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Final Report

ELECTRONIC DROP ANALYZER

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The following figures are omitted from this copy of the report:

Fig. 13. Circuit diagram of linear amplifier and discriminator.

Fig. 14. Circuit diagram for counter.

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ABSTRACT

The electronic drop analyzer is described from the view of the fundamental factors entering into its design and construction. Detailed circuits are also given. The performance is described with emphasis on the limits. The means of extending these limits are also discussed.

OBJECTIVE

The research project was established to develop an analyzer for sprays which could overcome the tedium and expense of available precision methods and improve the precision of available rapid methods. A working model was built for delivery to the sponsor.

LIST OF FIGURES

The electronic drop analyzer is an instrument for the analysis of sprays or suspensions of particles ranging from 45 to 1800 microns in diameter. The instrument gives statistically accurate data on medium-flow sprays from which distribution curves can be obtained. The raw data consist of cumulative particle rates and the variations of distribution of particles with time. Our experience has indicated that most spray systems are very irregular in time distribution of particles.

The instrument was developed to replace or augment the more tedious photographic[1] and coated-slide techniques of spray analysis. The data collected on this instrument in a few hours time are equivalent to the results of weeks of sampling and counting by earlier methods.

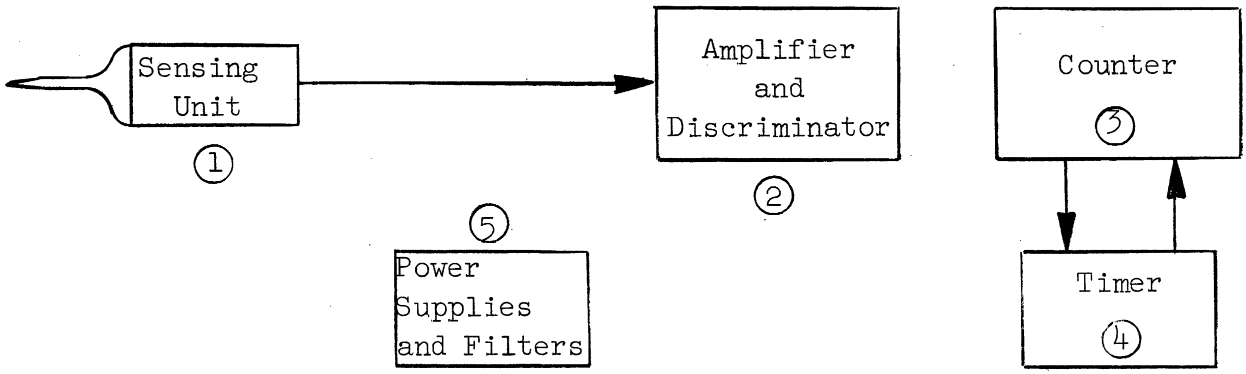

Fig. 1. Block diagram of electronic drop analyzer.
(each block corresponds to one chassis)

Figure 1 is a block diagram of the electronic drop analyzer. The sensing unit is inserted into the spray and connected by a shielded cable to the remaining components mounted in a portable rack. The signal is fed to the amplifier and discriminator. The discriminator rejects all pulse signals smaller than a set size and converts all larger pulses into uniform pulses which are passed on to the counter or scaler, which counts them. By changing manually the setting on the discriminator, a series of cumulative counts will be obtained, each count being the number of pulses (or drops) larger than the setting. The timer records the time necessary for the scaler to count the indicated number of pulses.

A detailed Operations Manual for the unit was issued separately as an Appendix and is still satisfactory, except for the calibration curves. For this information, substitute Fig. 16 of this report.

PRINCIPLE OF OPERATION

The operating principle of the drop analyzer is based on two fundamental concepts:

First: An energy change occurs when an electrical conductor makes contact with another conductor at a different potential.
Second: The magnitude of the energy change is a function of the size of each conductor.

The heart of the drop analyzer is a charged conductor (the sensing element) introduced into the spray where drops (the other conductor) can strike the element. The resulting energy changes create an electrical imbalance in the sensing-element charging circuit, which in turn results in a measurable pulse. The magnitude of this pulse can be determined experimentally as a function of drop size.

The sensing element inserted into the spray is charged to some predetermined voltage (1000 volts above ground is now being used) and the material being sprayed is grounded at the nozzle. The drops move toward the sensing element, with some striking directly, some stiking obliquely, and some passing by at various distances. The sensing element is attached to a constant-potential source and loses little or no potential during the time of approach, as shown in Fig. 2.

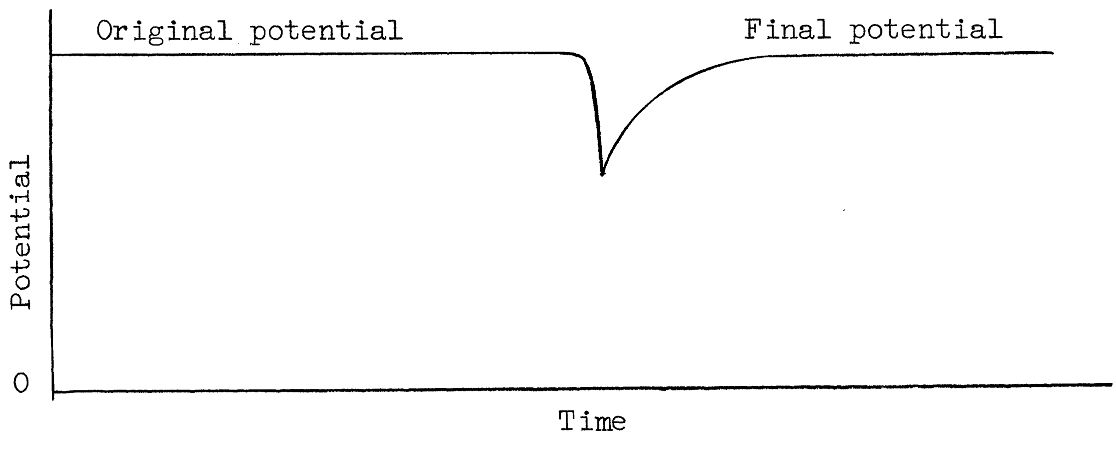

Fig. 2. Change in potential of sensing element when neutral drop strikes element attached to a potential source.

At the time of contact, a large change in potential occurs almost instantaneously as the charge is redistributed, but restoration of the original potential begins immediately. The potential is restored in approximately 10 to 15 microseconds for the circuits now in the analyzer.

This signal goes to the amplifier where it is modified by loss of the low-frequency components, to the shape shown in Fig. 3. The magnitude of the pulse is a function of the size of the sphere and of the magnitude and shape of the electric field around the sensing element.

