

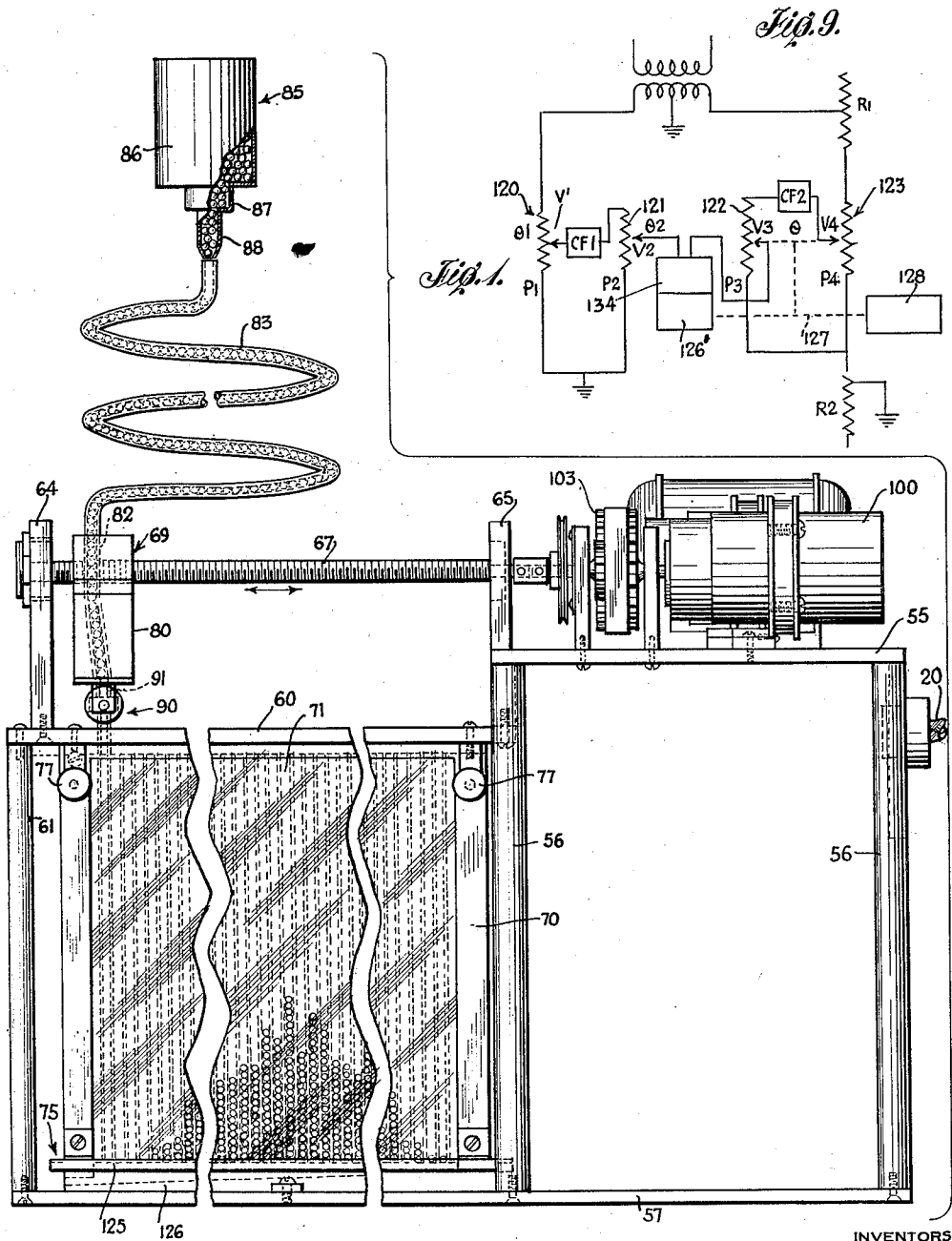
Jan. 9, 1951

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HISTOGRAM COMPUTER

2,537,628

Filed Sept. 4, 1947

3 Sheets-Sheet 1



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3 Sheets-Sheet 2

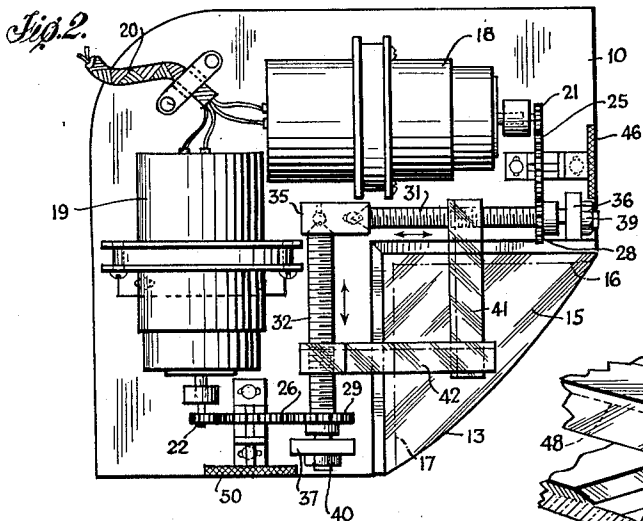


Fig. 3.

