Sept. 28, 1954 D. C. COX 2,690,258

HIGH-SPEED HIGH-SENSITIVITY SORTING MACHINE WITH MULTIPLIER TUBE

Filed Oct. 11, 1949 2 Sheets-Sheet 1

Fig. 1

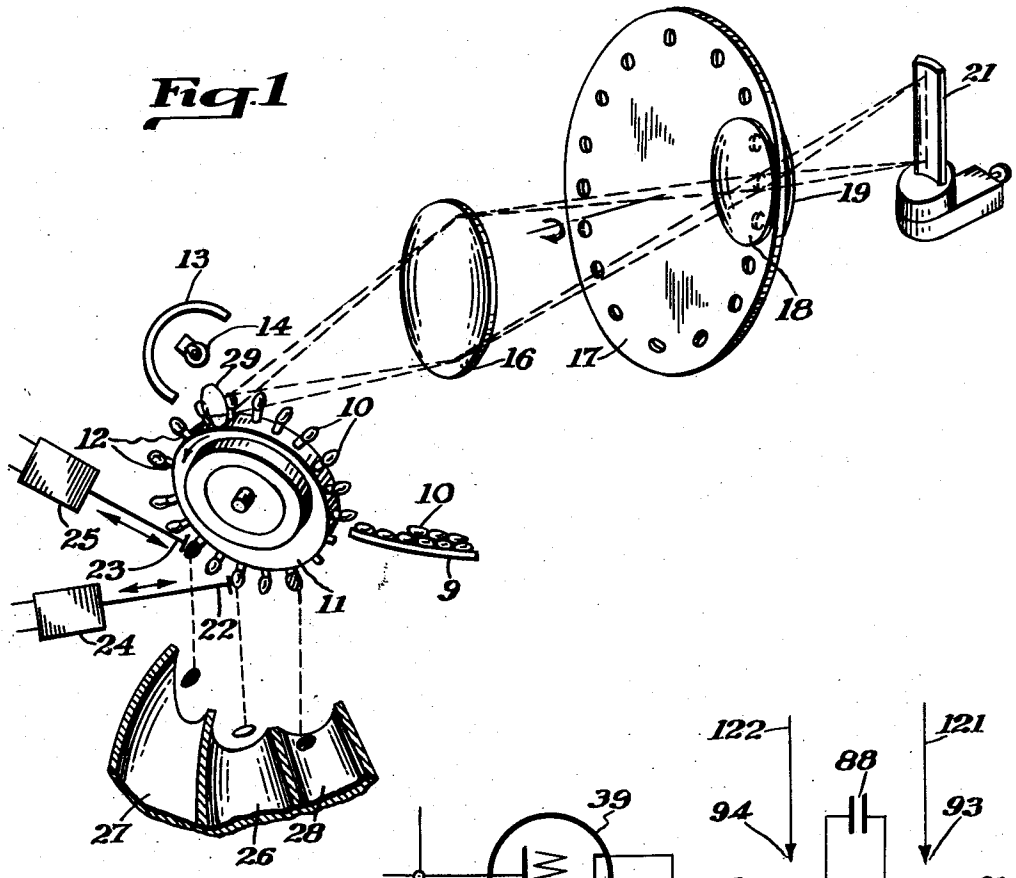
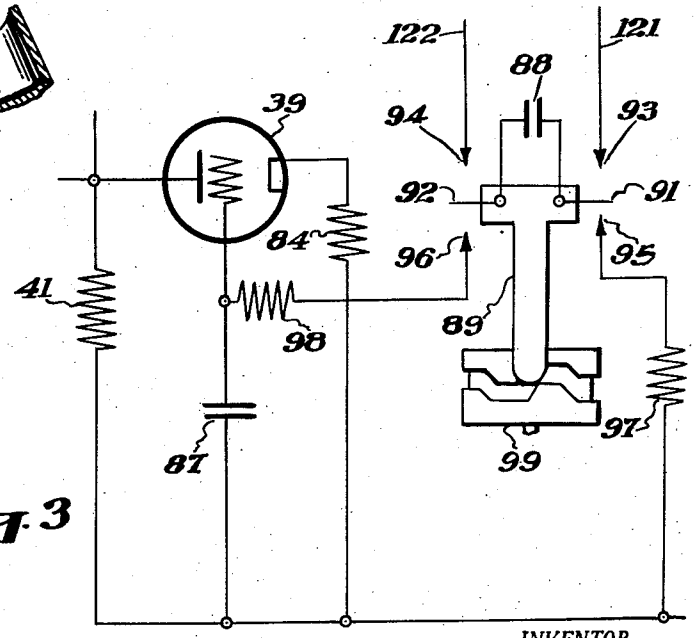


Fig. 3



INVENTOR.
DAVID C. COX.

BY Frederic B. Schramm

ATTORNEY.