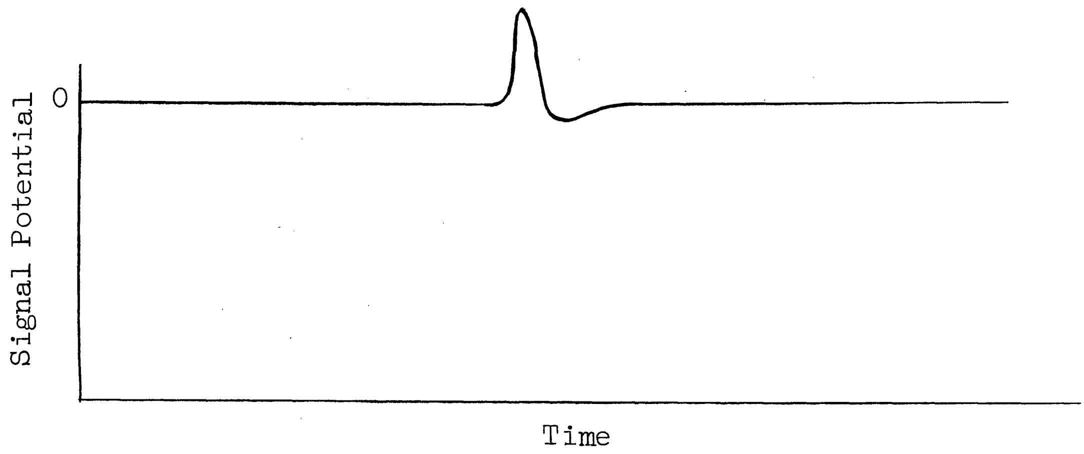

Fig. 3. Signal from amplifier to discriminator.

As the drop moves through the electric field surrounding the charged sensing element, an energy change occurs in a manner similar to that resulting from the motion of any conductor through an electric field. The change in potential of the sensing element when a drop misses by a small distance is shown in Fig. 4. The decrease in potential is quite small and of very low frequency. The amplifier filters out such a change and sends no signal to the discriminator.

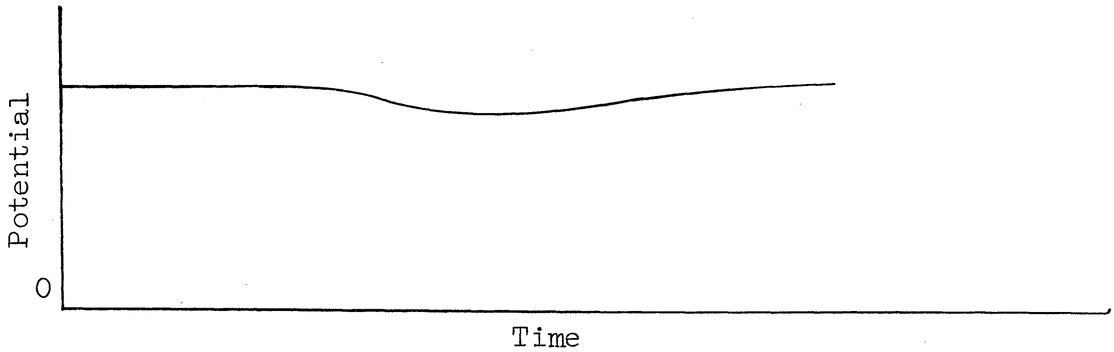

Fig. 4. Change in potential of sensing element caused by drop missing by a small distance.

SENSING UNIT

The sensing unit is the heart of the instrument. It is basically a spherical sensing element connected to a high-voltage source and to the grid of a cathode-follower-type amplifier. The sensing element and cathode follower are contained in the housing shown in Fig. 5. The circuit of the sensing unit is shown in Fig. 9.

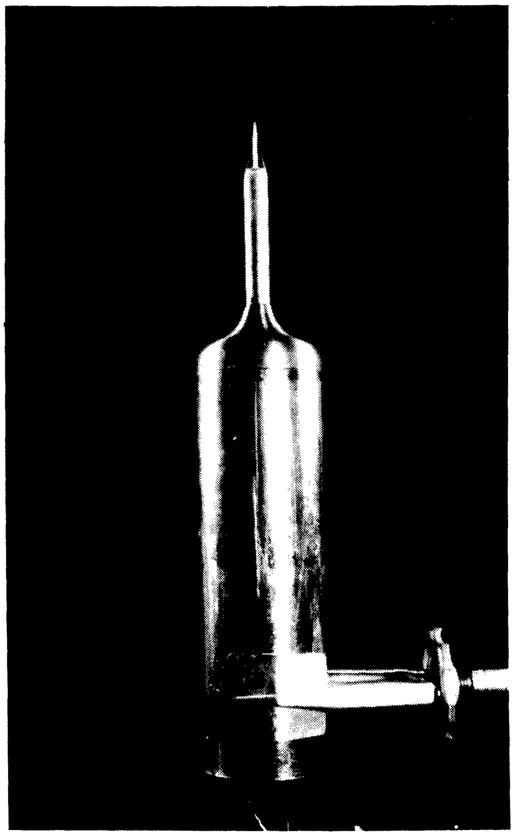

Fig. 5. Sensing Unit.

PHYSICAL-DESIGN CONSIDERATIONS

The results of early experiments clearly showed that some degree of uniformity in the electric field is necessary for proper operation of the instrument. The intercepting area of the sensing element must also be small to keep the number of particles counted within the counting-rate limitations. These two requirements are best satisfied by the field surrounding an isolated charged sphere, as in Fig. 6.

There are practical limitations, however, to reducing the physical size of the sphere. First, it is difficult to make small metallic spheres with the precision needed for a uniform field. Second, spheres which approach the drop size result in large variations in effective collecting area for different drop sizes. Third, the sphere must be connected to the amplifier and high-voltage charging source. This connector modifies the field to the form in Fig. 7. This figure shows that the field remains uniform above the line AA. Uniformity in the active area will then be satisfied if an insulator covers the sphere and conductor below line AA.

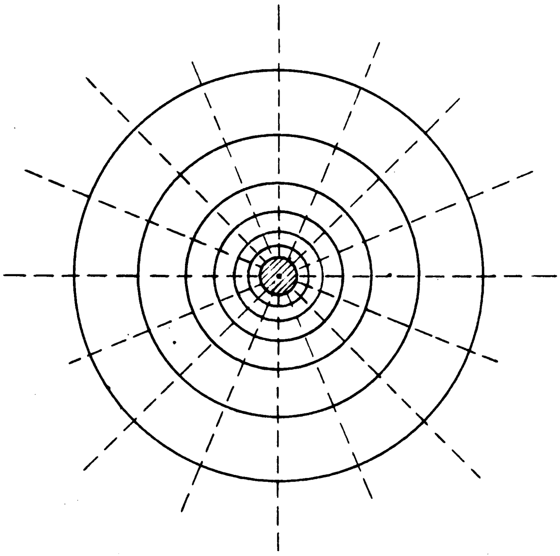

Fig. 6. Field around an isolated sphere.

