

Sept. 9, 1958

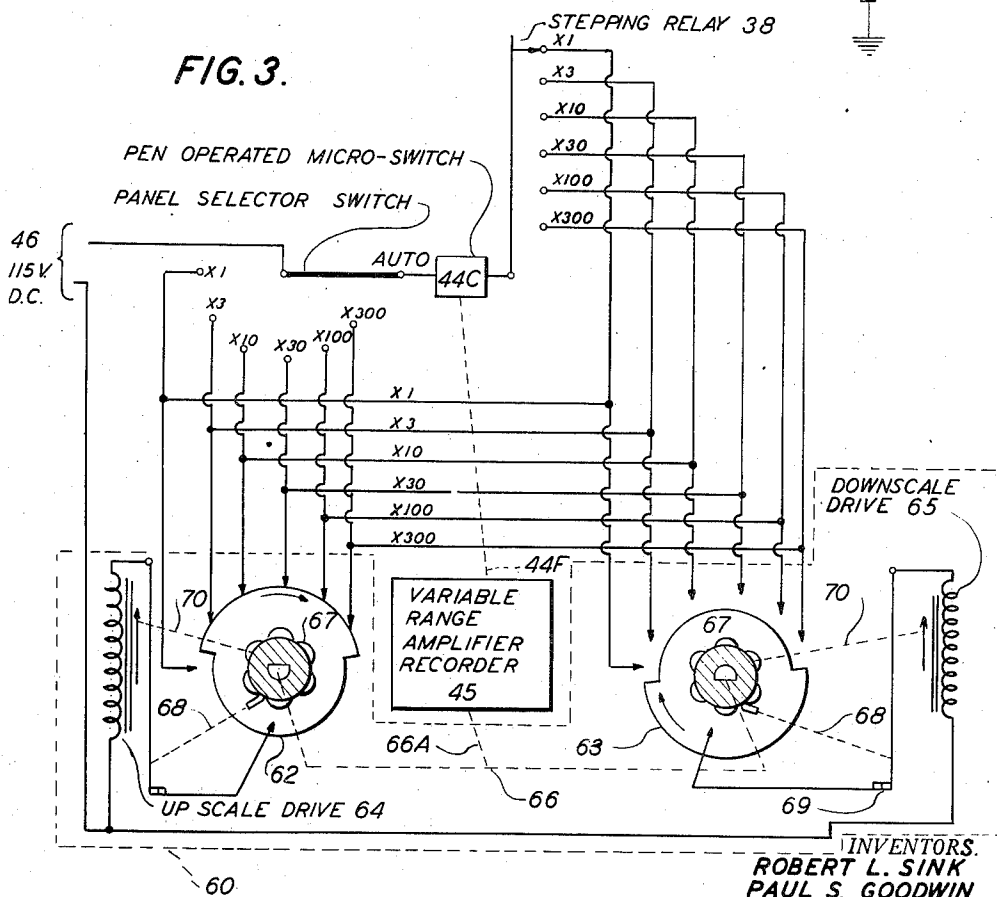
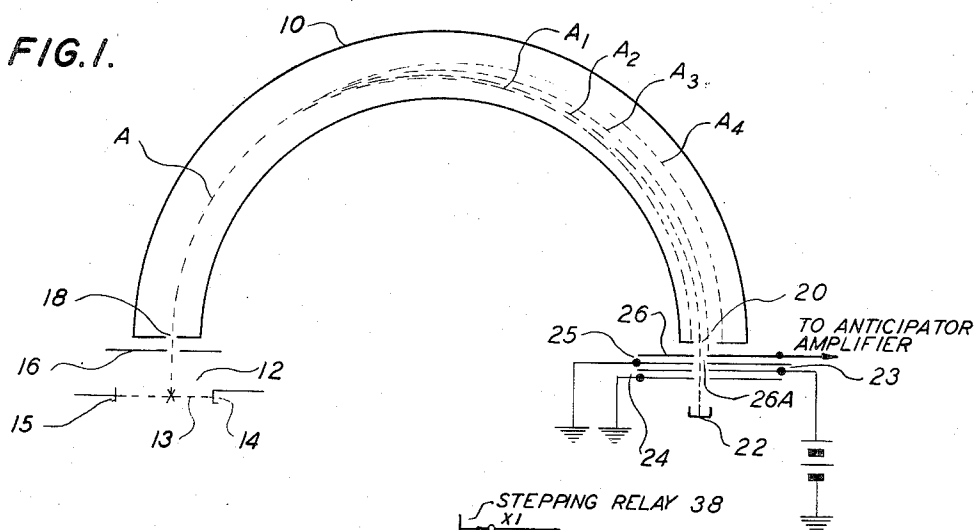
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2,851,606