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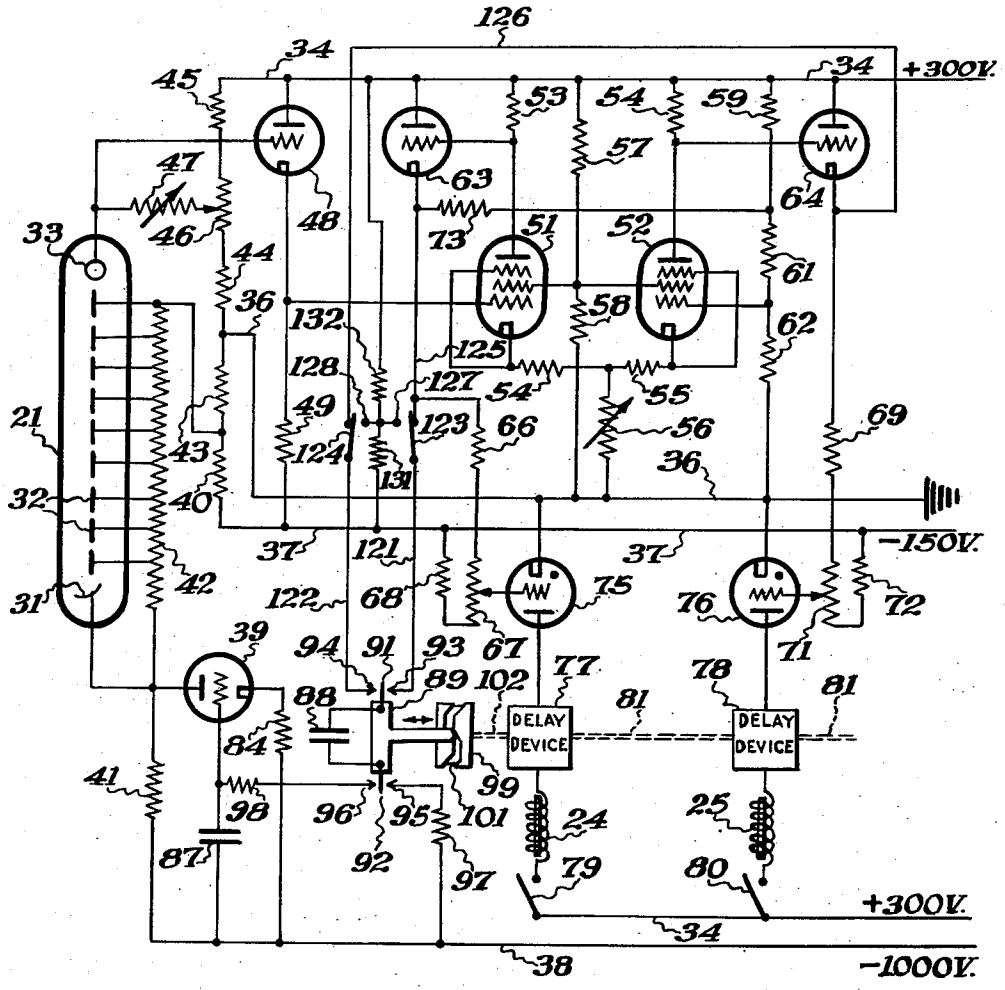


Fig. 2

INVENTOR.
DAVID C. COX.

BY Fredrik B. Schramm

ATTORNEY.

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2,690,258

HIGH-SPEED HIGH-SENSITIVITY SORTING MACHINE WITH MULTIPLIER TUBE

David C. Cox, Grand Rapids, Mich., assignor to Electric Sorting Machine Company, Grand Rapids, Mich., a corporation of Michigan

Application October 11, 1949, Serial No. 120,724

13 Claims. (Cl. 209—111)

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My invention relates to optical sorting and is principally directed to a light-responsive system.

The principal object of the invention is to improve the sensitivity, speed, and accuracy of photoelectric devices such as sorting machines.

Optical sorting machines of the photoelectric type have been employed, for example, in the classification of fruits, beans, and nuts on a basis of light reflecting power or color so that the product, after classification by the machine, is substantially uniform and so that discolored or otherwise defective specimens are rejected. The machines are not only much more rapid in action than human inspectors or graders, but are far more accurate and consistent.

Examples of the type of machines to which reference is made are disclosed in my U. S. Patents Numbers 2,131,095; 2,152,758; 2,244,826; 2,264,621; 2,325,665; and 2,474,230, and in my copending application Serial Number 738,714, filed April 1, 1947, now Patent No. 2,625,265. In general, these machines and the machine of the present invention include a conveyor by which the objects are moved through a viewing station in which they are illuminated and the light reflected from the objects affects a photoelectric cell. The photoelectric current, which varies with the reflection characteristics of the object, is amplified and the amplified potentials, by means of gas-filled tubes and electromagnetic actuators, operate ejectors or other means by which objects too light or too dark or of the wrong color are diverted from the normal path through the machine and thus separated. If color discrimination is desired, a masked cathode ray tube and photoelectric relay operated thereby may be employed, as in my Patent No. 2,244,826. The machines ordinarily may segregate either objects which are too light or those which are too dark, and in some cases, as in the present invention, may segregate both light and dark objects, passing those objects which fall within a predetermined range of reflectivity, which may be termed a band pass operation.

A serious problem with such machines is that of maintaining accuracy and constancy in calibration of the machine in spite of such disturbing effects as variations in line voltage, changes in temperature, ageing of lamps, photocells, vacuum tubes, and other elements of the electrical system, dust or dirt in the optical system, etc. Various approaches to this problem, which have greatly improved the performance of sorting machines, have been disclosed in the abovementioned patents. In general, this self-correcting feature of the machines, which I have termed "normalizing"

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has involved intermittently exposing the photoelectric cell to a standard of brightness, usually a reference background viewed in the intervals between the passage of the objects. The overall response of the system to the reference object is employed in some manner to vary the sensitivity or trip point of the amplifier so that a standard output is obtained when the standard object is viewed.

An important object of this invention is to regulate the system to maintain a constant response notwithstanding the abovementioned disturbing factors as well as to accomplish this result more reliably than heretofore. Another advance in the art accomplished by this invention is the improvement of the light-responsive system to achieve a higher sensitivity of response to small variations in reflectivity of the objects, which, moreover is achieved with a substantial decrease in the intensity of light required.