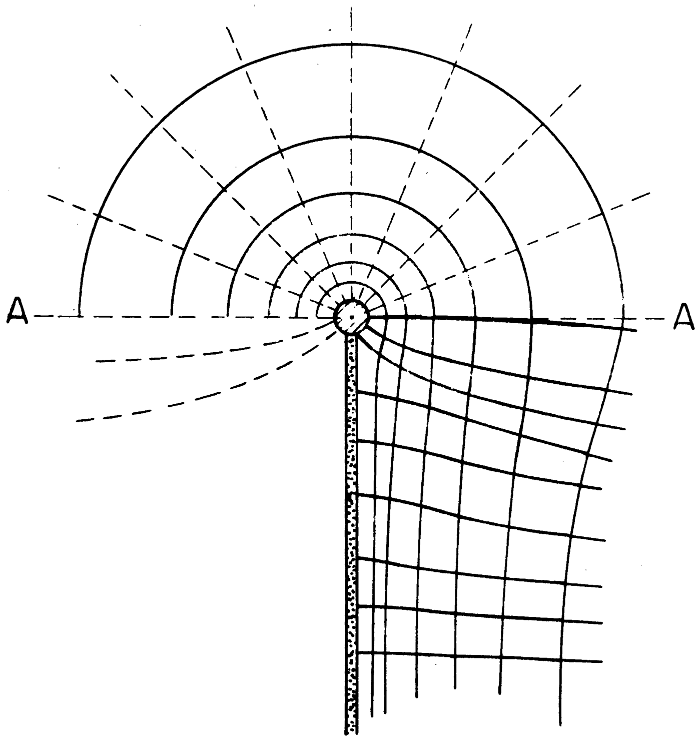

Fig. 7. Field about a charged sphere
with an attached conductor.

The high overall gain and the wide band width of the amplifier further require that a closely fitting shield be provided over as much of the sensing unit as possible to eliminate stray noise and interference pickup. The signal decreases with increased capacity of the sensing element, however, and the capacity increases as the shield is brought closer to the element. This shield also will influence the electric field about the sensing element, but if the sphere is small and relatively far away, as in Figs. 5 and 8, a reasonably uniform field is still retained above AA.

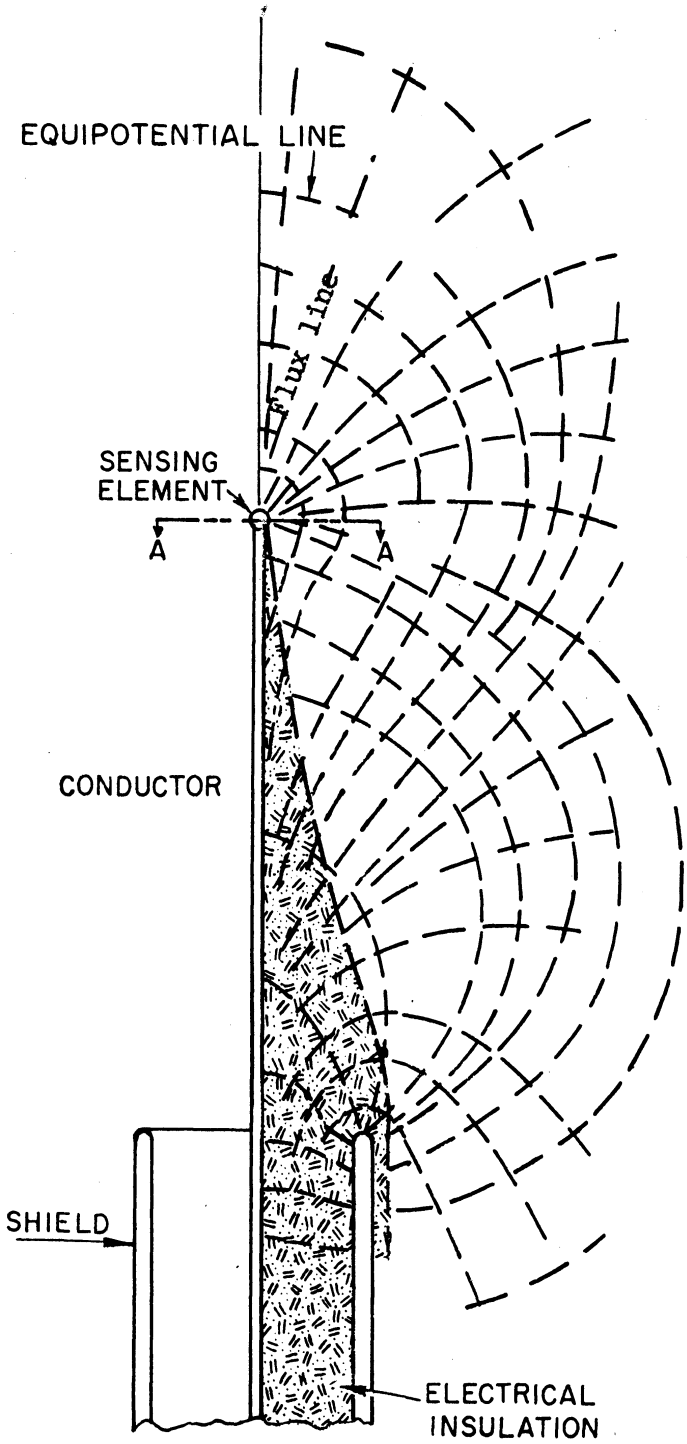

Fig. 8. Electric field around tip of sensing unit (4 times actual size).

The sensing unit must also be considered aerodynamically. The shape and size of the sensing unit can affect considerably the path of the drops approaching it. A blunt object placed in a flow field causes a large deviation of the flow lines at some distance ahead of the object, but a small needle-like object will cause much less deviation. This deviation of flow carries some drops, particularly smaller ones, around the sensing element instead of onto the element along the original path. Therefore, the sensing unit should be long and thin. The deviation is usually expressed as a collection effectiveness and typical values are found in Reference 2.

The relative number of drops of different sizes as recorded by the instrument must be corrected for the effective collecting area of the sensing element. The sensing element will intercept drops traveling along paths passing through a circular area whose diameter is the sum of the diameters of the sensing element and the drop. A sensing element of the same order of size as the drops will have an effective collecting area which varies considerably with the drop size.

