoulder 25 and a reduced external diameter lower portion 26 adjacent end face 22 terminating at an annular shoulder 28 facing in the same direction as end face 22.

The internal diameter of sleeve 18 is reduced in a stepwise manner from upper end face 20 to lower end face 22 so as to provide four coaxial cylindrical surfaces 30, 32, 34 and 36 of sequentially smaller diameters and three annular shoulders 38, 40 and 42, each facing in the same direction as upper end face 20 of sleeve 18.

A cylindrical block 44 is positioned within sleeve 18. Block 44 has a smaller diameter cylindrical portion 45, which is dimensioned to be a snug fit within cylindrical surface 36 and which extends downwardly from shoulder 42 towards lower end face 22 of sleeve 18 and terminates at a lower annular face 48, which is planar with lower end face 22 and is parallel to shoulder 42. Block 44 also has a larger diameter cylindrical portion 47 which is dimensioned to be a snug fit within cylindrical surface 34 of sleeve 18 and which has an annular face 46 abutting against shoulder 42. Block 44 terminates at an upper face 49 which is directed oppositely to lower end face 22 of sleeve 18 and is parallel to shoulder 42.

A piston assembly 50 is slidably fitted within sleeve 18 between its upper end face 20 and upper face 49 of block 44. The piston assembly consists of three telescopically engageable elements 52, 54 and 56. Element 52 is generally cylindrical, and has its outer cylindrical face 51 slidably fitted within surface 30 of sleeve 18. It includes a substantially frusto-conical inwardly directed end face 58 which tapers inwardly in a direction from upper end face 20 towards lower end face 22 of sleeve 18 to an inner cylindrical surface 55. The lower face 53 of element 52 abuts shoulder 38.

Piston element 54 is also generally cylindrical and has its outer cylindrical surface 57 fitted within element 52 in sliding contact with inner cylindrical surface 55 of element 52. It, too, includes a substantially frusto-conical inwardly directed end face 60 which tapers inwardly in a direction from end face 20 towards end face 22 to an inner cylindrical surface 61. Element 54 also includes an annular collar 62 which fits slidably within cylindrical surface 32 of sleeve 18 and has a lower face 63 engaging shoulder 40 and an upper face 65 adapted to abut lower face 53 of element 52. The slope of surface 60 is substantially the same as the slope of surface 58 of element 52 and, consequently, surfaces 58 and 60 are adapted to be aligned with one another, as can be seen most readily from FIG. 3.

Piston element 56 is a cylindrical plug having an upper, smaller diameter cylindrical portion 67 slidably fitted within piston element 54 and in sliding contact with the inner cylindrical surface 61 and has a concave face 64 directed towards upper end face 20 of sleeve 18. Element 56 also has a lower, larger diameter cylindrical annular collar 66 slidably fitted within surface 34 of sleeve 18 and having a lower face 69 engaging upper face 49 of block 44. Collar 66 also includes an upper face 71 adapted to engage face 63 of element 54.

As can be seen from FIGS. 2 and 3, collars 62 and 66 of piston elements 54 and 56, respectively, are shorter in axial dimension than the associated cylindrical surfaces 32 and 34, respectively, of sleeve 18 in which they slide. Thus, element 56 may slide freely between a lower limiting position where face 69 engages face 49 of block 44 and an upper limiting position where face 71 of collar 66 engages face 63 of piston element 54. Similarly, piston element 54 may slide freely between a lower limiting position where face 64 of collar 62 engages shoulder 40 and an upper limiting position wherein face 65 of collar 62 engages face 53 of piston element 52. Finally, piston element 52 may slide freely between a lower limiting position where face 53 engages sholder 38 and an upper limiting position where the upper rim 73 approaches an end plug 116 on the pressure sensor and indicator head 12, as will hereinafter be described. The limit position is actually defined by engagement of shoulder 28 with face 76 of hand knob 72 as will be described hereinafter. It is seen, further, that piston elements 52, 54 56 thus combine to form a variable volume chamber 75.

The piston actuator section 16 comprises a bolt 70 threaded into internally threaded aperture 77 in block 44 and a cup-shaped hand knob 72 secured to the head of bolt 70 by screws 74. Hand knob 72 fits slidably over reduced external diameter portion 26 of sleeve 18 and has an end face 76 facing towards and engageable with shoulder 28. To reduce friction between bolt 70 and piston element 56, bolt 70 and piston element 56 are provided with opposing recesses 78 and 80, respec-

tively, in which a ball **82** of steel or the like material is held.