In carrying out the invention there is incorporated in the system a phototube of the electron multiplier type and means are provided by which the multiplication factor of this tube is regulated to compensate for changes, both in this tube and in other units of the system, which affect the response of the system.

Another advantage of the invention is that it is well adapted to use with various devices for presenting the objects to the phototube and with various devices by which off-standard objects are separated. The conveying portion of the device may be, for example, of various forms disclosed in my previous patents, such as a wheel on which the objects are retained by suction, a screw or other conveyor by which they are pushed through the viewing zone, or a compartment through which the objects fall by gravity. The device by which the objects are segregated may be of any known type appropriate to the nature of the objects and the character of the apparatus by which they are presented for inspection.

Further objects of this invention are to increase the speed of response of the photoelectric system and the speed with which the intermittent regulating operation is accomplished.

Because of the rapid response, made possible by my arrangement, the invention is particularly suited to sorting machines of a scanning type as disclosed in my abovementioned Patent Number 2,474,230. In this machine, the surface of the object under examination is scanned, and therefore a large number of brightness measurements are made during the short time in which it is traversed through the sighting zone in comparison to

machines in which a single overall reflectivity determination is made.

A particular object of the invention is the improvement of sorting machines of the scanning type. For this reason, the invention is illustrated as incorporated in a machine of the type disclosed in Patent Number 2,474,230, although it is applicable to machines in accordance with my other patents, as previously stated, and may be employed beneficially in various photoelectric examining machines and processes.

Provision of an efficient, rapid, and accurate self-regulating feature for the system is an important object of this invention. The preferred regulating means employs a condenser which is charged in accordance with the response of the machine to a standard object and then furnishes grid bias to a vacuum tube in the system to standardize the output of the system. A relatively large condenser may be employed to provide great constancy of the bias voltage, without causing great charging time or requiring a low-impedance charging circuit. In this invention, the condenser is unaffected by the objects examined. A new principle of regulation, involving varying the inter-electrode voltage of an electron multiplier phototube under control of the regulating condenser, and which is extremely sensitive, also contributes to the advantages of the invention.

By way of introduction to the complete description of the preferred embodiment of the invention, the nature of the electrical system may be outlined as follows: The dynodes of the electron multiplier phototube are connected to a voltage divider in the usual manner. A regulating device is interposed between the power source and this voltage divider so that the electrode voltages may be regulated. This regulating device is preferably a vacuum tube, the effective resistance of which may be changed by varying its grid potential. Variations in light entering the photocell vary its output current and thereby the drop in a series resistor in the usual manner. The resulting potential variations control an amplifier, which is preferably one of a phase-inverting type employing two pentode tubes, the outputs of which vary oppositely with changes in the control potential but are normally balanced. It is desirable to couple the photocell to the amplifier by means of a cathode follower circuit.

Each pentode output is connected to a gas-filled tube or thyratron by means of a cathode follower circuit. The thyratron tubes, which are normally non-conducting, are each coupled to an ejector or other arrangement for separating the objects. Since the amplifier outputs vary reversely, one thyratron fires and operates an ejector when too light an object is inspected, and the other thyratron responds to objects which are too dark. The thyratrons will usually be coupled to the ejectors through time-delay circuits or devices which may, for example, be of the character of that disclosed in my Patent Number 2,264,621, so that the ejectors may be located at suitable distances from the viewing point.

Regardless of changes in constants of the system within almost any range short of complete failure of the circuit, there will be a value of multiplication factor of the photocell at which the two amplifier outputs are balanced when the tube is exposed to the standard object. If the two outputs are not balanced under this condition, the difference of potential of the two outputs is employed to vary the grid potential of the regulator tube previously mentioned. The actual regulating potentials are taken from the outputs of the cathode follower tubes, which makes possible rapid regulating action notwithstanding the high impedance of the pentode plate circuits.

Specifically, the regulating action is accomplished in the preferred form of the invention by charging a condenser by inserting it in the circuit between the output of one cathode follower and a reference potential. The condenser is then shifted into a circuit between the other cathode follower output and the grid of the regulator. The bias of the regulator tube is thus varied in either direction to balance the system.

The nature of the invention, the advantages thereof, and the manner in which the various objects are realized will be more clearly apparent from the following description of the preferred embodiment of the invention.

Referring to the drawings, Fig. 1 is a schematic diagram of a sorting device in accordance with the invention; Fig. 2 is a circuit diagram of the system; and Fig. 3 is a partial circuit diagram illustrating a modification.

Fig. 1 illustrates in a schematic manner the general layout of an exemplary sorting machine according to the invention, details of structure being omitted because they are not necessary to an understanding of the present invention and because the physical structure of a machine of the character illustrated herein is disclosed in my Patents Numbers 2,325,665 and 2,474,230. The articles 10 to be sorted, which may be beans, peas, nuts, or the like, are fed by suitable means, indicated at 9, to a rotating conveyor 11 fitted with suction cups 12 on its periphery by which they are carried through a viewing or scanning zone in which they are illuminated and the light reflected from the object is measured by the photoelectric cell. This viewing zone is indicated schematically by the fragmentarily represented housing 13 in which a light source 14 is mounted. Light reflected from the beans passes through a condensing lens 16, a perforated rotating scanning disk 17, and lenses 18 and 19 to the photoelectric tube 21. The optical system and scanner as well as the hood or housing are disclosed more fully in my Patent Number 2,474,230. The scanning arrangement may be omitted if only the overall reflection of the object is to be measured.