The wettability of the surface of the sensing element and insulation also affects the analysis. Drops of a fluid which easily wets the surface will spread into a film covering the hemispherical tip and extending down over the insulation. An equilibrium situation develops rapidly, with drops striking the tip, spreading into the film, and disengaging from the fringe of the film somewhere along the insulation. This film is conductive and acts to increase the area and the diameter of the sensing element and to affect the uniformity of the field. The equilibrium thickness and extent of the film varies with the physical properties of the fluid for any given surface condition of the element. Drops of a fluid which does not wet the surface would bounce or roll off without seriously affecting the characteristics of the sensing unit.

PHYSICAL-DESIGN COMPROMISE

The different electrical, aerodynamic, and surface considerations have been reconciled for the present general usage by the sensing unit shown in Figs. 5 and 8. The sensing element and shield have the following dimensions:

Spherical-tip diameter	0.020 in.
Wire-conductor diameter	0.010 in.
Shield internal diameter	0.25 in.
Insulation maximum diameter	0.375 in.
Unshielded length of sensing element	0.75 in.
Length of sensing element, including shielded portion	3 in.
Diameter of housing around cathode follower	2 in.
Length of sensing unit (element and housing)	9.5 in.

SENSING-UNIT CIRCUIT

A low capacity is desired for the sensing element to provide the largest signal amplitude possible. A high input impedance is also desirable for a larger signal, but the time constant, the time needed for restoring the original potential, increases with the impedance. A low output impedance is necessary to reduce interference in transmission of the signal to the amplifiers. The best compromise appears to be a moderate impedance in the sensing-element charging circuit and a cathode-follower circuit to reduce the output impedance. Figure 9 shows the sensing-unit circuit.

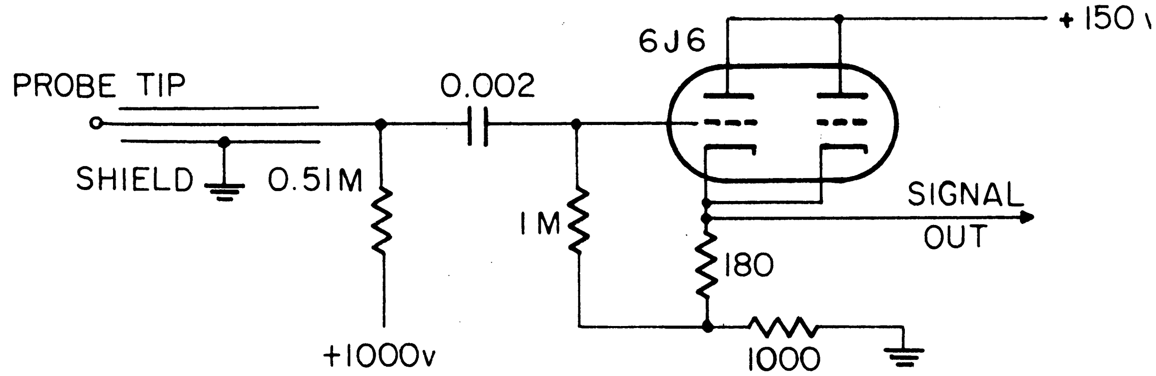

Fig. 9. Sensing-unit circuit.

OTHER TYPES OF SENSING UNITS

A spray which contains a small number of drops or is moving at a low velocity might give a low counting rate. This could be increased by increasing the area of the sensing element, if the design considerations discussed above are satisfied. One possibility is a larger spherical sensing element which maintains a uniform electrical field but gives increasing bias because of deviation of flow lines around the tip.

The sensing element shown in Fig. 10 presents an area 10 to 100 times as large as that in Fig. 8 and still exhibits uniform field characteristics.

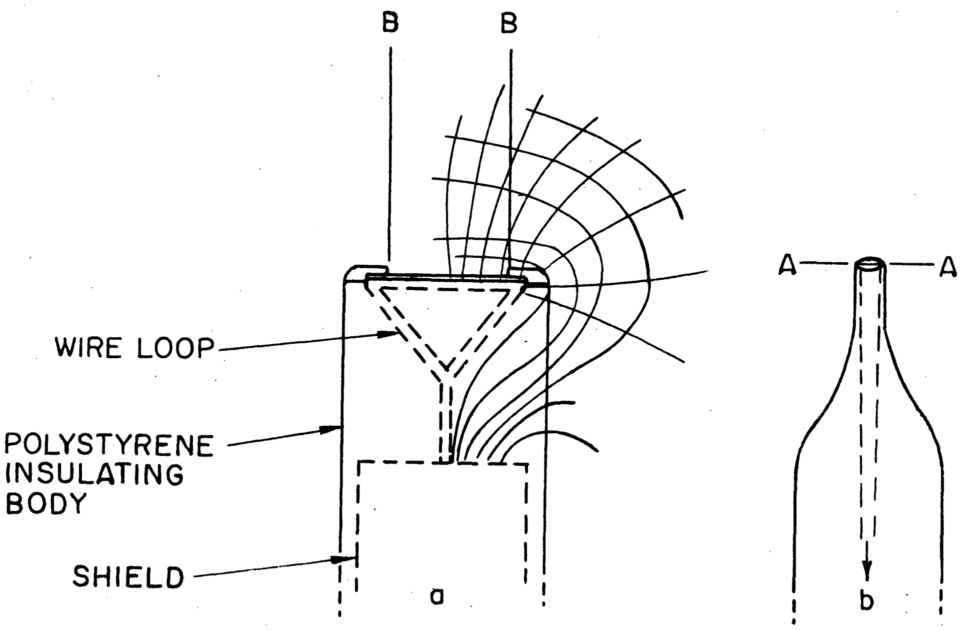

Fig. 10. Straight-wire sensing element.

Only the portion BB, above plane AA, is exposed to the spray and the remainder of the loop is coated with insulating material.

For applications in closed tubes, such as steam lines where the size and rate of entrained water drops needs to be analyzed, still another form of sensing element may be employed. The sensing element and its conductor are encased in a ceramic insulating material without a shield (see Fig. 11), the pipe line itself forming an ideal shield. The ceramic insulator need be only of sufficient size to provide adequate insulation and mechanical support.

In the early work on this instrument, an uninsulated straight wire served as the sensing element, along with a circuit quite similar to that reported by Geist.[2] The exposed straight wire gave differing results for particles of similar size because the pulse size was determined both by particle size and the point of impingement upon the sensing element. An investigation of the electric field around the straight wire showed the nonuniformity in Fig. 12 and led to the sperical and closed-loop sensing elements.

