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Bridges et al.

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[54] **APPARATUS FOR ELECTRODE RAPPER CONTROL**

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[52] **U.S. Cl.** **55/104,** 55/112, 55/148

[51] **Int. Cl.** **B03c 3/76**

[58] **Field of Search** 55/10, 11, 104, 106, 55/108, 109, 110, 112, 139, 148

[56] **References Cited**

UNITED STATES PATENTS

3,362,134	1/1968	Wiemer	55/104
3,487,606	1/1970	Bridges	55/13
3,606,733	9/1971	Arstikaitis	55/112
3,505,790	4/1970	Rothemich	55/274

OTHER PUBLICATIONS

Seegmiller, W. R., "Controlled Rectifiers Drive A–C and D–C Motors," Electronics, Nov. 13, 1959, pages 73–74.

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[57] **ABSTRACT**

A rapper control senses the particle load collected on selected electrostatic precipitator electrodes and automatically energizes corresponding rappers connected to the selected electrodes when the collected particle load magnitude on the electrodes exceeds a predetermined limit and de-energizes the rappers when the collected particle load magnitude obtains a predetermined minimum to optimize the amount of precipitant on the collecting electrodes. The control is preferably electronic and is normally used in conjunction with a plurality of sets of rappers which are independently and sequentially energized. The load distribution of the particles collected on the precipitator electrodes is monitored and the rapper sets are selectively energized in a sequence governed by the pattern of the particle load distribution.

8 Claims, 7 Drawing Figures

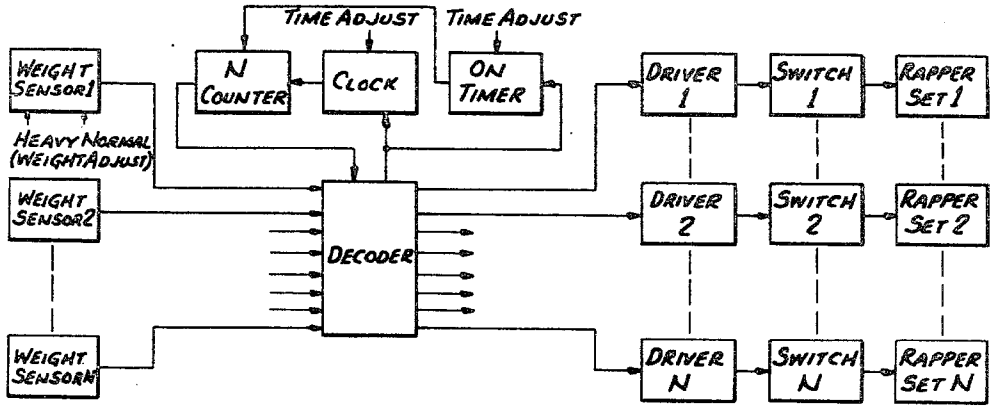


Fig. 1

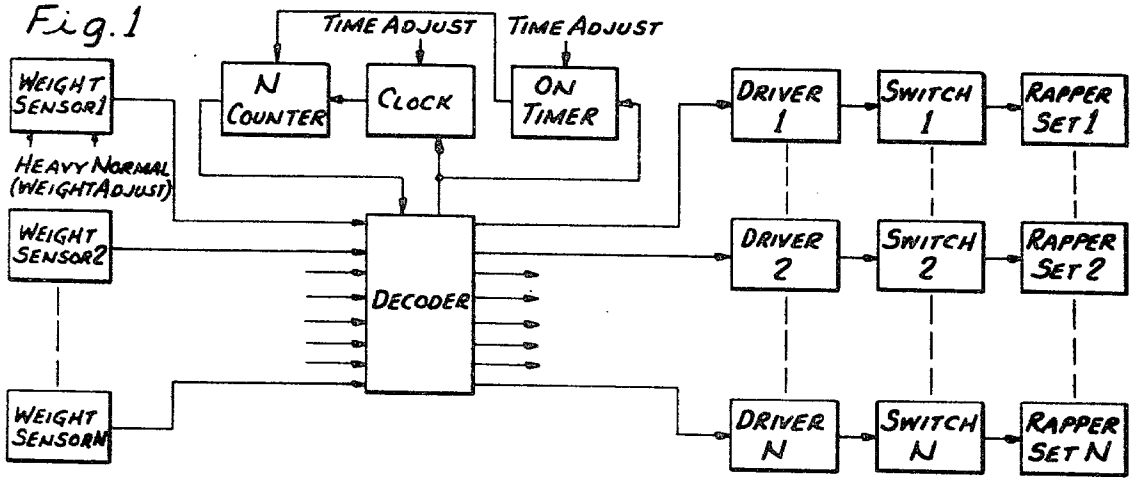


Fig. 6

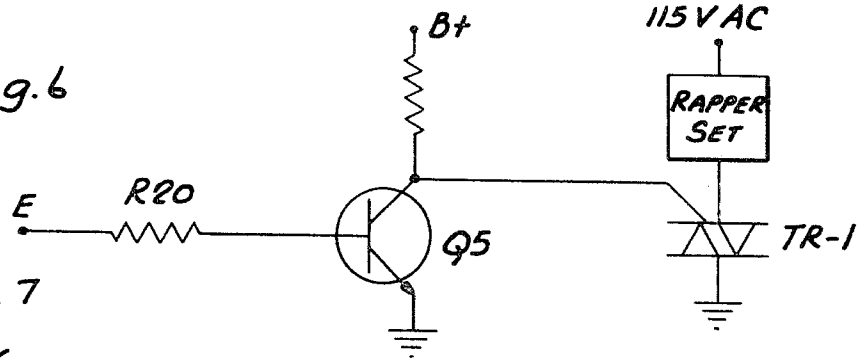
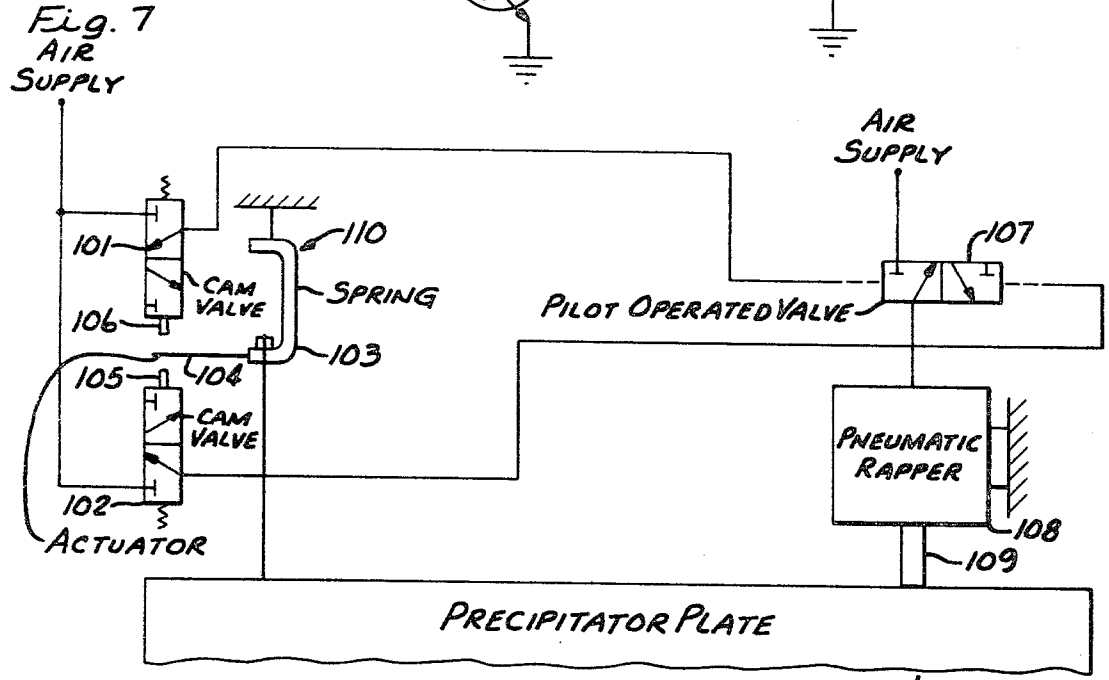