The pressure sensor and indicator section **12** consists of a main cylindrical member **90** having an internally threaded recess **92** in the lower end thereof, a recess **94** in the upper end thereof, and a bore **96** extending through the web **95** between recesses **92** and **94.** Recess **92** is threaded inwardly over a part of its depth from the end of member **90** and is engaged with the threaded end **24** of sleeve **18,** with the remaining part of recess **92** having a smooth cylindrical wall **98.** A cup-shaped piston **100** having an upper annular collar **102** at its open end is disposed within recess **92** with the collar **102** fitted slidably within cylindrical wall **98** of recess **92.** Collar **102** has an annular groove **104** in its peripheral surface and an O-ring seal **106** is fitted into groove **104** to form a seal between the collar **102** and wall **98.**

To hold piston **100** within recess **92,** an annular collar **108** with an external thread **110** is threaded into recess **92** so that its upper face **103** engages lower face **105** of collar **102.** Collar **108** is integral with a sleeve **112** whose inner peripheral surface **107** fits slidably about the outer peripheral surface **109** of cup-shaped piston **100.** The outer peripheral surface **111** of collar **108** fits slidably within inner cylindrical surface **30** of sleeve **18.**

An external thread **114** is provided on the lower surface of piston **100** at the end thereof remote from collar **102** and a plug **116** with a large, internally threaded recess **118** is threadedly engaged with thread **114.** Plug **116** and sleeve **112** have the same diameter and are arranged coaxially with respect to one another. The outer peripheral surface **117** of plug **116** is also slidably fitted within inner cylindrical surface **30** of sleeve **18.** The length of sleeve **112** is less than the spacing between collar **102** and plug **116** so that the assembly of piston **100** and plug **116** can slide to a limited extent with respect to sleeve **112.** The lower face **119** of plug **116** also provides the upper limit of the variable volume chamber **75.**

Piston **100,** with its integral collar **102,** defines with the end of recess **92** a pressure chamber **120** which communicates with recess **94** through bore **96.** Pressure chamber **120** is filled with hydraulic fluid indicated by the reference numeral **121.**

Bore **96** has a threaded counterbore **122** at its end adjacent recess **94.** A threaded coupling sleeve **123** of a pressure gauge **124** is engaged within counterbore **122.** Gauge **124** includes a gauge actuating element **126,** an indicating needle **128** and a circular scale **130.**

As will be apparent from the above, the gauge **124** indicates the pressure of hydraulic fluid **121** within chamber **120** applied through pressure on face **119** of plug **116.** To "zero" the gauge **124,** an axially extending bore **132** is provided extending from cahmber **120** into the end of a calibrating bore **134** extending radially into the web **95** of member **90.** Bore **134** has an internally threaded outer end portion **136** and an inner smooth walled cylinder portion **138.**

A plug **140** is disposed within bore **134** and has an inner piston end **142** with a peripheral O-ring seal **144** so as to engage the cylinder portion **138** of bore **134.** An outer end **146** of plug **140** is in threaded engagement with outer portion **136** of bore **134.** The outer end of plug **140** has a hexagonal recess **148** therein to receive an Allan wrench.

The end of member **90** surrounding recess **94** is threaded at **150** to receive an end of an internally threaded sleeve **152.** The outer end of sleeve **152** has a closure plate **154** of glass, transparent plastic or the like material mounted thereon. A timer **156** is mounted on plate **154** and has an actuating knob-pointer assembly **158** disposed on the outer side of plate **154.** The timer **156** is of a size and is positioned such that gauge scale **130** and needle **128** can be viewed through transparent plate **154** without difficulty.

The pressure sensor and indicator portion **12** is mounted on compression chamber portion **14** by inserting plug **116** and sleeve **112** slidably within cylindridal surface **30** of sleeve **18** and engaging the threaded end **24** of sleeve **18** with the threaded portion of recess **92.** The end of member **90** engages shoulder **25** at the end of threaded portion **24** of sleeve **18** when the two sections are fully engaged.