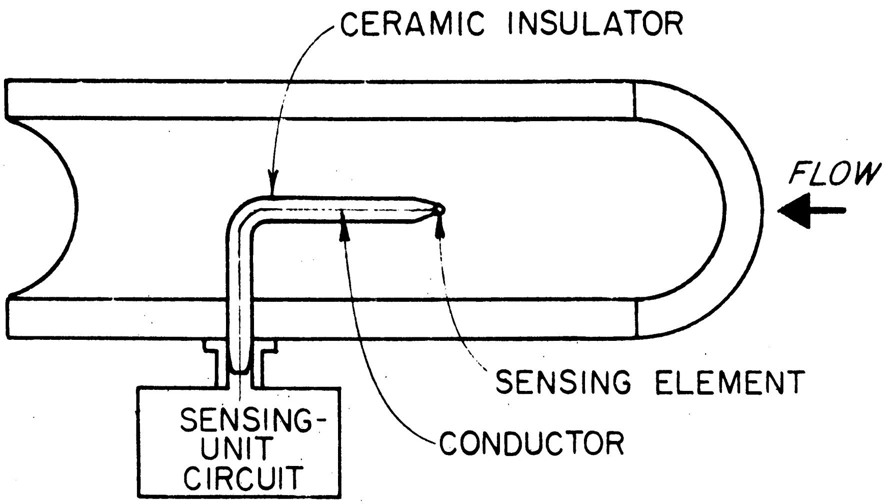

Fig. 11. Probe for entrainment studies.

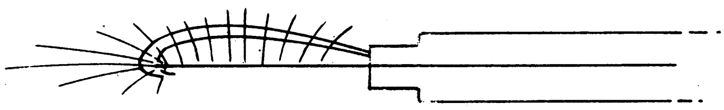

Fig. 12. Electrical field around exposed straight wire.

AMPLIFIER AND DISCRIMINATOR

The amplifier and discriminator are standard products of the Atomic Instrument Company, sold as their Model 204C (Linear Amplifier). The circuit diagram is Fig. 13. The discriminator accepts positive pulses above a set minimum level and produces uniform pulses (in time and amplitude) for any size of accepted pulse. The minimum level is continuously adjustable over a size range.

COUNTER

The counter is a standard Tracerlab SC-1-C "Auto-scaler" with one important modification. The 0.6-second timer furnished with the unit is replaced by a high-speed high-precision timer accurate to ± 0.01 second. In addition, an Eagle preset timer may be used to extend the total count range from 4096 to as high as 1,238,400. The circuit for the counter is Fig. 14.

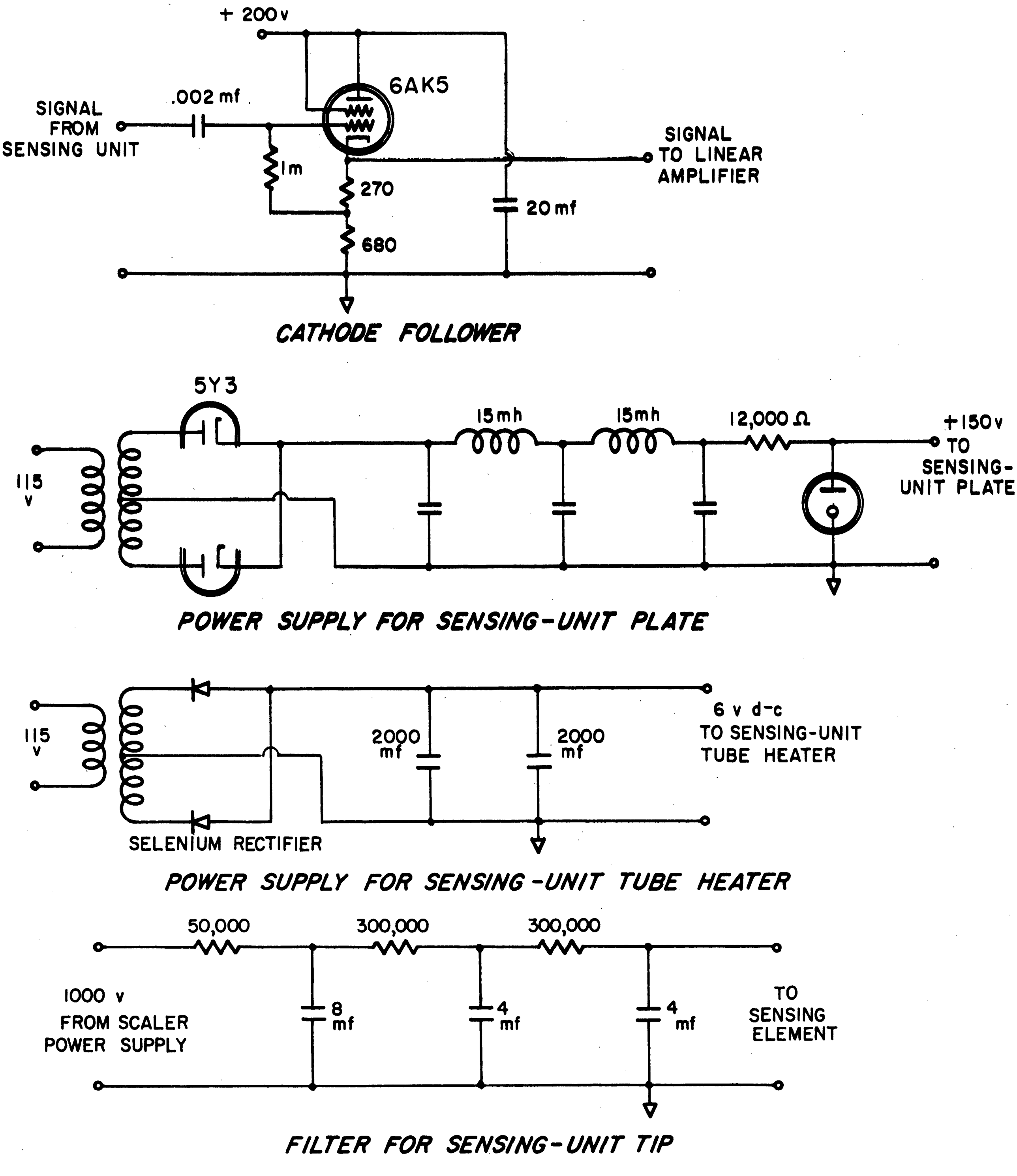

Fig. 15. Cathode follower and power-supply chassis.

POWER-SUPPLY UNIT

The power-supply unit includes a filter for the 1000-volt charging potential to the sensing unit to remove extraneous noise, a 6-volt d-c supply for the tube filament of the sensing unit,and a regulated 150-volt d-c supply for the sensing unit. A cathode follower for the signal path is also mounted on this chassis. The circuits are of standard design and are shown in Fig. 15.