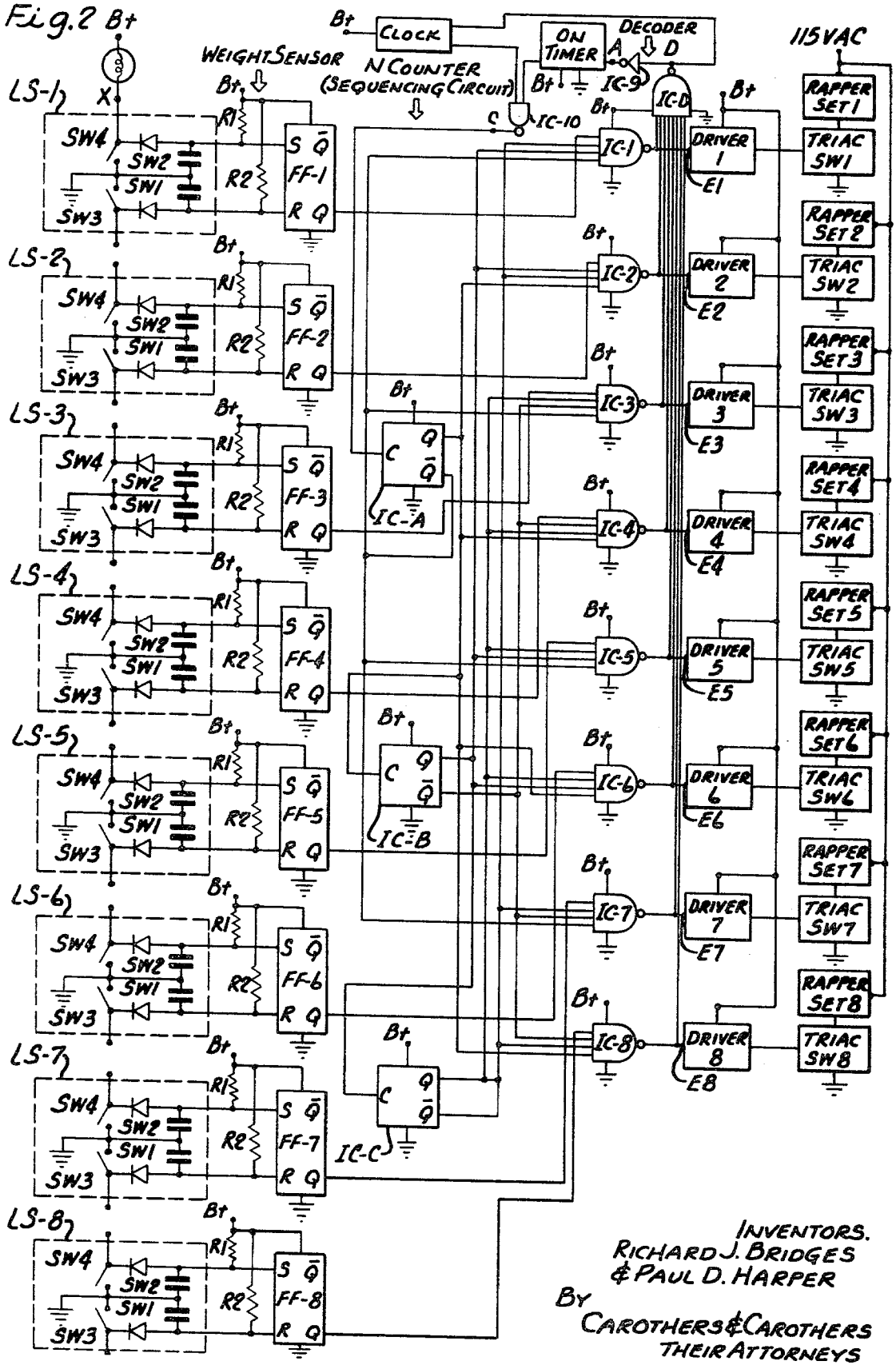
Fig. 7



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Fig. 2



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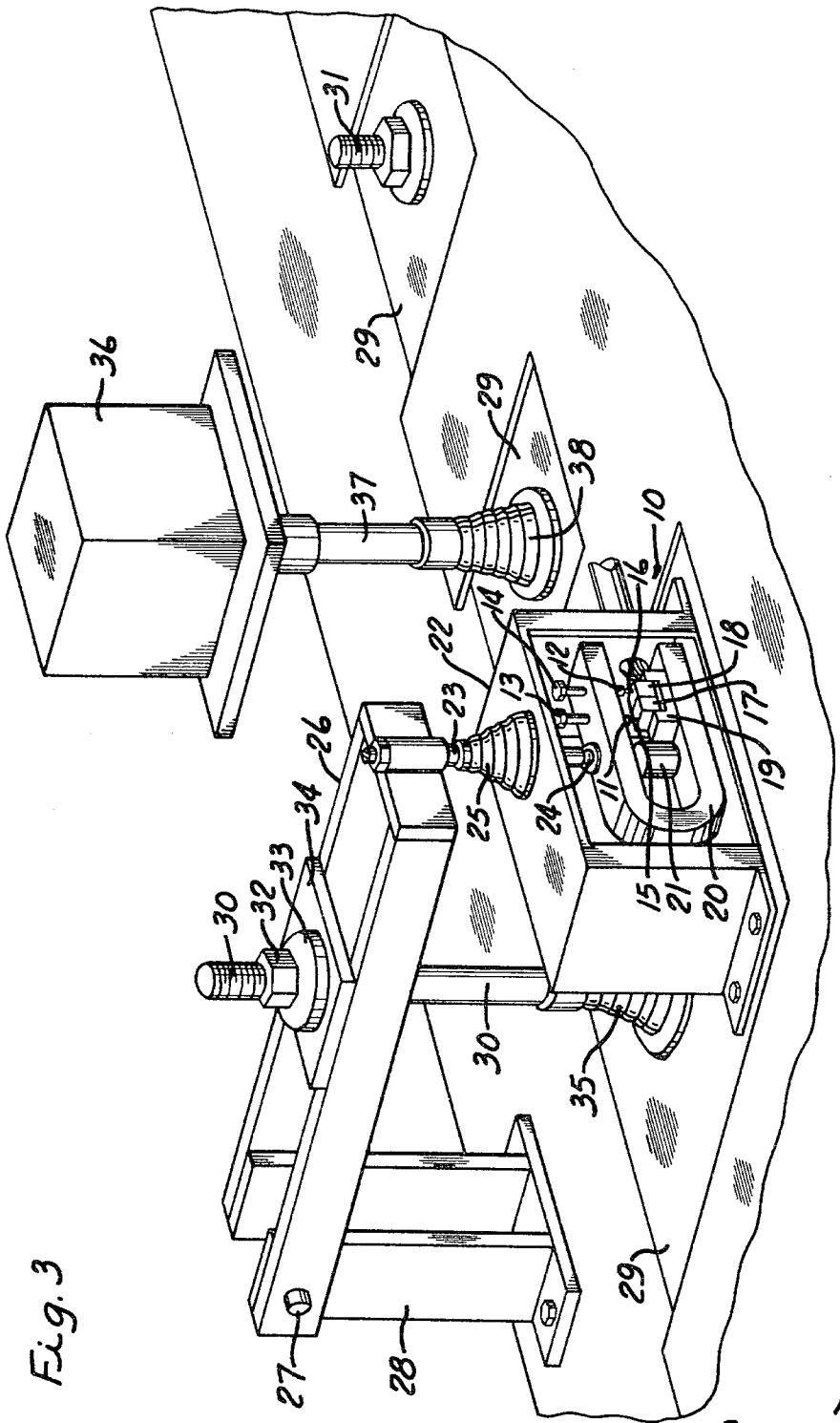
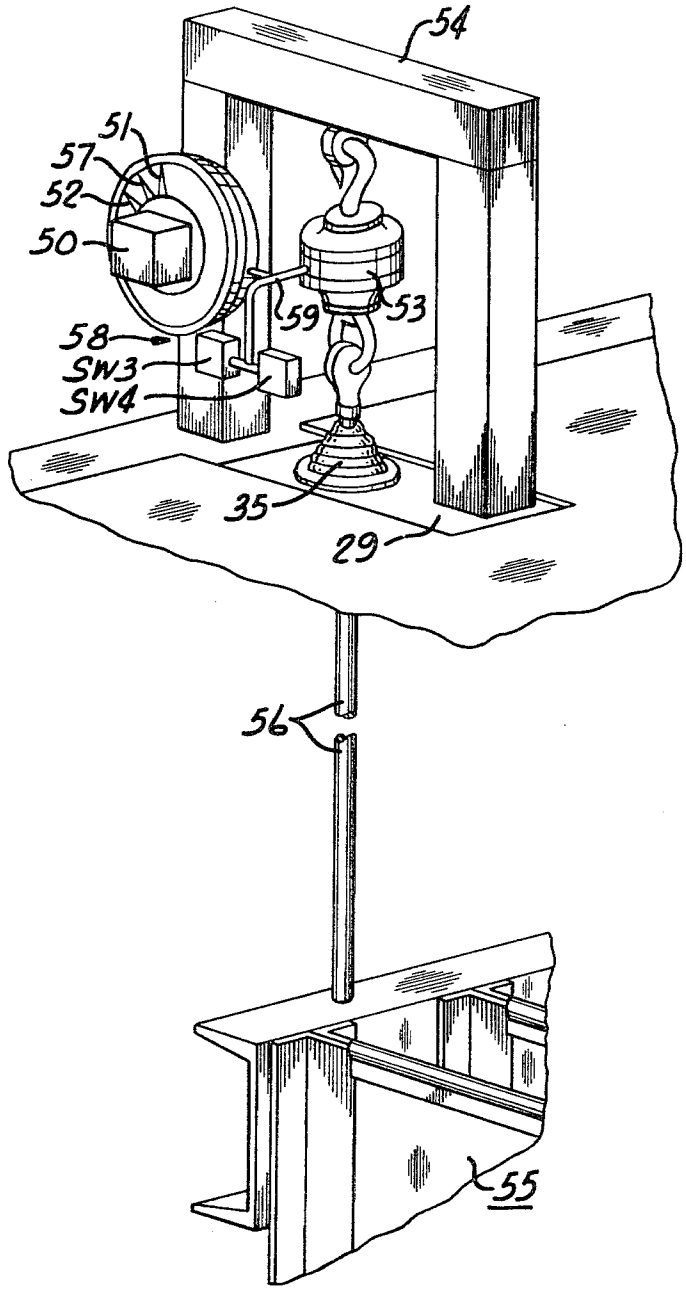