Continued rotation of the conveyor wheel carries the objects 10, retained by suction, into the path of ejectors 22 and 23 operated respectively by solenoids 24 and 25. When a solenoid is energized, the ejector or pusher knocks the bean or other object from the conveyor so that it falls into an appropriate chute 26 or 27. As will be seen, ejector 22 serves to remove objects which are too light and the other ejector objects which are too dark. Appropriate delay mechanism is provided so that the ejection is delayed with respect to the viewing of a particular object for an interval equal to the time required for the object to progress from the viewing zone to the particular ejector. Objects which are not removed by the ejectors continue movement with the conveyor until they reach a zone in which the vacuum of the cup is cut off so that the objects fall freely into a chute 28.

A replaceable standard object 29 is disposed within the field of the photoelectric tube and

illuminated by the light source 14 so that, when it is not eclipsed by the test object 10, the photocell responds to light reflected from the standard object.

The device may be used to reject and collect separately objects which are lighter and darker by predetermined amounts than the reference object or background, thereby collecting in the chute 28 all objects within the desired range. This may be called band pass operation.

If it is desired to divide the objects into only two groups, depending upon whether they are lighter or darker than the predetermined level, one or the other of the ejectors may be inactivated so that either too light or too dark articles are rejected and the remainder are accepted.

The electrical sensing system by which the light striking the photocell controls the operation of the ejectors is shown in Fig. 2. The heater circuits of the tubes and the source of direct-current voltages for energizing the system are not shown, since these may be of any suitable type, and a description of them is not necessary to the understanding of the invention. The energizing voltages should preferably be held at constant values for the greatest accuracy of the system.

The photoelectric tube 21, of the electron multiplier type, comprises a cathode 31, dynodes 32, and an anode 33. The multiplier tube 21 is connected for energization to the D. C. source, the plus 300 volt line 34, zero or ground line 36, the minus 150 volt supply 37 and the minus 1000 volt line 38. The cathode 31 is connected through the regulator tube 39 in parallel with a high resistance 41, as will be described presently, to the 1000 volt negative line. The cathode is also connected to one end of the voltage divider 42, the taps of which are connected to the dynodes 32 and the other end of which is connected between the minus 150 volt and ground lines by a voltage divider formed by resistors 40 and 43. The values of the resistances are such that the last dynode is approximately 40 volts negative and the interelectrode voltages are substantially equal. The anode 33 is connected between the ground and 300 volt positive lines by a variable voltage divider consisting of resistances 44 and 45 and a potentiometer 46. Adjustment of the potentiometer 46 determines the normal voltage level of the anode and the load resistance of the multiplier tube is further adjusted by a variable resistor 47 between the anode and the potentiometer 46.

As will be apparent, the potential across the last multiplier stage between the final dynode and the anode is independent of the voltages across the other interelectrode gaps. The anode 33 is directly connected to the grid of a triode 48 acting as a cathode follower with the plate connected to the positive supply and the cathode connected to the negative line 37 through a resistor 49. The cathode of the tube 48, which closely follows the grid potential of the tube in a well-known manner, is directly connected to the control grid of a pentode amplifier tube 51.

Tube 51 and a second pentode tube 52 are connected in a phase inverting amplifier circuit. The plates of the tubes are connected to the positive supply through resistors 53 and 54, respectively, and the cathodes are connected to ground through individual biasing resistors 54 and 55 and a common variable biasing resistor 56. The suppressor grids of the tubes are connected to the cathodes, and the screen grids are energized by voltage dividing resistances 57 and 58 connected between the positive supply and ground. The control grid of the tube 52 is connected to the positive line through resistors 59 and 61 in series and to ground through resistor 62. These resistors form a voltage divider establishing the normal potential of the control grid of tube 52.

The plates of tubes 51 and 52 are directly connected to the control grids of triodes 63 and 64 connected as cathode followers with their plates tied to the positive supply. The cathode of tube 63 is connected to the minus 150 volt line through resistor 66, potentiometer 67, and resistor 68, and the cathode of tube 64 similarly through resistance 69, potentiometer 71 and resistance 72. The cathode of tube 63 is also connected to the center point between the voltage dividing resistors 59 and 61 through a resistor 73.

In the normal operation of the system with a standard object, the potential level of the cathodes of tubes 63 and 64 should be equal. If all circuit components were exactly balanced, the voltages of the control grids of the two pentodes should likewise be at the same level which may be, for example, approximately plus two volts, and the pentode cathodes at an equal potential more positive than the grids. The resistances 59, 61, and 62 are of such values that the control grid of tube 52 will be held at approximately a plus two volt level under standard conditions. Likewise, the values of the fixed resistors 44 and 45 and the setting of the variable resistor 47 and potentiometer 46 should be such that the control grid of tube 51 is at the same value, plus two volts, under standard conditions. If, for example, an object lighter than standard is viewed by the photocell 21, the photoelectric current will increase and thereby the potential of the grids of the tubes 48 and 51 will be made more negative. The current in the plate circuit of tube 51 will decrease and the grid and cathode of tube 63 will become more positive.

Decreasing current in the tube 51 decreases the current and therefore the voltage drop in the resistor 56 and thereby the potential of the cathode of the tube 52, so that the grid of tube 52 is less negative with respect to the cathode and the current in tube 52 increases. The control grid of tube 52 is also made less negative by the positive swing of the cathode of tube 63 to which it is connected by the voltage divider circuit formed by resistors 73, 61, and 62. For both these reasons, as the plate of tube 51 swings more positive, tube 52 conducts more current, and its plate becomes less positive, which plate swing is transmitted by tube 64 to its cathode.