SUMMARY OF CHARACTERISTICS

The calibration of the analyzer as it now stands is presented in Fig. 16. The drop diameter corresponding to each setting on the discriminator scale for

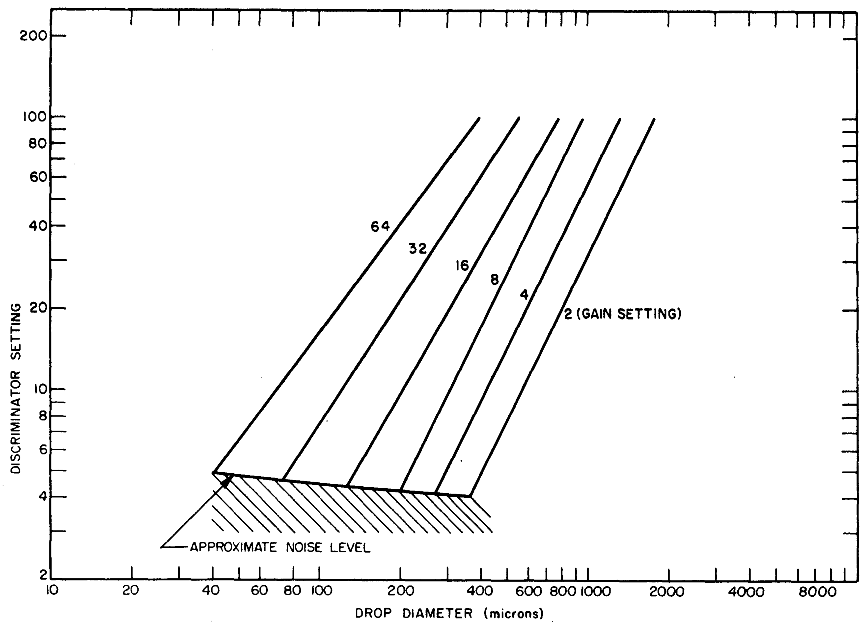

Fig. 16. Electronic-drop-analyzer calibration curve (tap water) (time constant = 4).

each gain setting on the amplifier is presented for all values above the noise level of the instrument.

The characteristics of the electronic spray analyzer are:

1. Maximum counting rates are about 15,000 - 20,000 random counts per second and become unreliable above these rates.

2. The maximum size of particle which can be measured is about 1800

microns by using a gain setting of 2, although larger drops will be counted. At the gain setting of 64 needed for measurement of the smallest sizes of drops, the maximum drop size which can be tolerated is about 800 microns because of overloading of the amplifier. These upper limits can be removed entirely if a protective clipping circuit is inserted in the amplifier.

3. The minimum size of particle which can be accurately counted depends upon the size spray of particles in the total spray being analyzed. With a wide size range the minimum is about 70 microns because of overloading of the discriminator. With a maximum drop size of about 200 microns the overloading is eliminated and the minimum is reduced to about 45 microns. A protective clipping circuit prior to the discriminator would allow the minimum of 45 microns to be attained with a broad size range in the spray.

EXPERIMENTAL TECHNIQUE

Three electrical instruments were used in evaluating the electronic analyzer: a square-wave generator for testing counting rate, a pulse generator for simulating pulses generated by the sensing element, and a high-frequency oscilloscope for observing circuits in operation.

Counting rate was investigated by feeding the output of the square-wave generator into the input of the linear amplifier, which in effect substituted the generator for the sensing element. The frequency of the square-wave generator was varied from zero to over 100,000 counts/sec.

In order to study linearity, overloading, and calibration problems, an electronic pulse simulator which closely duplicates pulses produced by drops striking the sensing element was built (Fig. 17).

The output wave shape is shown in Fig. 18. All observations and measurements were made using a Tektronix 514 AD oscilloscope.

The characteristics of the generator are:

1. Rise time of 0.5 microsecond.
2. Fall time of 3 to 10 microsecond (dependent on signal amplitude and capacity of C, 25 to 100 mmf).
3. Negligible overshoot.
4. Amplitude variable from 30 to 280 millivolts (lower amplitudes obtained by using attenuator on amplifier).
5. Repetition frequency variable from 1000 to 100,000 pulses per second.

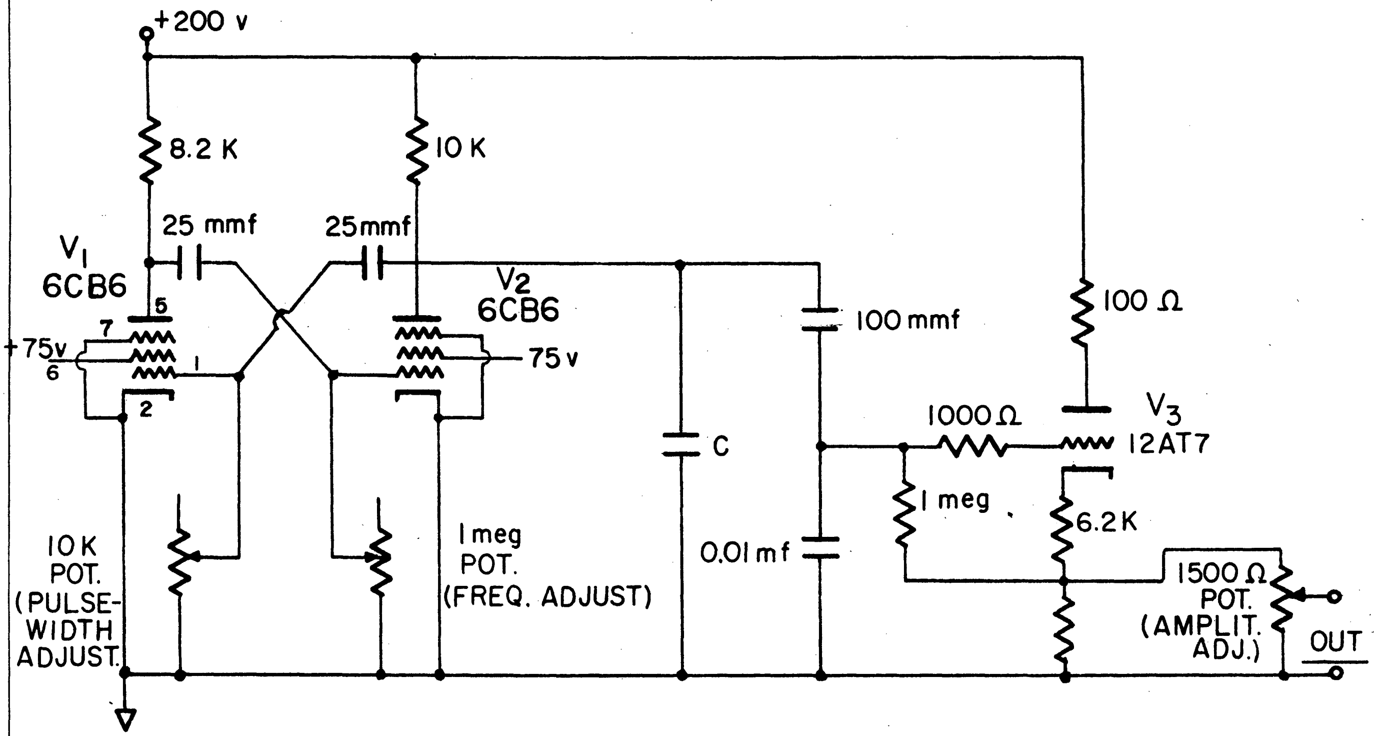

Fig. 17. Pulse generator.