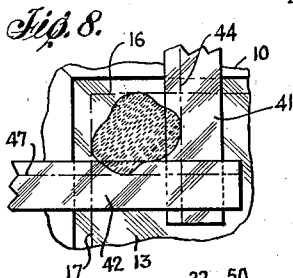
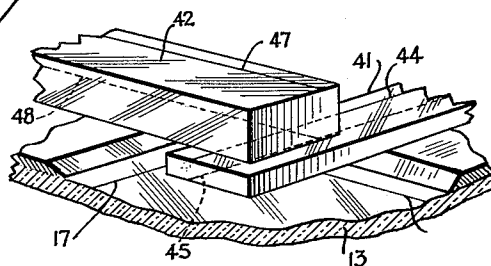


Fig. 4.

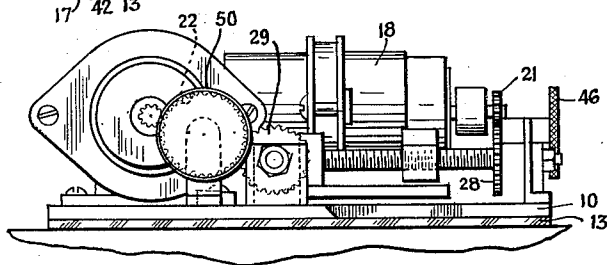


Fig. 11.

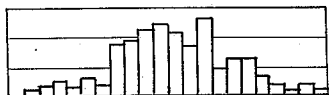
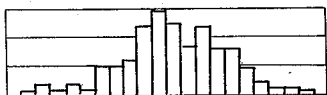
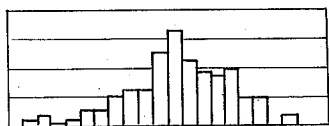
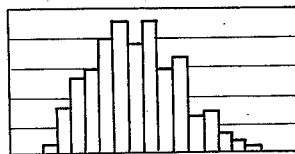
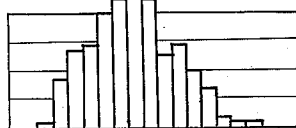
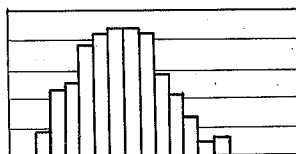


Fig. 10.

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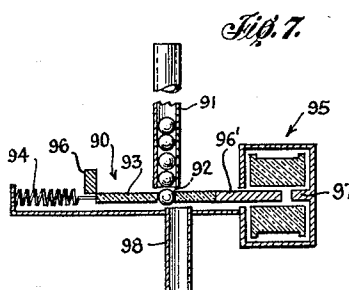
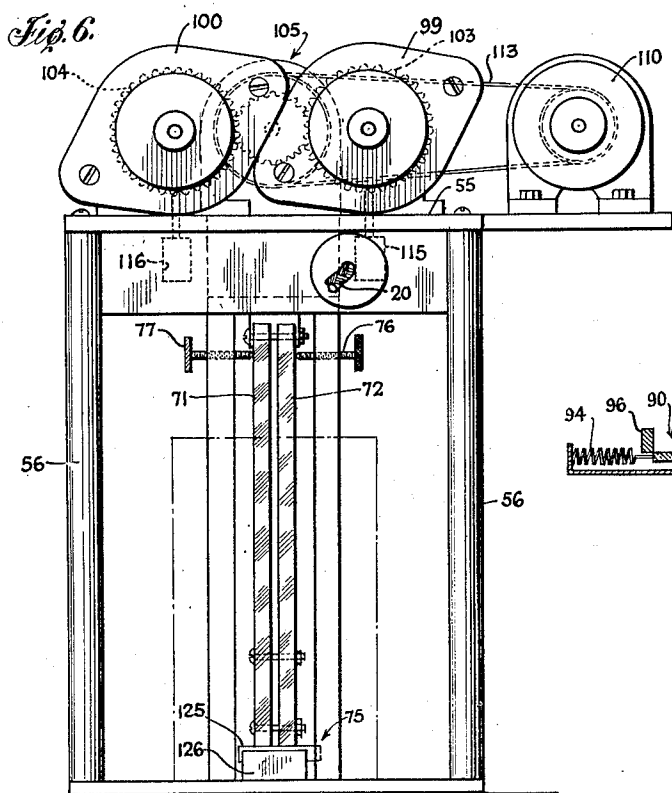
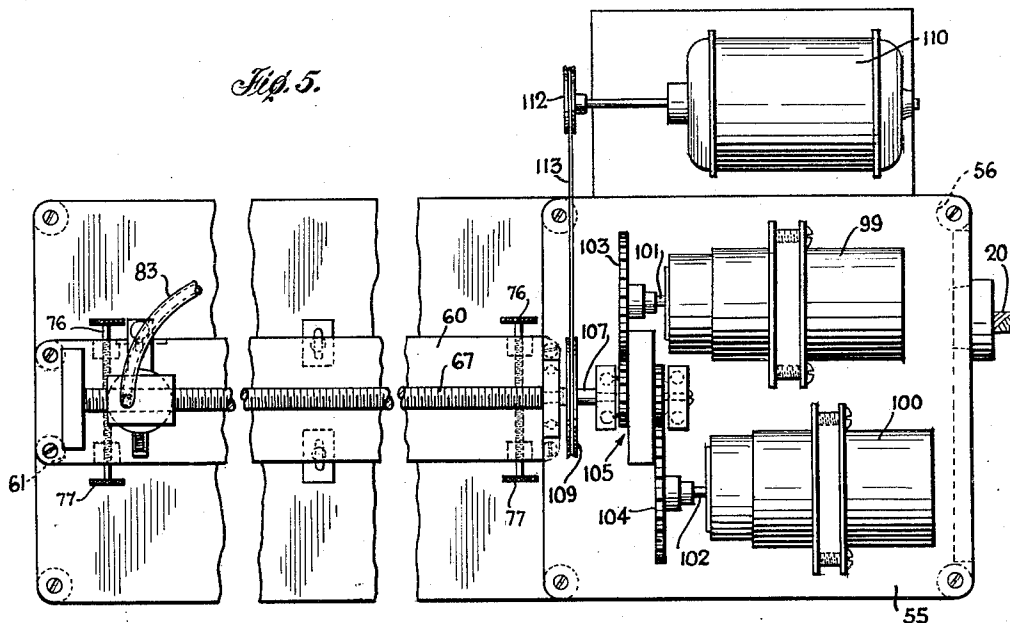
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HISTOGRAM COMPUTER