The operation of the apparatus of FIGS. **1 – 3** will now be described, with particular reference to FIGS. **2** and **3.**

To commence a test, the bolt **70** is withdrawn from block **44** by rotating hand knob **72** until faces **53, 63** and **69** of piston elements **52, 54** and **56,** respectively, engage shoulder **38,** shoulder **40** and face **49** of block **44,** respectively. This initial condition of the piston **50** is illustrated in FIG. **2** and will be herein referred to as a condition of "maximum concavity". The term "concavity" is used herein as a quantitative term generally indicating the depth of the recess defined by the generally concave piston face provided at least in part by faces **58, 60** and **64** of piston elements **52, 54** and **56,** respectively.

With piston **50** in its condition of maximum concavity as hereinbefore described, the pressure sensor and indicator section **12** is removed from the compression chamber section **14** by disengaging the threads of recess **92** from threaded portion **24** of sleeve **18.** The particulate material to be tested is then introduced into the variable volume chamber **75** within the interior of sleeve **18** through its upper end until a predetermined level which may be indicated by a reference line (not shown) marked on the inner surface **30** of sleeve **18.** The presssure sensor and indicator section **12** is then replaced on compression chamber section **14** by threading member **90** into engagement with threaded end **24** of sleeve **18** until the end of member **90** engages shoulder **25.** With the apparatus in this condition, a completely closed variable volume chamber **75** is thus provided between plug **116** and piston **50,** the chamber **75** being filled with the particulate material to be tested. At this point the calibrating plug **140** is moved to the appropriate position within its bore **134** to ensure that the pressure gauge **124** is reading "zero". This movement of the calibrating plug adjusts the pressure of hydraulic fluid **121** in chamber **120** and may cause piston **100** to move slightly within the recess **92.** While this movement of piston **100** does, in fact, alter the volume of chamber **75,** this variation in volume is very small when compared with the entire volume of chamber **75** and therefore does not materially change the volume of the material within chamber **75.** With the apparatus in this condition, there is therefore provided a variable volume compression chamber **75** closed by a piston **50** with a substantially concave face **64** and a plug **116** with a substantially flat face **119,** the chamber

75 being filled with the particulate material to be tested, the material being in an uncompressed state.

To compress the material within chamber **75**, the hand knob **72** is rotated to thread bolt **70** through block **44** into engagement with piston element **56**. Face **49** of piston element **56** is then moved upwardly out of engagement with face **49** of block **44** until face **71** of its collar **66** engages face **64** of piston element **54**. This movement of piston element **56** initially compresses a central core section of the sample within variable volume chamber **75**. Further rotation of hand knob **72** moves both of piston elements **56** and **54** together towards plug **116** further to compress the central core section of the sample and to compress portions of the sample disposed immediately around the previously compressed core section. This continues until face **65** of collar **62** of piston element **54** engages face **53** of piston element **52**. Upon further rotation of hand knob **72**, all three piston elements **52, 54** and **56** will be moved together towards plug **116** until end face **76** of hand knob **72** engages shoulder **28** on sleeve **18**. The apparatus is then in the condition shown in FIG. **3**. It is noted that rim **73** of piston element **52** does not necessarily abut plug **116**.

With the apparatus in this condition, a substantially uniform pressure exists throughout the sample and this pressure is exerted upon piston **100** through plug **116**. Since piston **100** is slidable within recess **92**, the pressure exerted by the grain is, in turn, transmitted to hydraulic fluid **121** in chamber **120** and thence to pressure gauge **124**.

Since particulate materials, such as, for example, grain, are not generally instantaneously compressible, the initial indication by gauge **124** is very high and will gradually decrease for a period of time until the condition of the grain has stabilized within variable volume chamber **75**. Thus, the timer **156** is set for a predetermined time, for example, 1 or 2 minutes, immediately following the compression of the sample. The time to which the timer **156** is set is selected to be sufficient for the state of the sample to stabilize within variable volume chamber **75**. When the condition of the sample has stabilized, gauge **124**, through its indicating needle **128** and scale **130**, gives a direct indication of the compressibility or moisture content of the sample, depending on the units marked on scale **130**.

By providing a concave piston in the variable volume compression chamber **75** and then compressing the particulate material by reducing the concavity of the piston, the detrimental effects of friction between the cylinder wall and the sample are minimized or even essentially eliminated by the elimination of a cylinder wall. The sequential compressing of the various areas of the sample results in a very uniform compression throughout the sample.