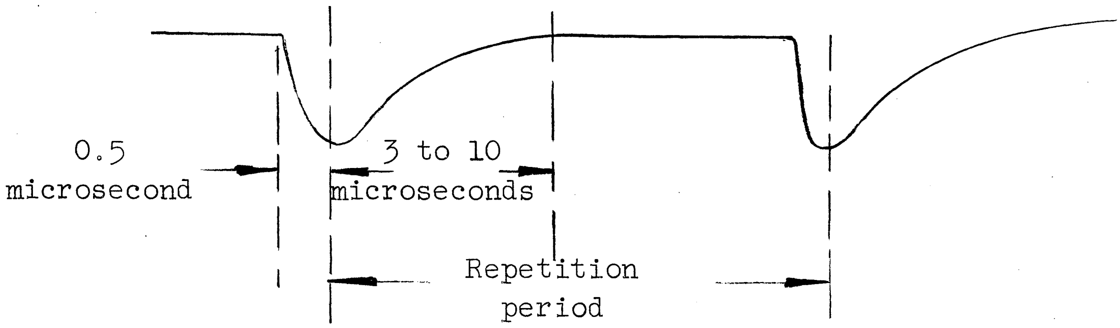

Fig. 18. Pulse wave shape.

Pulses are generated by an unsymmetrical multivibrator and are reduced in amplitude by a capacity voltage divider. The impedance is then lowered by a cathode follower so that the output can be connected directly into the input of the linear amplifier for test purposes.

A drop generator delivering uniform drops (see Report 1886:1-1-P) furnished a controlled source of drops for evaluating characteristics.

As information on the performance of the analyzer was obtained by the procedures above, corrections and changes in the circuits were continually being made, followed by rechecking of the performance. In addition, many experimental changes were made to provide information on the characteristics of the entire analyzer and its various components.

EVALUATION OF CHARACTERISTICS

COUNTING RATE

The counting rate of the analyzer is the maximum frequency the counter can register accurately. The electrical components of the counting and amplifying systems will faithfully reproduce the pulses fed into them up to hundreds of thousands of counts per second. The mechanical pre-set counter, a multiplier of the scaler setting, is not fast enough to keep up with the electrical counter and limits the counting rate to approximately 20,000 counts per second.

The findings from counting-rate investigations must be considered for applicability to a spray containing drops of a wide size range striking the sensing element randomly. The duration of a pulse has been observed on the oscilloscope to vary up to 20 microseconds. Uniformly spaced drops causing pulses of 20 microseconds could be counted at 50,000 counts/second. Smaller drops could be counted more rapidly, but as the rate of impact increases the probability of overlap increases. As the actual impingement rate increases the measured pulse rate increases more slowly, because overlap does not allow the circuits to recover sufficiently and a single pulse is recorded where two or more pulses are actually present. The diagrams of voltage output of the amplifier vs time in Figs. 19 and 20 show this.

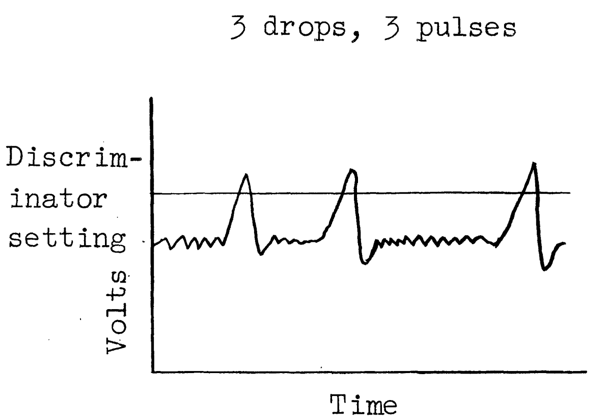

Fig. 19. Amplifier output for low impingement rate.

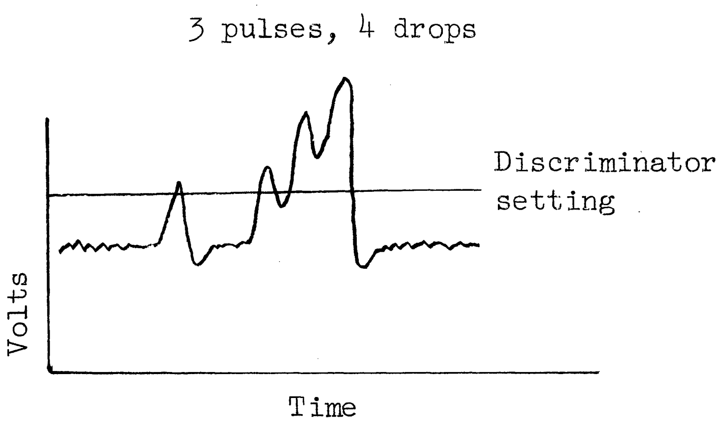

Fig. 20. Amplifier output for high impingement rate.

The degree of overlap is a question of probability, and all we can state here is that it will increase rapidly as the impingement increases. This may be improved somewhat by improving the recovery time of the input pulse, but the overall effect needs to be evaluated before a permanent change can be recommended. The recovery time may be reduced by decreasing the value of the charging resistor or by reducing the stray capacity. However, decreasing the resistance also decreases the amplitude, and any reduction of stray capacity in the present design would be at the expense of shielding. The value of the stray capacity based on the observed recovery time and charging resistance is about 25 micromicrofarads.

If the limiting rate as a result of overlap can be increased, the substitution of an electrical multiplier in place of the mechanical pre-set counter should be considered, because this would raise the limit from this source by tenfold or more.

MAXIMUM DROP SIZE

During the greater part of the work on this analyzer, an overloading of the amplifier circuit has set an upper limit on the drop sizes which could be tolerated in the spray. This is the result of the extremely large variations of signal amplitudes that must be handled simultaneously. When attempting to measure the total count of large and small drops with a high gain setting on the amplifier, the large drops give a signal so large that grid blocking of the final stages results.

To prevent this, these signals have to be clipped at some early point in the amplifier. They will then appear as 100-volt or slightly greater pulses at the output and of course will be counted in the total count, but will not develop into such large pulses as to cause this grid-blocking trouble.