MASS SPECTROMETER ANTICIPATOR CIRCUIT

Filed Sept. 30, 1955

2 Sheets-Sheet 1



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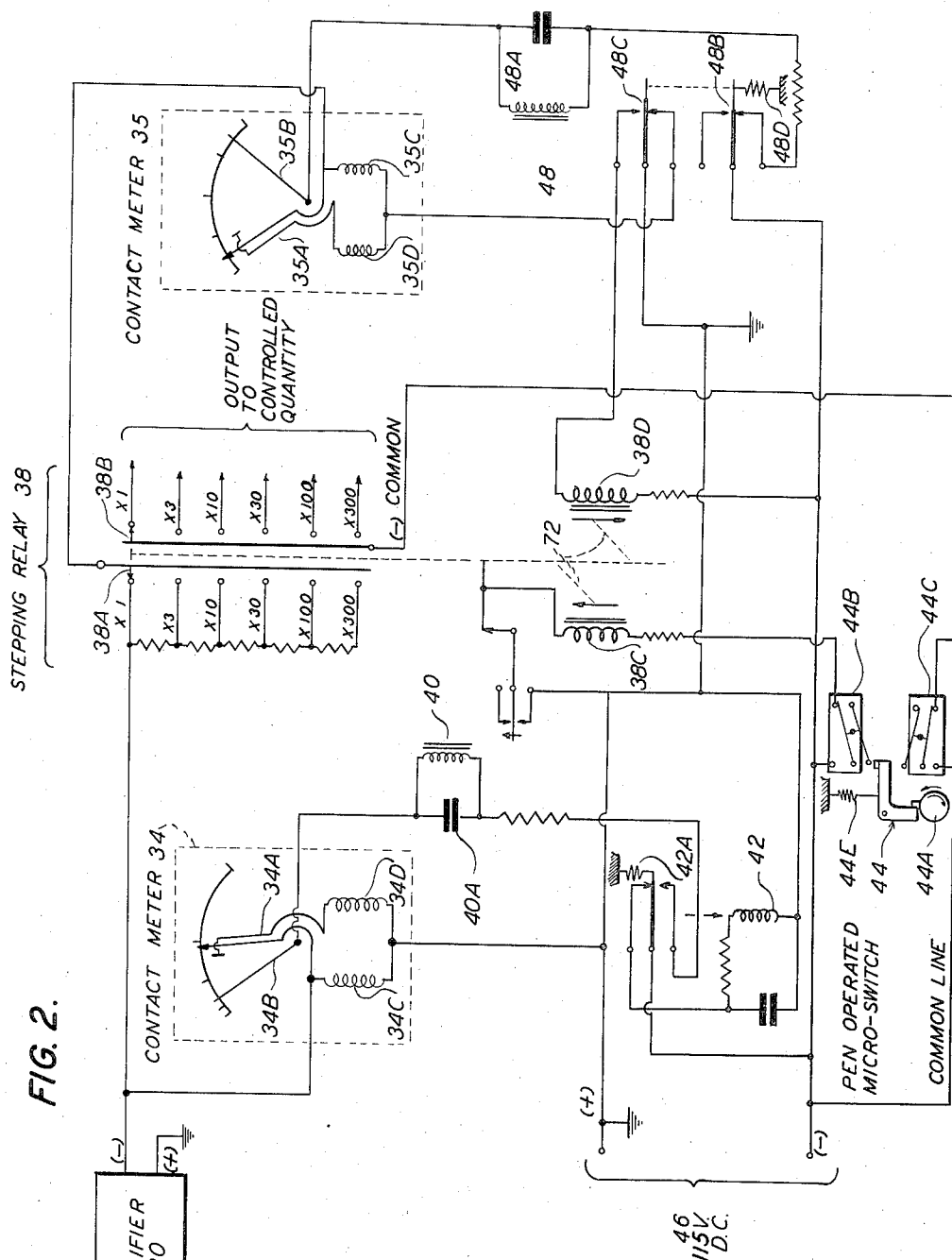
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MASS SPECTROMETER ANTICIPATOR CIRCUIT

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Application September 30, 1955, Serial No. 537,779

10 Claims. (Cl. 250—41.9)

This invention relates to a voltage calculator or sensing circuit adapted to direct the operation of an electrically controlled system responsive to the magnitude of voltage signals applied to the sensing circuit.

This is a continuation-in-part application of our co-pending application Serial Number 186,170, filed September 22, 1950 now abandoned.

The invention is hereinafter described with relation to its application as an anticipator channel for automatic attenuation of a mass spectrometer recording system although it will be apparent that such use does not in any way represent a limitation on the utility or applications of the circuit.

The principle of mass spectrometry is in general one of ionizing a sample to be analyzed as by an electron beam, segregating ions in accordance with their mass-to-charge ratio by inducing spatial separation thereof, and selectively discharging, as at a collector electrode, ions of a given mass-to-charge ratio. The current developed by discharge of a group or beam of ions of the same mass-to-charge ratio is proportional to the partial pressure of the particles in the original sample from which these particular ions are derived. Hence a method is afforded for calculating the concentration of these particles or molecules in the sample.

In analyzing a sample for more than one component, the segregated ion beams constituting a part or all of the mass spectrum of the particular sample are successively focussed on the collector electrode so that a plurality of separate discharge currents are obtained, each being proportional to the number of ions in a particular beam. The mass spectrum is scanned in this fashion by varying one or more of the parameters affecting the spatial separation between ions of differing mass-to-charge ratio.