Fig. 3

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Fig. 4



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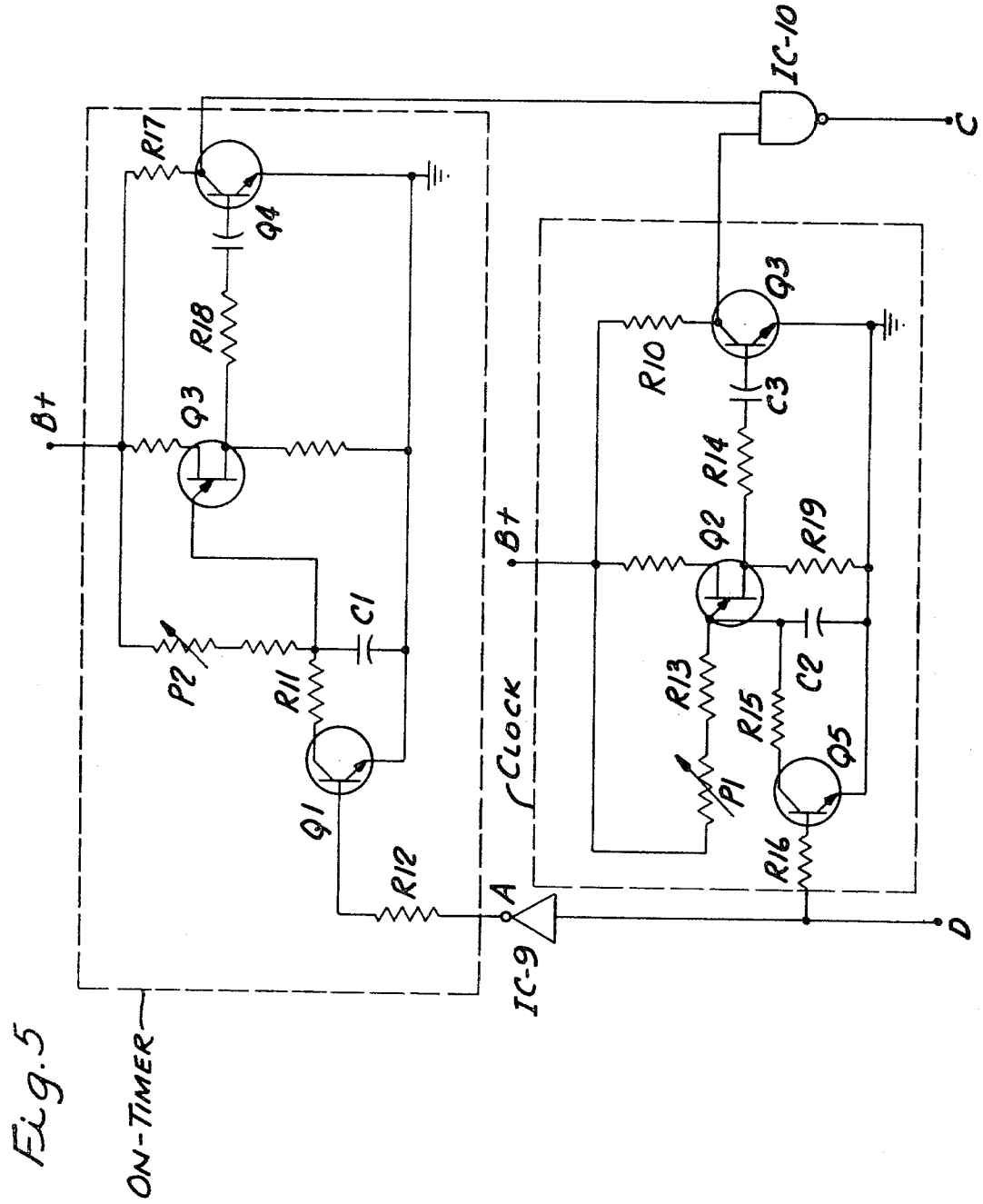


Fig. 5

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APPARATUS FOR ELECTRODE RAPPER CONTROL

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates generally to particle separation and more particularly to rapping means for cleaning the electrodes in an electrostatic precipitator and is directed to improvements in our previous invention entitled Frequency and Duration Control for Electrode Rappers as disclosed in U. S. Pat. No. 3,487,606, which issued Jan. 6, 1970.

2. Description of the Prior Art

As pointed out in our aforesaid patent disclosure, when particles build up or collect on the plates of an electrostatic collector, they must be removed in order to maintain the efficiency of collection. This is normally accomplished by vibrating or rapping the plates with motorized devices.

It is also pointed out that as the art of electrostatic precipitation developed, we found that rapping all the collector plates reduced collection efficiency because all the particles fell into collection hoppers at one time causing a reentrainment throughout the precipitator. Controls were developed which energized selected ones of the plate or wire (electrode) rappers at intervals and for selected length of time to confine reentrainment to small areas throughout the precipitator. Our former invention as disclosed in U. S. Pat. No. 3,487,606, provides a control for regulating the frequency and duration of energization for sets of rappers with both the frequency and duration being independently adjustable over wide ranges. This electronic control permitted greater reliability and versatility in the control of electrode rapping than theretofore thought possible.

However, experience now indicates that operating the rappers of a precipitator on a regular interval, and for fixed rapping times, leads to either overrapping or underrapping, but seldom to optimum rapping due to the changing conditions in the precipitator such as conditions of the dirt load, for example. Overrapping causes excessive reentrainment of the collected material and, in some instances, excessive precipitator arcing due to bare spots in the collecting plates and uneven distribution of coleected material. Underrapping cuses excessive build-up of the collected material on the plate and wires which lowers the arcing voltgge and, therefore, reduces the maximum power input into the precipitator as well as increasing the arcing rates. Accordingly, the efficiency of the electrostatic precipitator is impaired when the condition of underrapping or overrapping occurs

It has been further suggested that particle laden hoppers might be provided with a load cell device placed in a suspension system for the hopper or collector to permit automatic weighing of the collected particles in order to alert the operator to the fact that the device requires cleaning (See U. S. Pat. No. 3,505,790 issued Apr. 14, 1970 to Edmund F. Rothemich for Dust Collector.) However, no one until the present has devised, suggested or conceived of a rapper control which will automatically optimize the amount of precipitant on the collecting plates and wires of the electrostatic precipitator nor realized the need for such a control.