Turning now to FIGS. **4** through **6**, another embodimenet of compression or moisture tester **210** for particulate material is illustrated. The tester includes a pressure sensor and indicator section **212**, a compression chamber section **214** and a piston actuation section **216**.

The compression chamber section **214** consists of a generally cylindrical sleeve **218** having a reduced diameter externally threaded portion **224** adjacent the upper end face **220** thereof and a reduced diameter, externally threaded portion **226** adjacent the lower end face **222** thereof. It is preferred that the diameters of portions **224** and **226** be different to prevent their being threaded into the incorrect parts as will hereinafter become apparent.

Sleeve **218** has formed on its interior surface a plurality of longitudinally extending radial slots **228** so as to provide therebetween a plurality of radial blades **230** uniformly distributed around the inner periphery of sleeve **218**. (see FIG. **6**). Slots **228** terminate at a common plane **223** spaced slightly from end face **220** of sleeve **218**. In addition, the portions of blades **230** end at a postion spaced from end face **220** of sleeve **218** and indicated, in FIG. **4**, by broken line **219**.

A cylindrical sleeve **232** is integral with sleeve **218** and extends downwardly a short distance from end face **220** towards end face **222** and ends at an annular end face **234**.

A hollow cylindrical sleeve **240** having a lower annular flange **241** thereon is disposed slidably within sleeve **218** adjacent its end face **222**. A plurality of blades **236** project upwardly from flange **241** and are disposed slidably within respective ones of slots **228** of sleeve **218**. Together with blades **230**, these blades **236** define a variable volume cylinder **237** having a multi-part cylindrical surface **238**. The blades **236** are of substantially the same length as blades **230** and terminate at a common plane **221** spaced from the plane **223** defined by the ends of slots **228**. Thus, the chamber **237** is composed of an upper portion, comprising sleeves **218** and **232** including blades **230**, and a lower portion comprising sleeve **240** and blades **236** projecting upwardly from flange **241** between blades **230**.

At the upper portion of cylinder **237**, a plug **244** is provided having one cylindrical portion **246** thereof that is a close sliding fit within cylindrical surface **238** and a smaller diameter cylindrical portion **248** that is fitted slidably within sleeve **232** and which projects upwardly beyond end face **220** of sleeve **218** and terminates in face **249**. An annular shoulder **250** extends between portions **246** and **248** and is adapted to abut end face **234** of sleeve **232**.

At the lower portion of chamber **237**, a piston **252** is provided which is generally cylindrical and has a major, smaller diameter portion **253** in close sliding fit within sleeve **240**. Piston **252** has an integral annular collar **254** projecting radially outwardly therefrom so as to engage with the bottom of flange **241** to hold the piston in position with respect to sleeve **240** and cylinder **238**. The length of piston **252** is such that its inner end face **251** is coplanar with the inner end **255** of sleeve **240**.

An end member **256** is provided which has a neck **257** and a large threaded recess **258** therein which is threaded onto externally threaded portion **226** of sleeve **218**. A central threaded bore **260** extends through neck **257** of end member **256**. The bottom face **259** of recess **258** is engageable with the bottom face **261** of the collar **254** of piston **252** to limit the movement of piston **252**, sleeve **240** and blades **236** with respect to sleeve **218**.

The piston actuating section of this embodiment of tester is similar to that previously described with reference to the embodiment shown in FIGS. **1** through **3** and includes a bolt **270** threaded into bore **260** in element **256** and a hand knob **272** fixed to the head of bolt **270** by bolts **274**. Hand knob **272** has an annular end face **276** engageable with the end of shoulder **273** between recess **258** and neck **257** of end member **256** to limit the movement of bolt **270** with respect to the

compression chamber section of the device. Hand knob **272** is also provided with an annular recess **271**, into which neck **257** of end member **256** is adapted to nest.

As described for the embodiment of FIGS. **1 – 3**, to reduce friction between the end of bolt **270** and piston **252**, piston **252** has a central cylindrical recess **278** in its end adjacent bolt **270** and two mating recesses **280** and **282** are formed respectively in recesses **278** of piston **252** and in the end of bolt **270**. A ball **284** of steel or the like material is engaged between recesses **280** and **282**. The recess **278** aids in the proper placement of ball **284** as will hereinafter become apparent.