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3 Sheets-Sheet 3



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2,537,628

HISTOGRAM COMPUTER

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Application September 4, 1947, Serial No. 772,126

17 Claims. (Cl. 35-24)

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This invention relates to an improved method of constructing particle diameter histograms and to apparatus for practicing said method.

An important object of the invention is the provision of an improved method of constructing particle size histograms.

Another important object of the invention resides in the provision of apparatus by use of which an operator may substantially shorten the time required to construct particle size histograms, for example, a histogram of a multiplicity of particle diameters taken from an electron micrograph.

In certain studies of the polymerization of synthetic rubbers, it is desirable to obtain particle diameter distribution curves or histograms for the rubber latices. Such diameter histograms may be obtained from electron microscope photographs of the latex particles. The construction of particle diameter histograms has heretofore been a tedious and time-consuming procedure wherein the "longest" and "shortest" diameters of the projected image, or a photographic enlargement thereof, of a particle are measured with a rule, their arithmetic mean computed, and the number of particles with mean diameters in pre-selected diameter intervals plotted against the diameters. Multiplication by a scale factor, containing the reciprocal of the magnification, converts the diameter axis of the histogram to read directly in angstrom units.

The present invention has resulted in a substantial reduction in the time and labor required in the construction of such histograms.

Other objects and advantages will become apparent to persons skilled in the art upon examination of the drawings, the specification and the claims appended thereto.

In the drawings:

Fig. 1 is an elevational view of recording apparatus of the histogram computer described herein;

Fig. 2 is a plan view of the scanning mechanism of the present invention;

Fig. 3 is a perspective view, in enlarged fragmentary detail, of the particle outlining apparatus of Fig. 2;

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Fig. 4 is an elevational view of the scanning device of Fig. 2;

Fig. 5 is a plan view of the apparatus of Fig. 1;

Fig. 6 is a side elevation of the apparatus of Figs. 1 and 5;

Fig. 7 is a detailed sectional view of a ball release mechanism;

Fig. 8 is an enlarged detail showing a particle bracketed in the manner described herein;

Fig. 9 is a schematic diagram of an electronic histogram computer employing servo-motor control;

Fig. 10 shows three experimental particle size histograms; and

Fig. 11 shows another series of three experimental particle size histograms.

In the development of the histogram computer herein described, consideration was given to the question of whether the arithmetic or the geometric mean or some other function of the "longest" or "shortest" diameters of particles should be plotted. The device was constructed with special reference to the use thereof in computing the mean diameter of latex particles; however, it has broad application in respect to the other studies. References made herein to latex are for the purpose of explanation rather than limitation. With unbroken film in an electron microscope, latex particles usually appear approximately spherical in shape. However, when the film surface tears, which frequently is the case, the particle contours may be elliptical due to film distortion. Under the latter condition, the problem is to compute the diameter of the equivalent spherical particle having either the same volume, or the same surface area as the actual ellipsoidal particle. These two cases require calculation of different functions of the major and minor axes. The particles may be either prolate or oblate, or some shape in between, and there is no way to determine what volumetric shape a particle has short of some time-consuming process such as taking stereo-photographs. A comparison between the diameters of the volume-equivalent and the surface-equivalent spheres, and the arithmetic and geometric mean diameters of both prolate and oblate spheroids is given in the following tables.