SUMMARY OF THE INVENTION

Accordingly, the principal object of the present invention is to provide a rapper control which senses the particle load collected on selected precipitator electrodes, and in response thereto, energizes corresponding rappers connected to the selected electrodes when the collected particle load magnitude exceeds a predetermined limit. It can also deenergize the rappers when the collected particle load magnitude obtains a predetermined minimum in order to optimize the amount of precipitant remaining on the collecting electrodes of the electrostatic precipitator.

This is preferably accomplished with the use of solid state electronics and in larger precipitator installations the control includes means for monitoring the load distribution of the precipitant collected in the precipitator and selectively energizes corresponding rappers or rapper sets in a sequense governed by the pattern of the load distribution in the precipitator such that no two rapper sets are simultaneously energized, thereby minimizing any disturbance due to rapping in the precipitator. When the load sensing means senses that the rapping has been sufficiently carried out to obtain the optimum particle load collected on the selected precipitator electrodes, the control is responsive to deenergize the corresponding rappers and the process of sequentially monitoring the particle load distribution on the precipitator electrodes is continued until another monitored load limit is attained or exceeded within the load distribution pattern.

Another object of the present invention is to provide means for regulating the duration of energization of a rapper or rapper set to a time length defined within maximum and minimum desired particle load magnitude collected on corresponding portions of selected precipitator electrodes.

Another object of the present invention is to provide an intensity control means which starts rapping of the selected electrodes at a preset intensity level and then automatically raises this intensity to a maximum This is preferaby accomplished by changing the conduction angle of a triac switch employed to switch an electromagnetically operated rapper.

Another object of the present invention is to provide means in the control to vary the rapidity of sequentially monitoring the different particle load magnitudes in portions of the total precipitator distribution pattern.

Still another object of the present invention is the provision of an on-timer circuit which is operable to discontinue the energization of any one rapper or rapper set, when the optimum particle load minimum has been exceeded as sensed by a load sensing device when the control fails to function normally to discontinue rapping upon obtaining the desired minimum particle load collected on the corresponding precipitator electrodes.

The preferred electronic rapper control of the present invention incorporates weight sensors which are all adjusted such that a signal is produced when the proper weight is attained. An N or ripple counter clock strobes a decoder in a search manner such that any signals coming from the weight sensor will not pass through the decoder until the counter reaches the count corresponding to the number of the sensor in question.

At this point, the signal passes the decoder, oeprates the corresponding rapper set, simultaneously stops the N-counter and energizes the on-timer circut.

Other bjects and advantages appear hereinafter in the following description and claims.

The accompanying drawings show, for the purpose of exemplification without limiting the invention or the claims thereto, certain practical embodiments illustrating the principles of this invention.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings wherein like parts are marked alike:

FIG. 1 is a block diagram illustrating an embodiment of the rapper control of the present invention.

FIG. 2 is an electrical schematic diagram illustrating the rapper control shown in FIG. 1 in greater detail.

FIG. 3 is a perspective view of one embodiment of a weight sensor which may be incorporated in the control of the present invention.

FIG. 4 is a perspective view of the preferred embodiment of a weight sensor to be employed in the control of the present invention.

FIG. 5 is an electrical schematic diagram illustrating one embodiment of the weight sesor circuit, on-timer circuit, and clock circuit shown in the control system illustrated in FIGS. 1 and 2.

FIG. 6 is an electrical schematic diagram illustrating one embodiment of the rapper drivers and switches employed in the control system illustrated in FIGS. 1 and 2.

FIG. 7 is a diagrammatic illustration of an alternative embodiment of the present invention employing pneumatic controls.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In the well-known art of electrostatic precipitators, the various materials or particles to be collected are charged by high voltage between a number of plates and wires suspended between the plates. The material s normally attracted to the plates which are at ground potential. Some material is also attracted to the wires which are at a high negative potential.

The automatic rapper control described herein senses the weight of the material collected on the plates or electrodes and provides a control signal to energize rappers until the weight of th collected material is reduced to its predetermined level. Thus, a closed loop system is established. Since the amount, or volume, of the given material is proportional to weight, sensing its weight provides the information needed to control the rappers. Naturally, any signal proportional to weight can be derived by many techniques and conditioned to work properly in this control.

Referring now to FIG. 1, the control system of the present invention is illustrated in block diagram form wherein the system is shown for N rapper sets to illustrate its inherent flexibiiity fo use with either one rapper set or many. For each rapper set, there is a corresponding switch and driver which simply provides the power amplification needed to drive the rappers. The drivers also may contain additional circuitry for the purpose of starting the rapper set at a predetermined intensity level and automatically raising this intensity to a maximum. This, of course, minimizes the reentrainment of the collected material by first generally removing the heavier collected load portions, and thereafter increasing the intensity of rapping to remove the precipitant more closely adhered to the electrodes.

There are N weight sensors shown, each with characteristics such that a signal is produced when a given weight is reached, and the signal is removed when the weight decreases to some weight lower than the first by a predetermined amount. For all the sensors, the two weight levels are adjustable whereby the first weight, called "heavy" for example, and the second weight, called "normal" for example, can be adjusted over a wide range.

The decoder block, connected to the outputs of the N weight sensors and the inputs of the N drivers, essentially forms a routing network which determines the order and the frequency of rapping depending upon the inputs from the weight sensors and the N-counter. The N-counter and clock form a free running counter of a count equal to the number of rapper sets. The frequency of the count, of course, may be made adjustable by varying the clock time. The on-timer provides an overriding control signal to the N-counter clock to prevent excessive rapping to any given rapper set.

The operation of the system can be basically divided into "normal" and "abnormal" classifications where "normal" denotes the operation expected on a normal day-to-day basis and "abnormal" for unexpected situations, such a the failure of some component in the system or a circuit upset due to electrical interference, etc.

Under conditions of normal operation, the weight sensors are all adjusted such that a signal is produced when the proper weight limit is obtained. The N-counter strobes the decoder in a search manner such that any signals coming from the weight sensors will not pass through the decoder until the N-counter reaches the count corresponding to the number of the sensor in question. Thus, if the first sensor reaches "heavy" weight, a signal from the sensor reaches the decoder but waits for the N-counter to reach a "one" count. At this point, a signal passes the decoder and operates the first rapper set. Since the clock is designed to count quickly, a minimal delay is experienced from the time a sensor indicates "heavy" and the corresponding rapper set operates.

Simultaneous to the rapper set energization, the ontier circuit is started by the decoder. The output produced by the decoder is also used to stop the clock so that the search mode ceases. Thus the rapper set is operated in response to the weight sensor which has indicated a sufficient dirt build-up on a precipitator plate to cause the system to respond.

The on-timer is capable of producing an output for a time which is set to be no longer than needed to clean the plate of the desired amount of collected material. Thus, the on-timer forms a time limit on the operation of any given rapper set. Under normal rapping conditions, the weight sensor would indicate that the plate weight had returned to "normal" long before the on-timer was expended, thus causing the rapper set to stop operation.

As soon as any given weight sensor returns to "normal" the on-timer is reset which restarts the clock and causes the N-counter to go into search mode. Thus, any weight sensors indicating "heavy" will operate rapper sets in the order of the N-counter. This feature is important in that no two rapper sets are ever energized

simultaneously, thereby minimizing any disturbance due to rapping in the precipitator.

In the event that the weight sensor fails to return to "normal" in the allotted on-time for any reason whatsoever, the on-timer will time out, stop the corresponding rapper set and allow the clock N-counter to start the search mode, thus allowing any other rapper sets to operate on "heavy" plates. Eventually, the N-counter would return to the original "heavy" sensor (if it remained "heavy"), and rap it again until the defect is corrected.