The pressure sensor and indicator section **212** of this embodiment of tester is similar to the pressure sensor and indicator section **12** of the embodiment of tester illustrated in FIGS. **1** through **3**. Section **212** includes a main cylindrical member **290** having a threaded recess **292** in the lower end thereof, a recess **294** in the upper end thereof, and a bore **296** extending through the web **295** between recesses **292** and **294**. In this embodiment, a diaphragm **300** extends across the end of recess **292** and has an enlarged and thickened annular edge **302** which engages an O-ring seal **304** in an annular channel **305** in the end of recess **292** to seal the diaphragm **300** peripherally to the end of the recess **292**. The enlarged edge **302** also ensures that the central portion of the diaphragm **300** is spaced from the end of recess **292** so as to provide a sealed chamber **306** which is filled with hydraulic fluid **308** or the like.

To retain diaphragm **300** in position, an externally threaded annular collar **310** is threaded into recess **292** into face-to-face engagement with diaphragm **300**.

As with the previously described embodiment, the bore **296** has a threaded counterbore **293** to receive a coupling sleeve **323** of a pressure gauge **324** which also includes a gauge actuating element **326**, an indicating needle **328** and a circular scale **330**. The end of recess **292** is closed by a closure plate **354** held in place by an annular element **352** threaded onto member **290**. No timer has been shown as incorporated into this embodiment of tester although this may be done.

The operation of this embodiment of tester will now be described with particular reference to FIGS. **4** and **5**.

Initially, the end member **256** is removed from sleeve **218** by unscrewing, the piston **252** is removed and sleeve **240** is retracted to the position shown in FIG. **4**. Retraction of sleeve **240** also retracts blades **236** as these blades are attached to the sleeve. It will be noted that, with the apparatus in this condition, the ends of blades **236** are positioned at a point represented by line **221** intermediate the end of plug **244** and end face **220** of sleeve **218** and the ends of blades **230** are at a point represented by broken line **219** intermediate the end of sleeve **240** and the end face **222** of sleeve **218**. If desired, the blades may be provided with appropriate marks to indicate when the parts are properly aligned. The tester is then inverted and the chamber **237** then filled, through the bore through sleeve **240** resulting from the removal of piston **252**, with particulate material to be tested up to the level of the inner end face **253** of sleeve **240**.

Piston **252** is then reinserted in sleeve **240**, ball **284** is placed in recess **278** which thereby facilitates its location in recess **280**, and end element **256** is threaded onto sleeve **218**. Bolt **270** has, of course, been previously threaded out of element **256** prior to reassembling element **256** and sleeve **218**.

In this embodiment of apparatus, the end element **256** forms the "zero" adjustment mechanism of the tester. As element **256** is threaded onto sleeve **218**, it engages piston **252** to move piston **252**, sleeve **240** and blades **236** towards end face **220** of sleeve **218** and thus reduces the volume of the variable volume compression chamber **237** until a "zero" reading is achieved on pressure gauge **324**.

It will be noted that the smaller diameter part **248** of plug **244** is sufficiently long to engage diaphragm **300** and yet leave a small spacing between the end face **234** of sleeve **232** and shoulder **250** of plug **244**, so that plug **244**, in effect, "floats" between the sample in the variable volume compression chamber **237** and the diaphragm **300**.

To compress the sample, hand knob **272** is rotated to thread bolt **270** into engagement with piston **252** and thus force piston **252**, sleeve **240** along sleeve **218** towards its end face **220** while at the same time urging blades **236** between blades **230** in intersliding relation. When annular face **276** of hand knob **272** engages shoulder **273** of end member **256**, the compression has been completed. The pressure generated by the sample is then transmitted through "floating" plug **244**, diaphragm **300** and hydraulic fluid **308** to pressure gauge **324** so as to indicate the compressibility or the moisture content of the compressed sample.

The relative movement between the interleaved blades **230** and **236** greatly minimizes and even essentially eliminates friction between the particulate material being compressed and the wall **238** of the variable volume cylinder **237** so that the compression of the sample is substantially uniform.

A cross-sectional view of a modified embodiment is illustrated in FIG. **7**. In one modification of this latter embodiment of tester, the blades **230** are not integral with the sleeve **218** but are connected to a sleeve and annular plate arrangement similar to sleeve **240** and annular plate **242**.