An experiment was made using germanium diodes to show the operation of the protective clipping circuit, Fig. 21. From tube V2 of the amplifier, a

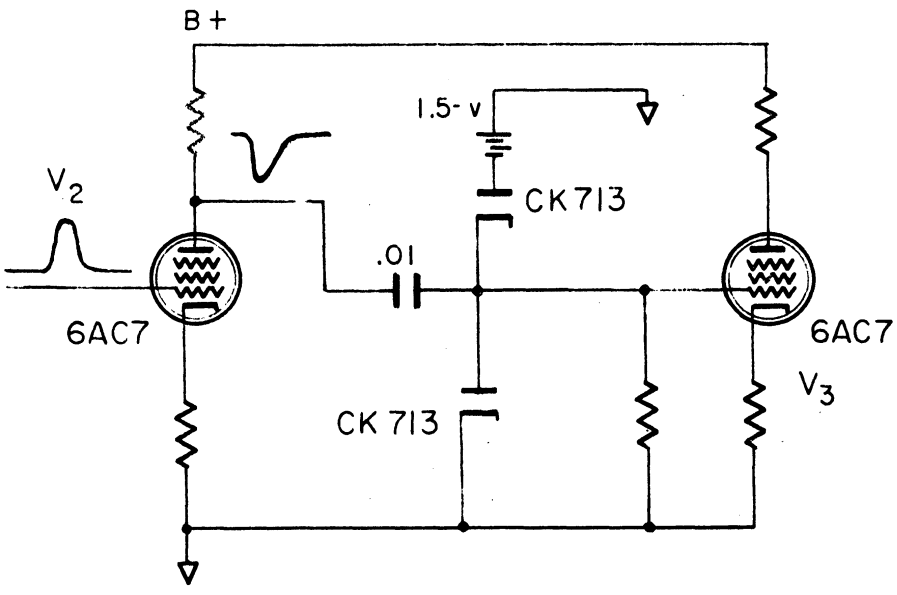

Fig. 21. Protective clipping against overload.

negative pulse of 1.2 volts is sufficient to drive the amplifier to full output (100 volts). However, this can be as much as 4 volts before overloading begins to appear in later stages. Therefore, if this signal is clipped at 1.5 volts as in Fig. 21, the amplifier will operate normally to slightly above full output, but overloading will be eliminated.

The results of the experiment are as follows. An input of 15 millivolts will give an output of 100 volts with a gain setting of 64. Without clipping, overloading will begin at about 50-millivolts input, corresponding to a 800-micron drop, and with the circuit of Fig. 21 overloading begins at 250 millivolts input. This could be improved by using better diodes and a series dropping resistor of 50,000 ohms. Prior to tube V2, the signals are so small that they can cause no trouble for the largest drops that will be encountered.

A maximum drop size which can be measured still will exist, although all larger drops will be counted. Figure 16 shows that a gain setting of 2 and the maximum discriminator setting of 100 corresponds to a drop size of 1800 microns. It is not possible to measure larger drops, but with the addition of the protective clipping circuits all larger drops can be counted.

MINIMUM DROP SIZE

The minimum usable setting of the dial is 10, corresponding to a minimum drop size of 70 microns, when a wide size range of drops is present. Below a setting of 10, the 100-volt pulses cause overloading of the discriminator circuit, producing multiple pulses at the output and causing miscounting. To extend the lower limit, it would be necessary to install a clipping circuit similar to Fig. 21 immediately prior to the discriminator. This circuit should automatically come into operation at low dial settings. This would permit the minimum drop size to be reduced to 45 microns with all sizes of drops present in the spray.

DISCUSSION OF CALIBRATION

The calibration of the analyzer was made with the time-constant control on the front of the linear amplifier set to position 4. This position has a time constant of 1.6 microseconds, which is only about 3 times larger than the rise time of the input signal. In order to obtain linear response, the time constant should be at least 10 times the rise time. The time constants of the various positions are:

Position	Time Constant
4	1.6 microseconds
5	3.2 microseconds
6	8 microseconds
7	16 microseconds

There was considerable attenuation observed at positions 4 and 5, but none on the higher positions 6 and 7. In addition to the amplitude reduction, a linearity error is introduced because slight variations in the rise time will affect the amplitude of the output even though the input amplitude remains constant.

A recalibration of the instrument could well be made, taking this effect into account.

RECOMMENDATIONS FOR FUTURE WORK

Future work on the instrument should include several objectives originally proposed and only partially attained.

EXTENDING OPERATING LIMITS

Development work on the circuits should be continued to extend the limits of operation, particularly the minimum drop size. This minimum size is limited fundamentally by noise, and further amplification will not lower the limit unless the noise can be reduced proportionally.

Two types of "noise" are significant in the operation of the analyzer. One is the circuit noise, which is fairly uniform in amplitude; the other is external noise resulting from the action of the sensing element as a receiving antenna. The external noise can be controlled to various degrees by different types of shielding. The circuit noise can be reduced only by isolating its source and making appropriate changes in the circuit.

At present, the two types of noise are of about the same magnitude, although at times the external noise is much larger. This means that attempts to improve the noise factor must include improvement of shielding of the sensing element against external noise and reduction of noise in the input circuit.

Another avenue of attack is to increase the amplitude, maintaining the same noise level as at present. However, the present sensing unit has been investigated for maximum output by varying the input-circuit component values and voltage and has been found to be nearly maximum. A new type of input mechanism would be necessary to achieve an improvement in this direction.

EFFECT OF OTHER FLUIDS

The original goal of the project was development of an instrument for analysis of sprays of all types of fluids. The existing instrument has been operated only on electrically conductive fluids and has been calibrated only with tap water. Wide variations in physical properties, especially viscosity, could easily affect the results produced by the analyzer and should be measured in some detail.

FUNDAMENTAL MECHANISMS

It would be advantageous if the mechanism of impulse formation resulting from drop contact were thoroughly understood. Various explanations have shown similar results and approximate the actual calibration findings. It is now possible to photograph in slow motion the particles hitting the sensing element and simultaneously watch the impulse on an oscilloscope. This would not only help to explain impulses, but also to determine the effect of near misses and give visual evidence of the collection efficiency of the probe.

SPEEDING ANALYSES

The ultimate goal has included the factor of rapid analysis as an important aspect. A significant step beyond this instrument would further reduce the operator's effort by eliminating secondary calculations.

A differential discriminator, with a maximum as well as a minimum setting, would give "frequency analyses" directly and by-pass the cumulative calculations. Such instruments are available, but neither the economics nor the technical problems have been evaluated. A frequency meter might replace the totalizing counter on such an instrument. An experiment with a frequency meter worked only at high rates of counting, but was inconclusive.

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