Occasionally, the aforementioned operation might conceivably occur and reoccur even though the system is set for the expected normal mode of operation. For example, an extra heavy dirt load in the precipitator for a short time might cause one or more plates to continue to build up unexpectedly. If this condition prevails, readjustment of the system of a new "normal" operation level would be required to eliminate such build-up. The value of the on-timer becomes apparent under abnormal conditions were, for instance, components in the mechanical or electrical system fail in such a way as to make a weight sensor appear "heavy" for an extended period of time. In this event, the rest of the system would function normally even though a malfunction had occurred.

Provisions are made in the weight sensor to sound appropriate operator alarms in the event that a plate becomes extremely light or extremely heavy (for instance, if a rapper stays on or remains off). This alerts the operator to the problem while the remainder of the rapper system continues to function normally. These same load limit sensors are also used to reset the circuitry of the rapper control in the event that electrical interference causes a rapper to stay on or off for a prolonged period of time.

The basic weight sensor device incorporated in the system of the present invention may be one of many types such as a hydraulic load cell with a Bourdon tube readout (which is preferred) employing various types of contacts, strain gauges, differential transformers, mechanical readouts, etc. The types of contacts employed in these devices are also various such as photoelectric devices, magnetically operated reed switches, direct contacts, etc. Furthermore, these load cells or sensors may be operated in the tension mode or in the compression mode to weigh a part of the entire mechanical electrode assembly plus the collected material. For purposes of illustration, the weight sensor herein first described will be of a type employing micro switches as shown in FIG. 3, as it is believed that the principles of the present invention will thus be visually illustrated with greater simplicity and clarity even though it is not the preferred embodiment.

The load cell device 10 illustrated in FIG. 3 is operated in the compression mode. This particular load cell device has adjustable actuators 11 and 12 adjustably positioned by means of adjusting screws 13 and 14, respectively, to provide a predetermined distance between actuators 11 and 12 and corresponding limit arms 15 and 16 of limit switches 17 and 18, respectively. Limit switches 17 and 18 are fixed in mount 19 which is in turn secured to the upper surface of the bottom leg of the C-shaped force spring 20.

Safety limit post 21 is secured to the bottom leg of the C-shaped force spring 20 adjacent mount 19 such that it is disposed directly between opposing surfaces of the top and bottom legs of the C spring in order to limit the downward movement of the upper leg and thereby protect the limit switches 17 and 18.

All these components combine to form a force control switch which is housed in weather tight housing 22 which has its front face cover plate removed to permit viewing of the force control switch.

The upper leg of the C spring 20 is flexed by the downward movement of spring compression rod 23 which is provided with a ball and socket arrangement 24 at its lower end to permit relative movable engagement with spring 20.

Boot 25 permits up and down movement of rod 23 while maintaining the housing 22 water tight.

Compression rod 23 is in turn adjustably secured to the forward end of level arm 26 which is in turn pivoted at its rearward end as indicated at 27 to the upward support 28. Support 28 and housing 22 are rigidly secured in relation to each other by means of mounting bolts as indicated which secure them respectively to the same roof plate 29 covering precipitator collector electrodes (not shown) which are suspended therefrom and thereunder by means of support rods such as indicated at 30 and 31.

The basic arrangement illustrated here shows one side of a four point suspension system wherein the load cell device 10 measures a portion of the collector plate unit suspended therebelow together with its collected particle load. Obviously, the load cells could also be mounted on all four corners but the present description is centered around weighing one corner of the assembly. In any event, the load cell is provided with adjustable contacts in order to permit one to predetermine the amount of weight that is desired for removal for a particular rapping period by weighing the total amount of weight, including plates or wires, plus the collected materials, so that the rapping can be appropriately controlled.

Support rod 30 has its upward end directly connected to pivot arm 26 in order to transfer a portion of the weight of the precipitator plus its particle load to compression arm 23 and subsequently to the upper arm of the C-shaped spring 20 in order to compress the same and actuate limit switches 17 and 18 when corresponding predetermined particle load limits are obtained.

The upper end of support rod 30 is threaded in order to permit vertical adjustmett by means of the nut 32 which bears on washer 33 and the pivot arm mounting plate 34. A flexible dust boot 35 provides a suitable dust seal between the precipitator and the load cell device.

An electromagnetic rapper 36 is positioned to the right of the load sensing device 10 and is supported directly on the end of rapper rod 37 which in turn has its lower end connected directly to the precipitator collecting cell in order to impart the rapper vibrations thereto to remove the collected precipitant. Dust boot 38 seals the opening in the roof plate 29 through which the rapper rod 37 passes and also permits vibratory movement of rod 37.

A preferred weight sensor of the Bourdon tube type equipped with photoelectric cells is illustrated in FIG. 4. This type may be readily substituted for the load cell device of FIG. 3. The Bourdon tub gauged is considered to be a more practical and accurate means for performing the weight sensing function of the present invention.

Here, the switching operation is similar to the device 10 of FIG. 3. Two photoelectric switches (not shown) housed within photoelectric switch assembly 50 (not shown) and preset by upper and lower trip set needles 51 and 52, serve the same function as micro limit switches 18 and 17, respectively, of FIG. 3. Two hydraulic safety limit switches SW3 and SW4 are also provided for the event that the "normal" and "heavy" collected particle load conditions sensed by assembly 50 are exceeded due to electrical or mechanical breakdown in the precipitator control.

Hydraulic load cell 53 is placed in the tension mode in this application, being supported at the top by support frame 54 and supporting a corner of the collecting cell unit 55 from its other end via support rod 56. The load cell assembly 58 is provided with a center weight pointer 57 that deflects to the left to trip the set needle 52 when the collected particle load on unit 55 has reached a "heavy" condition, and moves to the right or up to trip the trip needle 51 when a "normal" collected particle load condition is attained. Such Bourdon pointers are well known. The pointer 57 merely reacts to the hydraulic fluid pressure in load cell 51 via hydraulic lines 59, as does also safety switches SW3 and SW4. The photoelectric switches within housing 50 are actuated by a flag (not shown) on the internal portion of pointer 57 which passes through photoelectric beams as will be explained further on in greater detail.

Now referring to logic diagram FIG. 2, an eight rapper set system is described.

In FIG. 2 there are eight weight sensor limit switch sets, LS-1 chrough LS-8, corresponding respectively to each respective rapper set No. 1 through rapper set No. 8 which appear at the right-hand side of the figure. Each of the limit switch sets LS-1 through LS-8 include therein switches SW1, SW2, SW3 and SW4. Switches SW1 and SW2 are for "normal" particle load sensing and for 'heavy" particle load sensing, respectively, in each of the weight sensor load cell devices employed, such as indicated in FIG. 3.

For the purpose of illustration, FIG. 2 will first be discussed in conjunction with FIG. 3. Micro switch SW1 of FIG. 2 would be housed in limit switch 17 illustrated in FIG. 3 and micro switch SW2 would be housed in limit switch 18.

Switches SW3 and SW4 are employed only under abnormal operation conditions as previously discussed. Switch SW3 closes only in the event that overrapping occurs and switch SW4 closes only in the event of underrapping due to a system failure. These switches, SW3 and SW4, may be mounted in the same manner as illustrated for switches SW1 and SW 2 (limit switches 17 and 18) as illustrated in FIG. 3. They may be mounted in the same assembly shown in FIG. 3 or in any similar manner. In any event, they actuate only when the collected precipitant weight from the precipitator electrodes becomes less than or greater than the predetermined desired amount which is normally regulated by the operation of switches SW1 and SW2. The operation and function of the annunciator switches SW3 and SW4 will be explained in greater detail hereinafter.