Each of the cathode follower tubes 63 and 64 energizes a gas tube or thyratron which, in turn, energizes its respective actuating solenoid 24 or 25 of the ejector mechanism. The control grid of the thyratron 75 is connected to the variable tap of the voltage divider 67 and the grid of the thyratron 76 similarly to the voltage divider 71. The cathodes of these tubes are connected to ground and the anodes to the 300 volt positive line by way of delay mechanisms 77 and 78, indicated schematically, which are activated when the thyratron tube fires and energize the ejector solenoid 24 or 25 after suitable delay. These solenoids are connected to the positive line by switches 79 and 80 by which either ejector mechanism may be cut out if desired. The exact nature of the connections between the thyratron

tubes and the ejector solenoid is immaterial to the present invention. For example, the thyratron impulses may be stored in condensers carried by a rotating commutator and charged or discharged after appropriate rotation of the commutator to energize the solenoids, as described in my Patent Number 2,264,621. The delay mechanisms are indicated as actuated by a shaft 81 which may be coupled in any suitable manner to the driving mechanisms of the conveyor wheel 11.

The voltage dividers 67 and 71 are set so that under normal conditions the control grids of the thyratrons are of suitable potential to prevent firing of the tubes, as, for example, minus 6 volts. The normal level of the cathode follower outputs is in the neighborhood of 150 volts positive and the cathodes are tied to the minus 150 volt line, so that any appropriate control voltage for the thyratron may be derived by adjustment of the divider 67 or 71. As previously stated, when a light object is viewed the plate of tube 51, cathode of tube 63, and the grid of thyratron 75 swing positive. Therefore, by appropriate adjustment of the voltage divider 67, thyratron 75 can be caused to fire for any desired degree of deviation from standard of the object in the direction of lightness. Under these conditions, the grid of thyratron 76 becomes more negative, and the tube does not fire. Conversely, if the viewed object is too dark, the plate of tube 52 swings positive and that of tube 51 negative, so that thyratron 76 fires and thyratron 75 remains non-conductive. By appropriate adjustment of the potentiometers 67 and 71, the amount of swing required to fire the thyratrons may be adjusted and, thereby, the width of the band of color or brightness variation which the machine will tolerate.

The automatic adjustment of the machine to a standard of response, to prevent drift, is effected by varying the potential level of the cathode 31 of the multiplier tube and thereby of the dynodes which are coupled to the cathode through the voltage divider 42. The cathode 31 and voltage divider 42 are energized from the negative 1000 volt line 38 through the cathode-plate circuit of the regulator tube 39. The resistance 41 partially supplies the multiplier tube; its principal function is to limit the voltage across the regulator tube. The cathode of the regulator tube 39 is connected to the minus 1000 volt line through a low resistance 34 by which the cathode is maintained slightly more positive than line 38. The grid of the regulator tube is connected to one plate of a storing condenser 87, the other plate of which is connected to the negative line 38 for maintaining the grid bias of the tube during the viewing cycles. The charge of the condenser 87 is adjusted during the regulating cycle when the multiplying tube is viewing the standard object by means of a transfer condenser 88 which is successively coupled by a commutator or other switch device of any suitable type herein represented by a cam-operated switch 89 to sources of reference voltages within the system and to condenser 87. The switch 89 comprises moving contacts 91 and 92 connected to the condenser 88. The contact 91 is oscillated between the fixed contacts 93 and 94 which are normally connected directly to the cathodes of the follower tubes 63 and 64. The connection from the contact 93 is through lead 121, switch 123, and lead 125 which is directly connected to the cathode of tube 63. Contact 94 is normally connected in a similar manner through line 122, switch 124, and line 126 to the cathode of tube 64. In the preferred mode of operation of the machine the switches 123 and 124 are closed on the contacts as illustrated in Fig. 2. The contact 92 is oscillated between the contacts 95 and 96 coupled respectively to the minus 1000 volt line and to the grid of the regulator tube and the biasing condenser 87. The contacts 93 and 96 are connected through resistors 97 and 98 to limit the charge and discharge current of the condenser 88. The switch 89 is actuated by a suitable mechanism such as a barrel cam 99 with a sinuous groove 101 engaged by a follower coupled to the switch 89. The cam 99 is driven by a shaft 102, which is shown as coupled through the delay device to the shaft 81 so that the cam operates in synchronism with the conveyor. During each regulating period, the cam first brings the pairs of contacts 91, 93, and 92, 95 into engagement and then the opposing pairs 94, 91 and 96, 92. During the object viewing period both sets of contacts are held open.

The operation of the regulating device is as follows: If the outputs are balanced, as they should be under normal conditions, the contacts 93 and 94 will be at the same potential. The uncorrected grid potential of the regulating tube with no charge in condenser 87, is minus 1000 volts, which is the level of the contact 95.

Neglecting for the present the charging time of condensers 88 and 87 and the effect thereon of resistors 97 and 98 and the impedances of tubes 63 and 64, it will be apparent that when the condenser 88 is bridged across contacts 93 and 95 it will be charged to a potential equal to the difference between the minus 1000 volts of contact 95 and the potential level of the cathode of tube 63, approximately 150 volts positive.

When condenser 88 then bridges points 94 and 96, if point 94 is at the same potential as point 93 there will be no charge or discharge of condenser 88, and condenser 87 will remain discharged, leaving the grid of the regulator tube at the minus 1000 volt level. If, however, point 94 is more positive than point 93, condenser 88 will partially discharge into condenser 87, making the grid of the regulator 39 more positive. The effect of the increased positive bias of the regulator tube is to decrease the resistance of the tube and thereby increase the interelectrode potentials of the multiplier. The multiplier tube thus becomes more sensitive and, with a given illumination level, makes the pentode 51 less conductive and the pentode 52 more conductive. As a result, the cathode of tube 63 becomes more positive and that of tube 62 less positive, tending to equalize the potentials of contacts 93 and 94 and regulate the sensitivity of the system so that a balanced output of the amplifier coincides with the response to the standard object.