Prolate spheroid

Ratio, a/b	Arith. Mean $\frac{a+b}{2}$	Geom. Mean $(ab)^{1/2}$	Difference, Percent	D_v	Percent Error		D_s	Percent Error	
					Arith. Mean	Geom. Mean		Arith. Mean	Geom. Mean
1.0	b	b	0.0	b	0.0	0.0	b	0.0	0.0
1.5	1.25 b	1.225 b	1.0	1.145 b	9.2	7.0	1.165 b	7.8	5.6
2.0	1.50 b	1.414 b	2.9	1.280 b	19	12.2	1.316 b	14	7.9
2.5	1.75 b	1.58 b	5.1	1.357 b	29	16	1.445 b	22	9.7

a = Major axis.

b = Minor axis.

D_v = Diameter of sphere of equal volume.

D_s = Diameter of sphere of equal surface.

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Oblate spheroid

Ratio, <i>a/b</i>	<i>D_v</i>	Percent Error		<i>D_s</i>	Percent Error	
		Arith. Mean	Geom. Mean		Arith. Mean	Geom. Mean
1.0	<i>b</i>	0.0	0.0	<i>b</i>	0.0	0.0
1.5	1.31 <i>b</i>	-4.6	-6.5	1.33 <i>b</i>	-6.0	-7.9
2.0	1.587 <i>b</i>	-5.5	-11	1.66 <i>b</i>	-9.6	-15
2.5	1.842 <i>b</i>	-5.0	-14	1.99 <i>b</i>	-12	-21

a=Major axis.
b=Minor axis.
D_v=Diameter of sphere of equal volume.
D_s=Diameter of sphere of equal surface.

In some cases the geometric mean is the closer approximation, and in others the arithmetic mean is the closer. The apparatus illustrated and described is designed, for the purpose of simplicity, to give the arithmetic mean and in general the measurements should be restricted to particles having a major to minor axis ratio of less than two.

The apparatus comprises generally a scanning mechanism, Figs. 2 to 4, and a recording mechanism, Figs. 1, 5 and 6 cooperatively associated with the scanning mechanism in a manner to log the arithmetic average of two diameters of particles measured by use of the scanning mechanism.

As best shown in Fig. 2, the scanning mechanism includes a base plate 10, preferably metal, having a right angle section removed from the lower right hand corner thereof, as viewed, to permit bracketing of particles as hereinafter described. Base plate 10 is in turn supported on a glass or Lucite sub-base plate 13 substantially coextensive with base plate 10, except that plate 13 extends partially over the area defined by said removed section. A window 15 is thus formed to permit the computer to be placed on a photograph of particles to be measured with the particle to be measured visible through said window. A pair of perpendicularly disposed lines 16 and 17 are etched on the under surface of transparent window 15, lines 16 and 17 as shown being in parallel spaced relation to the margins of plate 10 defining the window.

Mounted on base plate 10 are Selsyn motors 18 and 19, the motors being positioned in 90° angularity as shown. Motors 18 and 19 are not electrically connected together to operate in synchronization, each motor being connected, through conduit 20, to a remote and operatively associated motor, later described. The armature shafts of motors 18 and 19 are provided with drive gears 21 and 22 respectively, said gears meshing with idler gears 25 and 26, which in turn engage driven gears 28 and 29, the latter gears being in fixed relation to rotatively mounted threaded shafts 31 and 32. Shafts 31 and 32 are mounted in 90° angularity as viewed in Fig. 2, the axes of the shafts being parallel to the axes of each associated Selsyn motor. The shafts have one end journaled in bearing block 35 and their opposite ends in journaled relation with mounting brackets 36 and 37; axial adjustment of the shafts being permitted by adjustment of lock nuts 39 and 40. A pair of scanning bars 41 and 42 have end portions threadedly engaged with shafts 31 and 32 respectively, the bars being constricted to movement in a horizontal plane by suitable means, such as non-rotating nuts, not shown. Operation of either Selsyn motor results in rota-

tion of the associated shaft driven thereby through the interconnecting gear train. The mounting shafts of idler gears 25 and 26 are provided with knurled knobs 46 and 50 to permit these gears to be manually rotated to effect linear displacement of scanning bars 41 and 42 through a horizontal plane. As best shown in Fig. 3, scanning bars 41 and 42 have lines scribed on the upper and lower surfaces thereof. Bar 41 is provided with lines 44 and 45 and bar 42 with lines 47 and 48 respectively, each set of lines being disposed in a vertical plane with respect to the horizontal plane of the bar. The sets of vertically disposed lines serve to prevent parallax during operation of the device, as later described.

Operation of the scanning mechanism is as follows. The window portion of the mechanism is placed over a photographic enlargement or other document containing particles, the major and minor axes of which are to be measured for a histographic record. Particles are normally measured in a manner to cover a certain area, each particle being crossed out after being bracketed. The scanning mechanism is moved in respect to each particle to be measured in a manner to frame the particle with lines 16 and 17 in vertical marginal alignment therewith. For example, if the particle to be measured is of circular configuration, lines 16 and 17 will cross the circumference thereof at points at 90° relation to the center of the circle. Bars 41 and 42 are then moved, either manually through movement of knurled knobs 46 and 50 or by driving Selsyn motors 18 and 19, as later described. The bars are moved into marginal registry with the particle being scanned as the operator aligns the particle with the scribed scanning lines from a vertical position. Since scanning bar movement is necessarily accompanied by movement of the Selsyn motor armatures, the extent of bar movement can in this manner be translated to a remote point through electrical connection of each motor 18 and 19 to an associated motor, rotation of each associated motor being identical to rotation of drive motors 18 and 19.