In order to provide the proper switch logic combination as required for the logic circuits of switches SW1 and SW2 contained in each limit switch set LS-1 through LS-8, switches SW1 and SW2 must be designed and adjusting screws 13 and 14 of FIG. 3 positioned such that the switches are never closed simultaneously. To accomplish this, switches SW1 and SW2 are designed to close when their limit arms 15 and 16 (FIG. 3) are depressed to a given position and then open again when their limit arms are depressed further by a small increment. The same operation occurs in reverse when their limit arms are released. Thus, by judicious adjustment of screws 13 and 14, switch SW1 (17) can be made to close and open before SW2 (18) closes as the weight on the collecting electrode increases and applies a downward force on the upper leg of C-shaped spring 20. As the weight decreases due to rapping, the reverse sequence of operation by SW1 and SW2 will occur, that is, SW2 will open before SW1 closes and opens. Since the operating characteristics of switches SW1 (17) and SW2 (18) are fixed by the physical assembly of the load sensor 10, the setting of adjustment screws 13 and 14 therefore permits one to regulate the desired particle load limits for "normal" and "heavy" precipitant loads by setting the switching points of SW1 and SW2 respectively. The ability to adjust these points provides the much desired flexibility to tailor the rapping system to the particular precipitator rapping needs with respect to the amount of precipitant collected to initiate rapping and the amount removed by rapping.

As previously mentioned, many other weight sensing load cell devices may be employed other than that illustrated in FIG. 3. For example, a preferred hydraulic load cell with a Bourdon tube readout employing a photoelectric device may be substituted as shown in FIG. 4. As the collected precipitant load increases, pointer 57 is pivoted or otherwise moved by the pressure exerted from the Bourdon tube. The flag of this pointer is thus free to pass through the exterior field of view of two spaced photoelectric switches thereby activating switch SW1 as the pointer blocks the light source of the upper photoelectric device (preset by trip set needle 51) when "normal" precipitant load has been achieved, and will pass thereon through to immediately open switch SW1 again and will then continue on its movement to the second (lower) photoelectric device (preset by trip needle 52) as the precipitant load increases until the pointer activates the second photo electric device to close (and open again after a further small increment of movement) switch SW2 to indicate a "heavy") precipitant load. This feature as previously explained is designed into the switching mechanism in order to prevent switches SW1 and SW2 from being closed simultaneously. This is required in order to operate flip-flops FF-1 through FF-8 in the desired manner for the operation of the rapper-set controls.

Masterslave flip-flops FF-1 through FF-8 are bistable, thus providing one of two logic outputs. The truth table describing operation of this type of flip-flop in conjunction with the weight sensor switches is as follows:

TRUTH TABLE I

Switching Sequence Steps	Collecting Electrode Weight	INPUTS R SW1	INPUTS S SW2	OUTPUTS Q	OUTPUTS $\bar{Q}$	Rapper
1	Below Normal	1 Open	1 Open	0	1	Off
2	Normal	0 Closes	1 Open	0	1	Off
3	Increasing	1 Opens	1 Open	0	1	Off
4	Heavy	1 Open	0 Closes	1	0	On
5	Decreasing	1 Open	1 Opens	1	0	On
6	Normal	0 Closes	1 Open	0	1	Off

Cycle repeats at Step 3. Switches SW1 and SW2 are normally open and a fixed bias representing a logic 1 is placed on the S(set) and R(reset) terminals from terminal B via resistors R1 and R2 to reduce the possibility of noice interference. In the truth table, the numeral 1 indicates a positive voltage and the numeral 0 indicates no voltage. The design of flip-flops FF-1 through FF-8 are such that a 1 on both the R and S terminal causes no change in the state of operation of the flip-flop. A logic 1 on the Q output of each flip-flop FF-1 through FF-8 represents the output signal, while a logic 0 represents no signal.

For the purposes of explanation, we will assume that to begin with there is no precipitant load on the precipitator plate. As the weight of the collected precipitant increases, the weight on the load cell icreases until the predetermined weight for "normal" precipitant load is obtained. At this time, switch SW1 of the corresponding limit switch LS-1 through LS-8 is closed or closes and this places a ground or a logic 0 on the R terminal of the corresponding flip-flop FF-1 through FF-8. A logic 1 remains on the S terminal of the flip-flop.

According to the truth table, the Q output of the flip-flop in question remains at a logic 0 regardless of how many times the R terminal goes to a logic 0 under these conditions, so long as a logic 1 remains on the S terminal. Thus, it will be noted that two logic 1's do not change the state of the RS flip-flop. The state of the flip-flop only changes when one of the terminals is driven with a logic 0 while the other remains a logic 1. As previously noted, switches SW1 and SW2 are designed such that it is impossible to obtain simultaneously a logical 0 on the R and S inputs of flip-flops FF-1 through FF-8 at the same time in order to provide or obtain the proper input conditions for the flip-flops so that the operation thereof will be as indicated by the truth table. Accordingly, after switch SW1 closes, it is automatically reopened quickly thereafter as indicated at steps 3 of the table, in order to prevent the simultaneous occurrence of a logic 0 on both the R and S terminals when the proper conditions are maintained for switch SW1 to close.

As the collected precipitant load continues to apply more pressure to the weight sensor load cell, no changes take place until the weight continues to increase in a sufficient amount to activate switch SW2 indicating that a "heavy" precipitant load has been obtained. At this point, the S terminal now has a logic 0 present while the R terminal retains its logic 1. Accordingly, the corresponding flip-flop will change states to have a Q output of a logic 1.

As will be explained hereinafter, when the conditions of step 4 of truth table 1 occur, a logic 1 is obtained at the Q terminal of the corresponding flip-flop, which we will assume at the moment energizes the corresponding rapper set. As the collected particle load diminishes due to the rapping, the weight applied to the weight sensor load cell device is diminished, thus withdrawing the contact which in the previous instance of step 4 had closed switch SW2, thereby opening switch SW2 again as indicated in step 5.

As the collected precipitant weight continues to decrease no change of the state of the RS flip-flop occurs until the switch SW1 closes at the time the precipitant weight collected diminishes to "normal." This applies a logic 0 to terminal R of the corresponding flip-flop to change the state thereof. When the Q output thus becomes a logic 0 at step 6, the corresponding rapper set is then deenergized. This represents one complete cycle of operation of the weight sensor. As the precipitator weight begins to once again increase, the cycle will repeat.

If we are dealing with a small precipitator unit which incorporates only one rapper set, then the output Q of the corresponding flip-flop, such as the flip-flop FF-1, for example, can be connected directly to a rapper set driving means which is functional to turn on the rapper set when presented with a logic 1 from the corresponding flip-flop Q output, and to deenergize the rapper set when a logic 0 output is obtained. However, when a plurality of rapper sets must be employed for a large precipitator unit, as illustrated in FIG. 2, then the decoder is preferably provided as indicated to prevent activation of more than one rapper set at one time.

There is a possibility that noise interference with any of the circuitry could be present and cause the rappers to turn on or off prematurely. Furthermore, it is also possible that the rappers may become very weak, or possibly, the micro switch assembly or photoelectric switch assembly used in conjunction with switches SW1 and SW2, may become defective. There is the additional possibility that the rappers may unexpectedly short to ground by causing them to remain on. In order to temporarily correct the situation, the aforementioned upper and lower limit switches SW3 and SW4 are provided for each load cell device. These switches perform two functions. In the event of noise, the upper and lower limit will reset the masterslave flip-flops FF-1 through FF-8 into the proper mode of operation by grounding either the R or S terminal. At the same time, these switches are operable to ground an alarm light or horn to inform the operator of the particular problem. An example of this alarm device is indicated in conjunction with switch SW4 of limit switch set LS-1 of FIG. 2. Here, a lamp L1 is used as the alarm signal and is supplied with a dc voltage as indicated. When switch SW4 is activated, the lamp L1 is grounded such that it is energized and at the same time the S terminal of flip-flop FF-1 is also grounded to apply a logic 0 to the S terminal thereby changing the state in the flip-flop to cause energization in the rapper set 1, assuming that the same failed to energize previously. As similar lamp circuit could be used in conjunction with SW3 to indicate a light precipitant load due to a rapper overrapping.

The N or eight-count counter consists of J-K flip-flops, IC-A, IC-B, and IC-C. These flip-flops form a standard ripple counter which is well known in the art. The eight counter is driven by the clock circuit which is shown in block form. The clock can eaily be made by using a unijunction transistor circuit or similar circuit and, simply provides evenly spaced pulses at predetermined intervals. The D input to the clock is provided for the purpose of stopping the pulse output of the clock when desired.