Obviously, the converse action will take place if contact 94 is more negative than contact 93. The condenser 87 will be so charged as to bias the grid of the regulator negatively and decrease the responsiveness of the system.

Actually, since the charging and discharging of the condensers 88 and 87 follow the well-known expontential curve, complete transfer will not occur in a single regulating cycle. However, as long as the system is out of balance, increments of charge are added to or subtracted from the condenser 87 to bring the system into balance. In this connection, the grid of the regulator tube is always negative so that there is no grid current and the condenser 87 need not be large to hold the grid potential constant between the regulating cycles.

One of the great advantages of the employment of cathode followers 63 and 64 is that they permit the charge and discharge of condenser 88 through a relatively low-impedance circuit, thus reducing the time constant and increasing the speed of regulation, or permitting the use of larger condensers so that less frequent regulation is necessary. This advantage is obtained notwithstanding the employment of high gain pentode amplifiers instead of less sensitive triodes. The pentodes, in combination with the multiplier tube, make possible highly sensitive operation of the system with a single stage of amplification between the phototube and the gas tube. If the condenser 88 were charged directly from the plate circuits of the pentodes, the resistors 53 and 54 would greatly increase the time constant of the charging circuit. With the cathode followers, this time constant is reduced by a factor approximately equal to the amplification factor of the triode. Preferably, the period during which the condenser 88 is connected to each set of contacts corresponds approximately to the time constant of the condenser 88 so that approximately 70% correction can be accomplished in one cycle. Of course, in the normal operation of the machine the correction required during each cycle will be slight because the corrections relate only to the gradual drift of the system. However, more sudden disturbances such as changes in the supply voltages make a rapid correction highly advantageous. It will be apparent that if approximately 70% correction is effected in each regulating cycle, even a large error will be brought to an insignificant amount in a very few regulating cycles.

The regulating action may take place after the viewing of each object, in which case the switch 89 will be oscillated to make and break both sets of contacts between the passage of successive objects through the viewing position. However, this is not essential, and where a less rapid correction is required phototube regulation may occur once in a number of viewing cycles of the machine. If desired, one or more of the cups 12 may be omitted from the periphery of the wheel 11 at evenly spaced points and the form of the groove 101 and the speed of rotation of the cam 99 relative to the wheel may be so fixed that regulation occurs at these points. In this way a longer regulating period may be obtained, but such an arrangement is not necessary.

It will be apparent that the regulating action will be stable and will bring the amplifier into balance as long as the correction at each cycle is less than that required and also as long as the correction is greater than that required, if the correction is not so great that the error after the correction exceeds that before. With a slight overcorrection, the response oscillates toward the correct value. In the event of any tendency for the overcorrection to be excessive, this can be avoided by the proportioning of the capacities of condensers 87 and 88. If condenser 87 is considerably larger than condenser 88, the increment of voltage of this condenser will be accordingly considerably less than the potential difference of the two outputs. The degree of correction may also be reduced by so proportioning the value of the resistance 97 to the capacity of the transfer condenser that the time constant of this condenser is large relative to the time it is bridged across contacts 93 and 95. Suitable values are matters of design, depending upon the characteristics of the vacuum tubes and the circuit elements.

Although I believe it to be preferable in the circuit shown in Fig. 2 to derive the reference voltages for contacts 93 and 94 from the cathodes of tubes 63 and 64, a feasible alternative arrangement is illustrated in Fig. 2. As previously stated, the switches 123 and 124 are normally closed on contacts connected to the cathode follower tubes. However, switch 123 may be closed on a contact 127 or switch 124 may be closed on a contact 128, these contacts being connected to the center point of a voltage divider consisting of resistors 131 and 132 connected between the plus 300 volt line and minus 150 volt line. The resistors 131 and 132 are so proportioned that the potential of points 127 and 128 is the same as the normal or standard potential of the cathode of the follower tube. If, for example, switch 124 is closed on contact 128, a fixed reference voltage for the contact 94 is established. Contact 93 remains connected to the cathode of tube 63 and thus the potential of contact 93 varies in accordance with the output of pentode 51. Therefore, if the output of tube 51 varies from the standard value during the regulating cycle, the potential of contact 93 will vary from that of contact 94 and the transfer condenser will operate to vary the bias of regulator tube 39 in the same manner as previously described. In this case, the difference of potential between contacts 93 and 94 for a given error in the system is only half that when the contacts 93 and 94 are both connected to the cathode followers. For this reason, the preferred position of switches 123 and 124 is as illustrated.

Obviously, if switch 123 is closed on contact 127, the regulating action will take place in the same manner as previously described except that contact 94 will swing with the output of pentode 52, and the potential of contact 93 will remain fixed.

The use of the fixed reference voltage on one of the contacts 93 or 94 would be advantageous in systems where band pass operation is not desired. Thus, for example, if it were desired to build a machine solely to reject too light objects, switch 124 could be left closed on contact 128 to provide a reference voltage on contact 94 and pentode 52, cathode follower 64, thyratron 56, delay device 78, solenoid 25, and associated circuit elements could be omitted.

Fig. 3 illustrates a modification of the circuit of Fig. 2, the modification residing in the connections of the cam-operated switch 89. Since the circuit otherwise is the same as that of Fig. 2, I deem it unnecessary to duplicate the major part of the circuit diagram of Fig. 2. In Fig. 3, parts corresponding to those in Fig. 2 are given the same reference numerals. As will be apparent from inspection, the circuit of Fig. 3 involves a change in the cam-operated switch device 89 such that the transfer condenser 88 is bridged across contacts 93 and 94 during one part of the cycle and across contacts 95 and 96 during another part of the cycle. Otherwise, the circuit may remain the same as in Fig. 2.