In yet another embodiment, illustrated in FIG. **8**, blades **230** and **236** are replaced by cylindrical rods (i.e. **230***a*, 236*a*) which interleave to form the peripheral wall of the compression chamber **237**. The rods **236***a* are secured to an annular ring **241***a* for movement independently of sleeve **218***a*. Similarly, the rods **236***a* are secured to another annular ring (not shown) also for movement independently of sleeve **218***a*.

It will be noted that the length-to-diameter ratio of the compression chamber **237** defined by cylindrical peripheral walls **238**, end plug **244** and piston **252** is fairly large and thus, when zeroing the gauge **324** by movement of member **256** and thereby piston **252**, the change in the length of the chamber results in a very small percentage change in the chamber volume. Additionally, the movement of plug **244** at the opposite end of the chamber **237** reduces this percentage with the result being that the initial volume of the sample in uncompressed state is maintained at a substantially constant initial volume during zeroing of the gauge.

In both of the above-described embodiments, an hydraulic fluid chamber is operatively associated with a plug provided within the compression chamber to generate a fluid balancing the pressure generated by the compressed material on the plug. These chambers therefore act as transducers operatively associated with

the plugs to provide pressure signals representative of the pressure generated by the material within the associated compression chamber. Alternative forms of transducers may, however, be incorporated in these testers, such as, for example, piezo-electric crystals and the like. Regardless of the type of transducer incorporated in the tester, the following criteria must be met: (1) the forces exerted by the compressed material on the plugs must be resisted such that only small displacements of the plugs are permitted regardless of the magnitude of the pressure within the compression chamber; and (2) the transducers must be operatively associated with the plugs to provide a signal indicative of the pressure within the compression chamber.

In the described embodiments, the pressure indicator has been shown and described as a pressure gauge connected to the hydraulic fluid chamber. In the case that another form of transducer is incorporated in the tester, another form of gauge must also be incorporated such as, for example, an electric gauge where piezo-electric cystals are used as transducers.

I claim:

1. An apparatus for determining the moisture content of particulate material by compressing said particulate material said apparatus comprising: (a) a substantially closed variable volume compression chamber; (b) a hollow piston slidable in said chamber, the interior of said piston including a substantially concave face and comprising a plurality of telescopically interengageable hollow piston elements relatively movable with respect to one another, whereby the interior of said hollow piston provides a generally frusto-conical compression chamber, and whereby the volume of said generally frusto-conical chamber may be varied; (c) a plug disposed movably therein to provide a wall of said generally frusto-conical chamber facing said concave piston face and movable towards and away from said concave piston face; (d) piston actuating means for moving said piston elements relative to one another, thereby to vary the volume of said generally frusto-conical chamber, said piston actuating means comprising means for sequentially moving said piston elements relative to one another; and (e) a transducer means operatively associated with said plug to resist movement of said plug in response to a pressure generated within said compression chamber, and to provide a signal indicative of a pressure generated within said compression chamber, said signal being indicative of the moisture content of said particulate material.

2. An apparatus for determining the moisture content of particulate material by compressing said particulate material, said apparatus comprising: (a) a substantially enclosed variable volume chamber having first and second longitudinally spaced-apart ends; (b) a peripheral wall extending between said ends, said peripheral wall forming a piston including a plurality of members movably interengageable with one another, and including a substantially cylindrical sleeve, provided on its inner face with a plurality of longitudinally extending peripherally spaced apart slots, directed radially outwardly, and a plurality of longitudinal, peripherally spaced apart, radially outwardly extending blades, the blades being intermeshed with the slots and being interslidably longitudinally movable with respect to the slots; (c) said piston, closing said first end of said chamber, and movable towards and away from said second end of said chamber and engageable with said blades for movement of said blades with said piston in movement of said piston towards said second end of said chamber; (d) piston actuating means for moving said piston towards said second end of said chamber; (e) a plug, disposed movably in said chamber, thereby closing said second end of said chamber and (f) pressure sensor means including a transducer operatively associated with said plug to resist movement of said plug in response to a pressure generated within said compression chamber, and to provide a signal indicative of pressure generated within said chamber, said signal being indicative of the moisture content of said particulate material.

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