The N-counter or sequencing circuit J-K flip-flops IC-A, IC-B, and IC-C, count the clock or timing pulses on line C emitted from the clock producing a different binary number for each pulse. The N(8) different binary numbers are then converted into N(8) different outputs by the decoder including N(8) logic NAND gates. This sequencing or counter circuit will thus produce N different sequenced outputs, for example, eight outputs as shown in FIG. 2.

The operation of the counter or sequencing circuit is well known and a detailed explanation of this operation may be had by referring to a description of the same in our U. S. Pat. No. 3,487,606 which issued Jan. 6, 1970 for Frequency and Duration Control for Electrode Rappers.

Truth table No. 2 applies for flip-flops IC-A, IC-B, and IC-C.

TRUTH TABLE 2

Clock Pulse	IC-A Q_1	IC-A $\bar{Q}_1$	IC-B Q_2	IC-B $\bar{Q}_2$	IC-C Q_3	IC-C $\bar{Q}_3$
0 - - - -	1	0	1	0	1	0
1 - - - -	0	1	1	0	1	0
2 - - - -	1	0	0	1	1	0
3 - - - -	0	1	0	1	1	0
4 - - - -	1	0	1	0	0	1
5 - - - -	0	1	1	0	0	1
6 - - - -	1	0	0	1	0	1
7 - - - -	0	1	0	1	0	1
8 - - - -	1	0	1	0	1	0

As explained in our aforementioned patent, the sequencing or counting circuit is easily adapted or reconstructed so that any number of flip-flops may be added or withdrawn in order to count the desired N binary numbers depending upon the number of rapper sets being operated by the control.

The N counter or sequencing circuit output is appropriately connected to the decoder input NAND gates IC-1 through IC-8 such that they are sequentially, but not simultaneously, strobed or made ready to open or turn on provided an input is also being received by the respective NAND gate from its corresponding weight sensor indicating a "heavy" precipitant load condition. Thus, each of these NAND gates IC-1 through IC-8 is connected to its correspondingly numbered RS flip-flop FF-1 through FF-8 in the weight sensor circuit. The remaining inputs of the decoder NAND gates are connected to the N-counter flip-flops to sense the eight unique binary numbers formed by the flip-flops of the eight counter. Thus, the outputs from any of the NAND gates IC-1 through IC-8 will change to a logic 0 state only in the presence of the eight counter number decoded by that gate and a logic 1 level from that gate's corresponding weight sensor RS flip-flop FF-1 through FF-8. In this manner, the weight sensors are sequentially monitored for sensing a "heavy" condition; however, they are not necessarily monitored in numerical order as presented as is the case in the control illustrated in FIG. 2.

To explain the operation of the decoder in a different manner, these NAND gates are connected to the flip-flops IC-A, IC-B, and IC-C, so that each clock pulse will cause only one gate at a time to change states. The truth table for the NAND gates is given in truth table 3.

TRUTH TABLE 3

INPUTS 1	2	3	4	NAND OUTPUTS
0	0	0	0	1
0	0	0	1	1
0	0	1	0	1
0	0	1	1	1
0	1	0	0	1
0	1	0	1	1
0	1	1	0	1
0	1	1	1	1
1	0	0	0	1
1	0	0	1	1
1	0	1	0	1
1	0	1	1	1
1	1	0	0	1
1	1	0	1	1
1	1	1	0	1
1	1	1	1	0

These gates thus provide a logic 0 output when any of the respective gates changes state to initiate a rapper set. This output then serves to energize the corresponding driver circuits, switches, and rapper sets and is also used to start the on-timer network shown in block form via the NAND gate IC-D which forms another portion of the decoder circuit.

NAND gate IC-D isolates the different outputs of the decoder and provides the appropriate logic level to start the on-timer and stop the clock and N-counter for the duration of the on-time of the respective decoder NAND gate.

This arrangement therefore allows only one rapper set to operate upon command of the corresponding weight sensor at any given time, regardless of the remaining sensor state. It also provides a limit on rapping time by the on-timer and suspends the search operation provided by the eight counter and decoder network as long as one of the rappers remains energized.

Referring now to FIG. 5, a detailed version of the on-timer and clock of FIG. 2 is illustrated. For convenience, the operation of the control system will be described concurrently with the construction.

Before initial rapping of any rapper set occurs, when all plates or wires are clean, the system is energized by the application of the B+ as indicated in FIGS. 2 and 4. The B+ is normally a dc voltage determined by the type of logic elements used in the circuit design.

Assuming for the moment that none of the weight sensor switches sense a "heavy" precipitant load, all the Q outputs of FF-1 to FF-8 will be at logic 0 and the outputs of gates IC-1 to IC-8 at logic 1. This condition will cause the output of NAND gate IC-D to be at logic 0 as well as preventing any rappers from being energized.

Referring to FIG. 5, the logic 0 from IC-D will enter the clock circuit on line D causing switching transistor Q5 to be in an "off" state, thus allowing capacitor C_2 to be charged through resistor R_{13} and potentiometer P_1. When capacitor C_2 reaches a voltage determined by the parameters of unijunction transistor Q2, capacitor C_2 will discharge through transistor Q2 through resistor R19, producing a voltage pulse. This voltage pulse is coupled to the base of switching transistor Q3 causing its collector to change from a voltage corresponding to a logic 1 to a logic 0. Thus, a logic 0 pulse is produced at the output of the clock circuit which is coupled through NAND gate IC-10 to line C which places a logic 1 pulse on the eight counter causing the count to advance by one. The clock will continue to produce output pulses to the eight counter with a time base determined by potentiometer P1 and capacitor C2. Thus, by adjusting potentiometer P1, a wide range of pulse rates, and therefore counting rates of the eight counter, can be obtained. This ultimately determines the search rate of the system as it scans the weight sensor switches for "heavy" conditions.

As long as all the weight sensor switches remain "normal," a logic 0 remains on line D. This logic 0 is inverted by IC-9 to a logic 1 on line A which is the input to the on-timer circuit as shown in FIG. 5. The logic 1 on A causes switching transistor Q1 to remain "on" which prevents capacitor C1 from charging. The uni-

junction transistor Q3 and switching transistor Q4 operate in a similar manner to transistors Q2 and Q3 in the clock circuit. Thus, as long as capacitor C1 remains discharge, the on-timer circuit remains quiescent with an output of logic 1 to gate IC-10.

If any of the weight sensors reach a "heavy" condition, its corresponding flip-flop (one of FF-1 through FF-8) will have a Q output of logic 1. As soon as the eight-counter reaches the count of the corresponding gate (one of IC-1 through IC-8), the gate's output will change from a logic 1 to a logic 0 immediately energizing the corresponding rapper set. Simultaneously, the logic level on line D will change from *a*0 to *a*1, preventing capacitor C2 on the clock circuit from charging, stopping the pulse output from the clock. This suspends the search mode for the duration of the rapping. The logic 1 on line D is converted to a logic 0 on line A which releases capacitor C1 of the on-timer. Thus, the charging of C1 initiates the on-time. Potentiometer P2 determines the length of this on-time over a wide range of variation.

At this point, one of two possibilities exist in the system. Under normal operation, the on-time is set such that the precipitant load will decrease to the "normal" weight before the on-timer times out. If abnormal circumstances exist, the weight may not return to "normal" and the on-timer will time-out first.

If the normal operation prevails, the weight will reach a "normal" load causing the weight sensor to stop rapping. This causes the logic 1 on line D to change back to a logic 0, clamping capacitor C1 of the on-timer and resetting the on-timer. Simultaneously, the clamp on the clock capacitor C2 will be removed and it will start charging. Thus, the clock is placed back in operation to once again initiate the search mode for "heavy" plates.

In the event that abnormal conditions exist and the precipitant weight does not return to "normal" before the on-timer times out, a logic 0 pulse is produced at the output of the on-timer at the end of the on-time. This pulse is coupled through gate IC-10 to line C causing the eight counter to advance one count. Thus, the rapper in operation will cease and the system will revert to its normal search mode. Any other "heavy" plates will be rapped until the abnormal plate is again rapped. In this manner, the system is prevented from locking on any one set of plates and ignoring the remaining plates.

The operation and construction of drivers 1 through 8 and their respective triac switches 1 through 8 is explained in detail in connection with FIG. 6.