Referring to Figs. 1, 5 and 6, a recording unit includes motor and reduction gearing apparatus mounted on an elevated platform 55 supported by vertical posts 56 in turn supported on base plate 57. An elevated platform 60 extends from the left hand side of the structure of platform 55 as viewed in Figs. 1 and 5, to be suitably supported at one end by said structure and at the opposite end by posts 61, which in turn find their support on base plate 57. A pair of upstanding brackets 64 and 65 are mounted on platform 60 and 55 respectively to provide support for an elongated screw element 67, the screw element being longitudinally and transversely aligned in

respect to platform 60 and retained in journaled engagement with brackets 64 and 65. A ball dispensing mechanism, generically designated 69, threadedly engages screw element 67 to be supported thereby and operated in a manner later described.

A ball receiving unit 70 is positioned directly below and in alignment with the path defined by the ball dispensing mechanism 69 in its movement along screw element 67. Unit 70, as shown in Figs. 1 and 6, comprises a pair of identical plates 71 and 72 of transparent material such as Lucite, between which a plurality of thin shims are vertically disposed in mutual parallel spaced relation to define multiple ball receiving wells. In the device shown, unit 70 includes 80 such wells, only a portion of which are illustrated. Unit 70 is suitably positioned on a base member 75 and is adjustable in respect to a vertical plane by means of two pairs of laterally positioned thumb screws 76 and 77 disposed at each upper end of the unit.

Returning to the ball dispensing mechanism, a member 80 is provided adjacent one end thereof with a transverse bore threaded complementary to screw 67 from which member 80 depends. The lower end of a coiled metallic tube 83 extends through a vertical bore 82 provided in member 80 and into a depending tube 91 supported thereby. Coiled tube 83 provides a magazine for the storage of a large number of steel balls. The coil is periodically filled by means of a refilling device 85 consisting of an open ended cylinder 86, the bottom end of which leads into a pair of progressively reduced and interconnected cylindrical portions 87 and 88, portion 88 terminating in a nozzle receivable in tube 93 to permit the passage of a single ball therethrough. Refilling unit 85 is attached to tube 83 only during refilling operations and is removed therefrom prior to operation of the computer. Tube 83 is carefully selected as to diameter, being slightly larger than the balls used and the interior thereof may be given an acid bath to insure a smooth surface to promote the passage of the balls therethrough.

Referring to Fig. 7, vertically disposed tube 91, receivable in the lower end of bore 82, feeds individual balls into a suitable aperture 92 provided in a horizontally disposed plate 93, slidably mounted for movement in one direction under the urge of spring 94 and in an opposite direction by the pull of solenoid 95. A suitable stop 96 is provided to position plate 93 in a ball receiving position as shown, under tension of spring 94 with solenoid 95 non-energized. Upon energization of solenoid 95, armature 96¹, to which plate 93 is attached, is drawn against housing block 97 to position the plate aperture 92 in vertical alignment with a feed spout 98 to allow a single ball to be discharged there-through and into one of the vertical channels of unit 90, as governed by the position of dispensing mechanism 69 at the time of ball release.

As best shown in Figs. 5 and 6, platform 55 provides support for Selsyn motors 99 and 100. Armature shafts 101 and 102 carry fixedly mounted gears 103 and 104. A differential mechanism 105 of a known type is disposed intermediate gears 103 and 104 in meshed engagement therewith. Mechanism 105 includes a driven shaft 107 directly coupled to the screw element 67 in a suitable manner. A pulley 109 is mount-

ed on shaft 107 in keyed relation thereto, to be driven by a conventional motor 110 mounted laterally of platform 55, through pulley 112 and belt 113. Motors 99 and 100 are electrically connected, through a suitable conduit 20 to motors 18 and 19 respectively. Thus motors 18 and 99 operate as a Selsyn motor unit and rotation of the armature of one motor, either manually or electrically, results in a like degree of rotation of the companion motor, as is well known in the art. In the same manner, motors 19 and 100 function as a unit. Differential mechanism 105 is of the additive type whereby the rotations of armature shafts 101 and 102, in the same driven direction, result in rotation of drive shaft 107, and hence screw element 67, an amount proportional to the sum of the rotation of armatures 101 and 102. The translating mechanism in the specific apparatus described is designed to give a step-up ratio or amplification factor of 18 from the scanning to the recording unit.

In the device illustrated, $\frac{3}{32}$ " steel balls were supplied to a magazine of $\frac{1}{8}$ " inside diameter. The recorder compartment unit 70 was constructed by bolting together two pieces of Lucite 71 and 72, measuring 6" x 11" x $\frac{1}{4}$ " against .096" thick spacers. Strips of .010" thick shim stock were inserted into grooves accurately milled into the inner surfaces of plates 71 and 72 on $\frac{1}{8}$ " centers. A U-shaped metal plate 125 slides over a box-like elongated receptacle 126 to form a bottom closure for the vertical channels of unit 70. The balls may be easily removed from the unit by sliding plate 125 from box 126 to allow the balls to fall into box 126, which may then be removed and emptied.