With the modification illustrated in Fig. 3, the regulating action is effected as follows: When the condenser 88 is bridged across contacts 93 and 94, it is connected to the two sources of reference voltage such as the cathodes of tubes 63 and 64 or the cathode of one of these tubes and the center point of the voltage divider 131, 132. If there is any difference between the reference

voltages, the condenser 88 is charged to this difference (or more exactly to the greater part of the difference, since the full charging of the condenser requires in theory an infinite time). After the condenser 88 has been charged from the lines 121 and 122 it is then bridged across contacts 95 and 96 so that any charge on the condenser 88 increases or decreases the charge of condenser 87 to effect the regulating operation as previously described.

The significant difference between the transfer condenser circuits of Figs. 2 and 3 is that in Fig. 2 the condenser 88 is charged to a high potential of the order of 1150 volts, whereas in the circuit of Fig. 3 the condenser potential order would ordinarily be only a few volts and when the system is perfectly balanced, it is zero. On the other hand, in the circuit of Fig. 3 the potential level of the condenser as a whole, as distinguished from the potential difference across the condenser, swings between approximately minus 1000 and plus 150 volts. For this reason there is some possibility of disturbing effects resulting from the capacity to ground of condenser 88. These effects may be minimized by making the circuit between the contacts 91 and 95 before the circuit is made between contact 92 and 96, which is indicated in Fig. 3 by the closer spatial relations of contacts 91 and 95, as compared to contacts 92 and 96.

I have shown and particularly described herein the preferred embodiment of my invention and the methods of operation embraced therein for the purpose of explaining its principle and showing its application, but it will be obvious to those skilled in the art that many modifications and variations are possible within the scope of the invention, which is defined by the appended claims.

I claim:

1. A photoelectric discriminating device comprising, in combination, a phototube of adjustable sensitivity, means for presenting an object to be tested to the phototube, means for presenting a standard object to the phototube, a phase inverting amplifier coupled to the phototube with two outputs varying oppositely with increase in brightness of the object, and means to regulate the sensitivity of the phototube so as to balance the said outputs when the standard object is presented to the phototube, the regulating means comprising a vacuum tube connected in the energizing circuit of the phototube and means to vary the grid bias of the vacuum tube in accordance with unbalance of the outputs when the standard object is presented.

2. In a photoelectric sorting device comprising, a phototube of adjustable sensitivity, means for presenting a succession of objects to be classified to the phototube, means for intermittently presenting a standard object to the phototube, and an object separator, a sensing system comprising in combination with the phototube a phase inverting amplifier coupled to the phototube, the said amplifier including two output terminals and the output of the amplifier varying about a balance point in accordance with change in brightness of the object, the said output being coupled to the separator, and means responsive to the potential relationship between said output terminals to regulate the sensitivity of the phototube so as to balance the said output when the standard object is presented to the phototube, the regulating means comprising a vacuum tube connected in the energizing circuit of the phototube and means operatively actuated by the presenting means to vary the grid bias of the vacuum tube in accordance with the value of the said output when the standard object is presented.

3. In a photoelectric sorting device comprising, a phototube of adjustable sensitivity, means for presenting a succession of objects to be classified to the phototube, means for intermittently presenting a standard object to the phototube, and an object separator, a sensing system comprising in combination with the phototube a phase inverting amplifier coupled to the phototube, the said amplifier including two output terminals and the output of the amplifier varying about a balance point in accordance with change in brightness of the object, cathode follower means coupled to the amplifier output, the cathode follower output being coupled to the separator, and means to regulate the sensitivity of the phototube so as to balance the said output when the standard object is presented to the phototube, the regulating means comprising a vacuum tube connected in the energizing circuit of the phototube and means responsive to the potential relationship between the said output terminals to vary the grid bias of the vacuum tube in accordance with the value of the cathode follower output when the standard object is presented comprising a condenser and means operatively actuated by the presenting means for successively coupling the condenser to the cathode follower output and then to the vacuum tube control grid.

4. A photoelectric sorting device comprising, in combination, a phototube, means for presenting a succession of objects to be classified to the phototube, means for intermittently presenting a standard object to the phototube, a light object separator, a dark object separator, a phase inverting amplifier coupled to the phototube with two outputs varying oppositely about a balance point with change in brightness of the object, each of the said outputs being coupled to one of the separators, and means to regulate the sensitivity of the phototube so as to balance the said outputs when the standard object is presented to the phototube, the regulating means comprising a vacuum tube connected in the energizing circuit of the phototube, the said vacuum tube having a control grid, and means responsive to the potential relationship between the said outputs to vary the grid voltage of the vacuum tube in accordance with unbalance of the outputs when the standard object is presented and comprising a condenser, and means operatively actuated by the presenting means for successively connecting the said condenser to an output of the said amplifier and then to the grid of the vacuum tube upon presentation of the standard object to the phototube.

5. A photoelectric sorting device comprising, in combination, a phototube, means for presenting a succession of objects to be classified into the field of the phototube, means for intermittently presenting a standard object to the phototube, a light object separator, a dark object separator, a phase inverting amplifier coupled to the phototube the said amplifier including two output terminals and the output of the amplifier varying about a balance point in accordance with change in brightness of the object, a cathode follower operatively connected to one of the terminals and one of the separators, a second cathode follower operatively connected to the remaining terminal and to the remaining separator, and means to regulate the sensitivity of the phototube so as

to balance the outputs at the cathode followers when the standard object is presented to the phototube, the regulating means comprising a vacuum tube connected in the energizing circuit of the phototube and means to vary the grid bias of the vacuum tube in accordance with unbalance of the outputs when the standard object is presented, the last-named means comprising a condenser and switching means operatively actuated by said presenting means to connect the condenser successively between one said cathode follower and a reference point in the vacuum tube cathode circuit and between the other said cathode follower and the vacuum tube control grid.