Once any of the NAND gates IC-1 through IC-8 is energized or turned on, a logical 0 (essentially ground) appears on the base of transistor Q5 through base resistor R20. Transistor Q5 then shuts off, and allows the proper gate power to flow into the triac switch TR-1 through resistor R21 thereby turning the respective rapper set on.

A suitable rapper is shown and described in the John W. Pennington U.S. Pat. No. 3,030,753 and our U.S. Pat. No. 3,487,606.

One particular advantage of incorporating the triac switch TR-1 for energization of the respective rapper set is that the firing angle of the triac may be varied by a suitable phase controlled circuit. Accordingly, the rapper intensity may be selectively preset to any desired value by adjusting the firing angle of the triac TR-1.

Furthermore, it is advantageous to initiate the rapping of any one rapper set with a preset intensity level and then to thereafter raise this intensity level up to a maximum. In this manner, the outermost collected precipitant load will be gently removed in large amounts thereby preventing the reentrainment and thereafter the precipitant lying more closely adjacent the electrode is removed by gradually increasing the intensity level of the rapping to a maximum. This feature can be accomplished by the use of an automatic phase control circuit which are well known in the art for the control of a triac switch. Furthermore, the aforementioned feature of phase control adjustability by a manual presetting and the latter mentioned automatic feature may be combined in one unit to provide an automatic adjustable phase control circuit for the control of the triac switch TR-1. For reference to such intensity controls, one should refer, for example, to Chapters 7 and 9 of the *General Electric SCR Manual*, 4th Edition; Chapter 8 of *Semiconductor Controlled Rectifiers; Principles and Applications*, by Gentry, Gutzwiller, Hollonyals, and Von Zastrow, Prentice Hall; and Pages 226 to 261 of the *RCA Power Circuits Handbook*, 1969. U. S. Pat. No. 3,525,021, issued to R. G. Engam illustrates another example.

The foregoing describes the construction and operation of a solid state electronic control system for the removal of precipitant collected on the precipitator electrodes wherein load sensors sense or weigh the collected particle load and energize corresponding rappers when the particle load exceeds a predetermined limit to deenergize the same when the particle load magnitude reaches a predetermined minimum or "normal" condition. The control of the present invention not only permits the operator to select the mode of rapping best suited for conditions within the precipitator, but also initiates rapping only when it is needed and removes only a predetermined amount in order to optimize the amount of precipitant on the collecting plates and wires of an electrostatic precipitator in order to permit it to operate at its greatest efficiency. Furthermore, the weight sensors are sequentially monitored when a plurality of them are provided in order to prevent the simultaneous rapping of more than one rapper set.

Although the invention has been described in its preferred embodiment and mode of operation as a solid state electronic device, it is obvious that the principles of the present invention may be carried out with mechanically equivalent power systems such as fluid or hydraulic systems. As an example, FIG. 7 illustrates an alternative embodiment wherein the control is pneumatically operated. The control here is shown in its simplest form for a small precipitator unit requiring only one rapper set.

A pneumatic cam valves 101 and 102 respectively, which are part of the weight sensor 110. The weight sensor 110 further includes the C-shaped tension spring 103 which has its upper arm anchored as indicated and its lower arm connected to a precipitator plate in order to suspend the same.

When the precipitator plate together with its collected precipitant reaches the "heavy" condition actuator 104 is secured to the bottom arm of C spring 103 and deflected downwardly in an amount sufficient to depress contact 105 of the lower limit pneumatic cam valve 102 to thereby actuate the same and subse-

quently displace the pneumatic pilot operated valve **107** such that the air supply connected thereto is directed to the pneumatic rapper **108** in order to actuate the same and rap or vibrate the precipitator plate through the rapper rod **109** which is connected to and suspends the other end of the precipitator plate.

As the precipitant collected on the precipitator plate is removed the C spring **103** raises actuator **104** until the "normal" precipitant load condition is attained at which time actuator **104** will engage contact **106** of the pneumatic cam valve **101** to activate the same and whereby displace the pneumatic pilot operated valve **107** in order to disconnect the air supply to pneumatic rapper **108** to deenergize the same. At the same time, cam valve **102** is forced to its off position.

A suitable pneumatic rapper which may be incorporated in the pneumatic embodiment of the present invention is illustrated in the J. W. Pennington U. S. Pat. No. 3,030,753.

We claim:

1. An electrostatic precipitator having electrodes, rapping means therefor, and an electronic logic control for regulating the frequency and duration of rapper energization comprising:

a clock pulse generator circuit for producing a series of clock pulses at a selected frequency having first and second logic levels;

a ripple counting circuit operative in response to first and second logic levels of said clock pulses to produce monitoring sequence pulses having first and second logic levels;

a load sensing circuit operable to sense the particle load magnitudes collected on different selected ones of said electrodes and produce in response to said sensing load pulses having first and second logic levels indicative of a desired rapping on-time and off-time respectively as defined within a maximum and minimum desired particle load magnitude for each of said different selected ones of electrodes;

a decoding monitor circuit operable in response to said first and second logic levels of said monitoring sequence pulses and to said load pulses for sequentially monitoring said load pulses and selectively producing rapper driving pulses having first and second logic levels, said rapper driving pulses being produced in separate output channels corresponding in number to and respectively associated with each of said different selected ones of electrodes and being sequentially selected by said first and second logic levels of said monitoring sequence pulses when the on-time is indicated by said first and second logic levels of the respective one of said load pulses then being monitored;

a rapping means driving circuit having associated channels for connecting said rapper driving pulses to respective ones of said rapping means respectively associated with said different selected ones of said electrodes for energization;

means responsive to said first and second logic levels of said rapper driving pulses to interrupt the feed of said series of clock pulses to said ripple counting circuit during said rapping on-time and activate the feed of said series of clock pulses to said ripple counting circuit during said rapping off-time; and

an on-timer circuit operable in response to said first and second logic levels of said rapper driving pulses for timing a maximum allowable duration of energization of any of said rapping means and reactivating the feed of said series of clock pulses to said ripple counting circuit in the event said maximum time is attained.

2. The control of claim **1** including means for regulating the intensity of said rapper energization.

3. The control of claim **1** wherein said load sensing circuit includes a plurality of load cell actuated switches connected respectively to a corresponding number of bi-stable flip-flops, said switches operable to set and reset said flip-flops for producing said load pulses.

4. The control of claim **3** wherein said load cell actuated switches include means for setting a maximum and minimum load actuation switching limit therefor corresponding to said desired maximum and minimum particle load magnitudes respectively.

5. The control of claim **1** including an annunciator circuit responsive to load cells in said load sensing circuit for producing alarm signals when said particle load magnitude is above said maximum magnitude by a preselected amount and said particle load magnitude is below said minimum magnitude by a selected amount.

6. The control of claim **1** further including:

a solid state switch for completing a current path upon being made conductive for a current supply to each of said rappers for energization thereof;

each of said switches connected to corresponding ones of said channels and made conductive during the duration of said monitored load pulses present on the respective channels;

whereby said rappers are energized in a sequence and for a time regulated by need.

7. An electrostatic precipitator for removing particles from a gas comprising:

discharge electrodes for applying an electrostatic charge to said particles,

collecting electrodes for collecting said charged particles,

a plurality of rappers operable upon energization for vibrating preselected portions of said collecting electrodes to remove particles collected thereon,

means for sequentially monitoring the amount of precipitant load collected on said preselected collecting electrode portions,

means for interrupting said means for monitoring and energizing said rappers having corresponding collecting electrode precipitant loads exceeding a predetermined limit upon being monitored,

means for de-energizing said energized rappers and reactivating said means for monitoring when said precipitant load attains a predetermined minimum,

and on-timer means for reactivating said means for monitoring upon the failure of said means for de-energizing the rappers and reactivating the means for monitoring to function after a maximum predetermined period of energization time required for attaining said minimum predetermined precipitant load.

8. The electrostatic precipitator of claim **7** including means for rigidly supporting said collecting electrodes, said means for sequentially monitoring the amount of said collected precipitant load including pressure sensitive load cell devices operatively positioned in said rigid supporting means to sense in the tension or compression mode the weight of respective of said preselected collecting electrode portions plus the corresponding precipitant load collected thereon.

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