Operation of the device is as follows. A particle count can of course be made either from a photographic enlargement or directly from an image of the electron micrograph plate projected at a desired magnification on a ground glass screen. The scanning unit is first set at the zero position with the scribed lines of elements 41 and 42 directly over scribed window lines 17 and 18 respectively. The ball dispensing unit 67 is set at the zero or extreme left hand position, Fig. 1, of recorder unit 70. The compartmentized unit 70 is longitudinally shifted until the balls fall equally often on both sides of the chosen zero wall. With a translating mechanism magnification of 18, a total magnification of 35,300 diameters is required to give a value of 50 angstroms to each $\frac{1}{8}$ " wide compartment interval as employed herein. Other values may of course be given the compartment interval by suitable choice of gearing and total magnification of the electron micrograph.

The scanning unit is next positioned successively on the particles to be measured, with each such particle bracketed by the scribed lines as shown in Fig. 8. As each particle in turn is thus bracketed, dispensing unit 67 is moved, by the combined rotation of the Selsyn motors, to a position determined by the axes of the particle, and a ball release switch, not shown, is manually closed to actuate the release mechanism 90 of Fig. 7 to release a ball. Bracketing may be done by hand through manual manipulation of knurled knobs 46 and 50, or the process may be speeded up by use of a conventional reversible motor 110, preferably controlled through a conveniently located micro-switch, not shown, in conjunction with means diagrammatically illus-

trated at 115 and 116 for the positive and selective braking of either Selsyn motor 99 or 100. Since motor 110 is connected to drive the output shaft 107 of differential mechanism 105, it is apparent that with either motor held fast, the other motor may be driven any desirable amount and that the rotation thereof will be accompanied by a like rotation of the companion Selsyn motor forming a part of the scanning unit. Since this principle may be advantageously employed to speed up the process of bracketing particles, the solenoid operated braking mechanisms 115 and 116 are positioned below armature gears 103 and 104 and are electrically controllable by means of a double throw switch located adjacent the micro-switch which controls motor 110 to provide readily accessible means for locking either motor 99 or 101 and driving its companion motor and associated bracketing bar.

While the above described apparatus includes mechanical means (Selsyn motor drive) for the purpose of translating the added values of two diameters of a measured particle as a magnified linear function, the invention is not limited to the precise apparatus illustrated in Figs. 1 through 8, since other means of accomplishing the objects of the invention will become apparent to persons skilled in the art. Fig. 9 illustrates schematically electrical apparatus for accomplishing the same objects by the employment of electrical control mechanism in place of Selsyn motors.

Referring to Fig. 9, potentiometers 120 and 121, of the rotative type, have resistances linear with their respective angles of rotation, θ_1 and θ_2 , to the desired degree of accuracy. Mechanism operative on the general principles of the computing device above described, but with potentiometers replacing the Selsyn motors, may be employed to obtain settings of potentiometers 120 and 121 which reflect the relative settings of associated scribed scanning bars not shown. Potentiometers 120 and 121 are thus set proportional to the major and minor axes of the measured particle. Similar potentiometers 122 and 123 are mechanically interconnected in a manner that their angles of rotation remain always equal to a single angle which is determined by the position of a servo-motor 125¹. Motor 125¹ may for example be a squirrel-cage two-phase type of low inertia and suitable power requirements, as for example the Diehl F-49-7, 115 v., 60 C. P. S. motor manufactured by Diehl Manufacturing Company, Somerville, New Jersey, and having a rated power output of 22 mechanical watts at 2200 R. P. M. Optimum motor rating will of course vary with the type of potentiometer to be driven. Servo-motor 126 is connected, as illustrated by dotted line 127, to a ball dispensing recorder 128. The recorder illustrated in Figs. 1, 5 and 6, minus the Selsyn motors and the differential mechanism, may be employed at 128. The two voltages V_2 and V_3 , applied to the sum amplifier 134, will always differ 180° in phase, hence when their magnitudes are equal, the output of sum amplifier 134 will be zero. Sum amplifier 134 may for example be a simple current amplifier with the potentials of V_2 and V_3 fed to the grid of the input tube in a manner whereby the potential of that grid is equal to, excepting possible D. C. bias, the sum of potentials V_2 and V_3 . Amplifier 134 may thus be an ordinary current amplifier with only the above-mentioned method of introducing the two voltages V_2 and V_3 dignifying it as a sum amplifier.

The output of amplifier 134 may be coupled through a suitable transformer to one coil of a two-phase motor having a second coil which is maintained in 90° out-of-phase relation to the first coil to introduce reversibility in response to a change of phase in the transformer excited by amplifier 134. An example of such an amplifier is given on page 219 of a pamphlet entitled "Electronics for Industry" by W. L. Bendz, published by John Wiley & Sons Inc., London. The direction of rotation of servo-motor 126¹, when voltages V_2 and V_3 are not equal, will depend on which voltage is the greater.