6. A photoelectric sorting device comprising, in combination, an electron multiplier phototube; a phase inverting amplifier coupled to the output of the phototube, and delivering two output voltages respectively increasing and decreasing about a balance point with change of illumination of the phototube; a gas tube and a cathode follower connected to said gas tube and to said amplifier for operating said gas tube in response to one of the output voltages, a second similar gas tube and cathode follower operatively actuated by the second output voltage classifying means actuated by said gas tubes, the gas tubes being normally non-conducting and being fired by subnormal and abnormal response of the phototube, respectively; means for presenting a standard object to the phototube; and means for balancing the output potentials of the cathode followers when the standard object is presented to the phototube comprising means for varying the sensitivity of the phototube connected to the phototube and actuated by the object presenting means.

7. A photoelectric sorting device comprising, in combination, an electron multiplier phototube; a phase inverting amplifier coupled to the output of the phototube, and delivering two output voltages respectively increasing and decreasing about a balance point with change of illumination of the phototube; a gas tube and a cathode follower connected to said gas tube and to said amplifier for operating said gas tube in response to one of the output voltages, a second similar gas tube and cathode follower operatively actuated by the second output voltage; a regulator tube connected to control inter-electrode potentials of the phototube by change of voltage upon a control grid of the regulator tube; and means actuated by unbalance of the output potentials of the cathode followers while a standard object is presented to vary the grid voltage of the regulator tube, and comprising a first condenser connected to the grid of the regulator tube for maintaining the voltage thereof and a second condenser for charging and discharging the said first condenser to adjust the grid bias to a balance condition and means operatively actuated by the presenting means for connecting the said second condenser either to a cathode follower or to the first condenser in accordance with the position of the standard object.

8. A photoelectric sorting device comprising, in combination, an electron multiplier phototube; a cathode follower controlled thereby; a phase inverting amplifier coupled to the output of the cathode follower, and delivering two output voltages respectively increasing and decreasing about a balance point with change of illumination of the phototube; a gas tube and a cathode follower connected to said gas tube and to said amplifier for operating said gas tube in response to one of the output voltages, a second similar gas tube and cathode follower operatively actuated by the second output voltage; a regulator tube connected to control inter-electrode potentials of the phototube by change of voltage upon a control grid of the regulator tube; means for presenting a standard object to the phototube; and means actuated by unbalance of the output potentials of the last-named cathode followers while the standard object is so presented to vary the grid bias of the regulator so as to vary the sensitivity of the phototube to balance the said output potentials.

9. A sensing system for photoelectric sorting apparatus, comprising in combination with an electron multiplier phototube of adjustable sensitivity having a plurality of dynodes, an amplifier therefor with an output varying with the illumination to which the phototube is subjected, a voltage-responsive control circuit with a voltage divider and means for varying the potential difference therein, said voltage divider having taps connected to said dynodes for varying the potential differences between dynodes, thereby varying the sensitivity of the photoelectric tube, a condenser having plates and means for adjusting the potential-difference between its plates in accordance with variations in the output of said amplifier, said phototube sensitivity control circuit having control-voltage terminals, and a switch for transferring said condenser from said potential-difference adjusting means to said control voltage terminals for regulating the sensitivity of the phototube.

10. A sensing system for photoelectric sorting apparatus, comprising in combination with a phototube of adjustable sensitivity, an amplifier therefor with an output varying with the illumination to which the phototube is subjected, a voltage-responsive control circuit for varying the sensitivity of the photoelectric tube, a condenser having plates and means for adjusting the potential difference between its plates in accordance with variations in the output of said amplifier, said phototube sensitivity control circuit having control-voltage terminals, and a switch for transferring said condenser from said potential-difference adjusting means to said control voltage terminals for regulating the sensitivity of the phototube; one of the control-potential terminals having a relatively low potential and the condenser transfer switch being provided with separate terminals for each plate of the condenser, one of the switch terminals being set for making contact earlier than the other when the connection is transferred to the control potential terminals for the purpose of fixing the potential of the condenser plate associated with such terminal before the connection is completed whereby stray capacity to ground effects are eliminated.

11. A photoelectric sorting device comprising, in combination, a phototube having a cathode, and anode and a plurality of electrodes disposed in succession between the cathode and the anode, the said phototube being relatively responsive to changes in electrode potential, a phase inverting amplifier coupled to the anode of the phototube, the said amplifier having two output terminals and the voltage at the terminals respectively increasing and decreasing about a balance point with change of illumination of the phototube, a vacuum tube connected to at least some of the electrodes of the said phototube for regulating the voltages applied to those electrodes, the said vacuum tube including a control grid and means for adjusting the voltage of the said control grid in accordance with the output of the amplifier

upon presentation of a standard object to the phototube to balance the output of said amplifier at a reference level corresponding to the shade of the standard object.

12. The invention in accordance with claim 11, said last-named means comprising a condenser and switching means operatively actuated by the said presenting means for connecting the said condenser either to an output terminal of said amplifier alone or to the control grid of the regulator tube.

13. The invention in accordance with claim 12, and including a condenser connected to the said

control grid and adapted to be charged and discharged by the said first-named condenser.

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