Cathode follower circuits are identified as CF1 and CF2, giving an extremely constant amplification of less than unity. Cathode followers CF1 and CF2 are of a known type, commonly employed for impedance matching, as for example the type shown on page 157 of "Reference Data for Radio Engineers," second edition, published by Federal Telephone and Radio Corp., February 1947, or as shown on page 149 of "Electronic Transformers and Circuits" by R. Lee, published by John Wiley & Sons Inc., New York, in 1947. Setting $R_1=R_2=0$ for the moment, the following relation will exist.

$$V_2 = V_1 A c f_1 \theta_2 = V_1 A c f_1 k_2 D_2 \\ = k_1 D_1 C_1 V_0 A c f_1 k_2 D_2 \quad (1)$$

$$V_3 = V_4 A c f_2 \theta = A c f_2 \theta^2 C_4 V_0 \quad (2)$$

where $\theta_1 = k_1 D_1$; $\theta_2 = k_2 D_2$; voltage across $P_1 = C_1 V_0$; voltage across $P_4 = -C_4 V_0$

When the servo-motor has equalized V_3 and $-V_2$, and the recorder ball dispenser comes to rest, the following relation will exist:

$$A c f_2 \theta^2 C_4 V_0 = k_1 D_1 C_1 V_0 A c f_1 k_2 D_2 \\ \theta = \left(k_1 k_2 \frac{C_1}{C_4} \frac{A c f_1}{A c f_2} \right)^{\frac{1}{2}} (D_1 D_2)^{\frac{1}{2}} \quad (3)$$

Hence the position of the recorder ball dispenser is proportional to the geometric mean of the particle major and minor axes.

Since V_0 does not appear in Equation 3, line voltage regulation is unnecessary. Rheostat R_1 allows the increment of diameter for the histogram to be varied. The combination of R_1 and R_2 allows a shift of recorder zero for cases where no small particles are present.

To obtain a histogram of approximate surface areas, a switching arrangement feeds V_4 instead of V_3 to the sum amplifier, thus giving θ proportional to the product $D_1 D_2$.

To obtain a histogram of the arithmetic mean of particle diameters, a switching arrangement removes CF1 and CF2 from the circuit, connects the ungrounded ends of P_1 and P_2 , and feeds V_1 and V_2 separately, and V_4 instead of V_3 , to the sum amplifier (for this arrangement k_1 must equal k_2 , as would normally be the case).

To obtain a histogram of volumes, V_4 instead of V_3 is fed to the sum amplifier, P_3 is connected mechanically and electrically to P_2 in the same manner it was formerly connected to P_4 , and the series outputs of P_1 , P_2 , and P_3 , are fed to the sum amplifier. In the case of a prolate spheroid, θ_1 must be set proportional to the major axis; for an oblate spheroid, θ_1 must be set proportional to the minor axis. Obviously, only a small range of particle sizes can be covered in volume histograms as compared to diameter histograms.

Fig. 10 shows three successive histograms of an experimental GR-S type latex, each run being made from the same electron micrograph field. Fig. 11 includes three histograms of another ex-

perimental GR-S latex. All were constructed from the same electron micrograph field, and are therefore indicative of the reliability of the method and reproducibility of the instrument. In these measurements an interval of 100 angstrom units was chosen. Since the limit of resolution of the electron microscope was about 50 angstroms for the specimens used, it was concluded that the sharp variations between 50 angstrom intervals, shown in Fig. 1, were not significant.

What is claimed is:

1. Apparatus for obtaining particle size histograms comprising means for bracketing individual particles to obtain measurements of the major and minor axes thereof, means for translating the additive sum of the aggregate of said quantities into mechanical energy, and means for employing said mechanical energy for computing said sum.

2. A device of the character described having in combination, mechanical means for rapidly computing the major and minor axes of a particle, means associated with said computing means for generating an amount of mechanical energy proportional to the sum of said computed measurements, and means for employing said generated mechanical energy for recording the magnitude of said sum.

3. In a particle size computer, two pairs of Selsyn motors, means for electrically connecting each pair of said motors for synchronized translation of armature movement therebetween, means associated with one motor of each pair for the translation of linear movement to armature rotation, and means cooperatively associated with the other motors of each pair for adding the effect of the individual armature rotations of said first-mentioned motors, and means for utilizing said added effect for computing the magnitude thereof.

4. In a device of the character described, the sub-combination comprising a supporting member provided with a window, a pair of threaded elongated elements supported in a common plane in mutual right angular relation, a bar-like member mounted on each of said elongated elements in screw threaded engagement therewith for movement along right angularly disposed linear paths, said bar-like members having portions extending over said window, and Selsyn motor means for translating the linear displacement of each of said bar members to a single linear displacement at a position remote therefrom.

5. A particle size recorder having in combination a plurality of upwardly open vertically disposed and equally spaced chambers, means disposed above said chambers for storing a quantity of metallic balls, and means movable along a path aligned with said upwardly open chambers for individually receiving said balls from said storage means and dispensing them into said chambers.

6. A device of the character described having in combination, a scanning device including right angularly disposed fixed boundary lines and right angularly disposed movable boundary lines associated with said fixed boundary lines in a manner to define a rectangle, a motor means associated with each of said movable boundary lines for the translation of linear movement of said lines to rotation of said motor, means for translating said motor rotation to a point remote from said scanning device, means for adding, at said remote point, the combined angular rotation

effected by linear movement of both said movable boundary lines, and means for translating said added angular rotation back to linear displacement.

7. The device of claim 6, including means disposed at said remote point and operative in response to said linear movement resulting from said motor rotation whereby to permanently record the magnitude of any given added angular displacement.

8. The device of claim 6, including a recording device disposed at said remote point for cooperative association with said angular rotation translating means, said recording device comprising a multiplicity of uniformly spaced and linearly aligned article-receiving chambers, an article-dispensing device adapted for movement in a path aligned with said article-receiving chambers, said article-dispensing device being in cooperative association with said linear displacement means, and means for selectively dispensing individual articles into said chambers.

9. A device of the character described having in combination a pair of movable boundary line elements disposed in mutual right-angular relation, an electrical circuit including variable resistances for the control of voltage drop there-through, each of said movable boundary line elements associating with one of said resistances in a manner to effect voltage change in a part of said circuit in response to linear movement of either of said boundary line elements, a sum amplifier associated with said circuit for adding the voltage variation thus produced in said circuit, servo-motor means responsive to the output of said sum amplifier, and means associated with said servo-motor means for recording through said circuit, sum amplifier and servo-motor means, the added displacement of said boundary line elements.

10. In a device of the character described, the sub-combination comprising a plurality of linearly aligned ball-receiving chambers, a ball dispenser mounted above said chambers for movement in a path aligned therewith, said ball dispenser comprising a tubular ball magazine, a ball dispensing spout, and an electrically operable means disposed intermediate said magazine and said spout for the individual transfer of a single ball from the magazine to the spout.

11. The device in claim 10 in which said ball dispensing mechanism comprises an apertured element movable through a horizontal plane, spring means urging said element in one direction and solenoid means disposed diametrically opposite said spring means for movement of said apertured element against the urge of said spring upon magnetization of said solenoid, a tubular guide for feeding said balls from said magazine into the aperture of said element, and a tubular spout for the discharge of said balls from said aperture into one of said chambers, said tubular spout and said guide being in offset relation in respect to the plane of said apertured member and in 90° angularity thereto, whereby said apertured member alternates, under the urge of said spring, and the urge of said solenoid between a ball receiving and a ball dispensing position whereby to permit only single ball feed through said device in response to solenoid actuation.

12. A method of constructing particle size histograms consisting of individually framing a plurality of particles to obtain measurements of the major and minor axes thereof, translating the sum of said measurements into amplified linear

displacement, and utilizing said linear displacement to record the sum of said diameters.

13. A method of computing the arithmetic mean of the major and minor axes of particles for the purpose of constructing a particle size histogram, consisting of framing each particle in a rectangle formed by two fixed and two movable right angularly disposed straight edges, employing the relative positions of said movable edges in respect to their opposite fixed edges to effect linear displacement of a ball dispenser in a manner whereby the resulting position of said dispenser is a function of the sum of the major and minor particle axes thus framed, and causing said dispenser to release a ball to permanently record said position.

14. A ball receiving histogram computer comprising a pair of planiform elements of transparent material, each of said elements provided on one face thereof with a series of identical parallel grooves, and means maintaining said planiform elements in mutually spaced clamped engagement with the grooves of one element in registry with the grooves of the other element to form ball receiving chambers.

15. In a device of the character described, the combination with a pair of fixed straight edges disposed in right angular relation, a pair of movable straight edges disposed in right angular relation to complete a rectangle with said fixed straight edges, said last-mentioned straight edges being defined on members restricted to movement in linear paths in a manner to retain parallel and right angular relationship respectively with said fixed straight edges to permit selective adjustment of the area of said rectangle, and means associated with each member defining said movable straight edges for the translation at a point remote therefrom of displacement of said members along said linear paths, means for adding at said remote point the values of linear displacement of each said movable straight edge defining members, and mechanical means operative in response to said added value of linear displacement for permanently recording the magnitude thereof.

16. In a device of the character described, the combination with a pair of fixed straight edges disposed in mutual right angular relation, a pair of movable straight edges disposed in right angu-

lar relation to complete a rectangle with said fixed straight edges, said last-mentioned straight edges being restricted to movement in linear paths in a manner to retain parallel and right angular relationship respectively with said fixed straight edges to permit selective adjustment of the area of said rectangle, an electrical network including at least a pair of variable resistances and a source of energizing current connected in a manner to cause current flow through said resistances, means operatively associated between said movable straight edges and said variable resistances whereby linear movement of either straight edge results in a corresponding change in the value of its associated resistance, electrical means associated with said resistances for amplifying the sum of the potential drop across at least a portion of said resistance and means associated with said last-mentioned amplifying means for translating the sum of said potential values into linear mechanical displacement.

17. In a device of the character described, the sub-combination comprising a ball dispensing unit, means associated therewith to permit only single balls to be dispensed therefrom, and a magazine associated with said dispensing unit, said magazine comprising helically disposed tubing having an inside diameter slightly larger than the balls to be dispensed therefrom, and means for charging said magazine with a multiplicity of balls.

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