The currents produced by ion discharge are generally converted to appropriate voltages across a dropping resistor, the voltages are amplified, and the amplified signals are recorded on either a multichannel recorder such as an oscillograph or on a single channel recorder such as a pen and ink recorder. The recorded signals appear as separate peaks on the record with each peak representing ions of a different given mass-to-charge ratio, the recorded trace returning to "zero" or a base level between succeeding peaks. The peak heights are determined by the recorder sensitivity as well as by the number of ions of the given mass-to-charge ratio represented by the given peak.

Because of the wide differences in the number of ions which may be encountered in different beams as a result of wide concentration spreads in the original sample, it is necessary, when using a single channel recorder, to provide means for varying the sensitivity of the recorder so as to adapt it to this wide variation in ion abundance. If such provision is not made, the less abundant ions of a given spectrum may not develop a recorded peak of sufficient height on a record having a full scale sensitivity such as to accommodate the most abundant ions. This

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principle has been recognized in the prior art, and various so-called anticipator circuits have been suggested for anticipating the ion abundance in successive beams of the spectrum and suitably adjusting the sensitivity of the recorder in advance of each separate peak.

In U. S. 2,656,498 there is described and illustrated a variable range recording amplifier suitable for combination with such an anticipator circuit. In general, the amplifier circuit there shown includes an amplifier and a slidewire potentiometer combined in a null network so that the balance position of the potentiometer slider is achieved responsive to the output of the amplifier and gives a measure of the magnitude of the input signal to the amplifier. A pen or other recording means is connected to record and excursions of the potentiometer slider. In the patent referred to, variable sensitivity is achieved by connecting a voltage source across the potentiometer slidewire and including in series therewith means for varying the magnitude of the full scale voltage across the slidewire. By varying this full scale voltage, the sensitivity of the network is varied in inverse ratio, it requiring a greater excursion of the potentiometer slider to arrive at a balanced position as the voltage applied across the potentiometer is reduced, and vice versa. The aforementioned patent suggests attenuation of the variable range recording amplifier by manual selection of the optimum full scale potentiometer voltage. The anticipator or automatic attenuation circuits of the prior art and of the instant invention are adapted to incorporation with a variable range recording amplifier such as that described to vary automatically the full scale voltage across the balancing potentiometer in response to the intensity of an ion beam sensed in advance of the time that this beam is focussed on the collector electrode.

In general, anticipator circuits for this use employ a double collector system in the analyzer tube of the mass spectrometer. The two ion targets are so arranged that a so-called auxiliary or anticipator target receives the full ion current signal in advance of the collector target. The anticipator signal is amplified and fed into a calculating device which selects the optimum attenuation range to be used in recording the data when the same signal later appears at the collector target. The information as to the proper attenuation range is delivered from the calculator to the main recording channel at a pre-selected time intermediate the recording of succeeding peaks. Automatic selector switches provided in the main channel operate responsive to the information derived from the calculator to establish the proper voltage across the balancing potentiometer.

We have now developed a simplified voltage sensitive calculator which as a mass spectrometer anticipator circuit exhibits greater reliability and greater flexibility than circuits of like nature described in the prior art. The greater reliability of the circuit of the invention is due in part to the provision of protective features preventing accidental loss of the information established in the calculator circuit and protecting against premature transfer of this information. The voltage sensitive anticipator circuit of the invention is made repetitive so that after transfer of the desired information to the recording channel and attenuation thereof, the calculator will be reset to await the next signal.

Accordingly, the present invention contemplates a voltage sensitive circuit comprising a stepping relay, a contact meter sensitive to the magnitude of an input voltage to step the relay in accordance therewith, a source of voltage connected through the relay to be delivered thereby through one of a number of separate channels depending upon the position to which the relay has been stepped,

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and means for resetting the relay after deliverance of the voltage signal therefrom.

In the particular application above described, the invention contemplates in a mass spectrometer having a source of ions, means for segregating the ions in accordance with their mass-to-charge ratio, a collector electrode, means for successively focussing ions of different mass-to-charge ratio on the collector electrode and a variable range recording amplifier, the combination comprising an anticipator electrode positioned in the mass spectrometer to receive ions in advance of the collector electrode, a stepping relay, means connected between the anticipator electrode and the stepping relay to step the latter in proportion to the current developed at the anticipator electrode, means operable responsive to the setting of the stepping relay to vary the range of the recording amplifier and as a function of the setting of the stepping relay, and means operable to reset the stepping relay after the range of the recording amplifier is established thereby.

In its preferred form, the voltage sensing circuit of the invention includes elements which prevent premature transfer of the intelligence stored in the stepping relay and likewise prevent premature resetting of the stepping relay before the stored intelligence has been utilized.

These and other preferred features of the invention will be more clearly understood by reference to the following detailed description taken in conjunction with the accompanying drawing in which:

Fig. 1 is a schematic diagram of a conventional 180° mass spectrometer provided with the usual collector electrode and an anticipator electrode for adapting the mass spectrometer to use with the circuit of the invention;

Fig. 2 is a circuit diagram of a voltage sensing circuit of the invention including means for synchronizing its operation with that of a mass spectrometer of the type shown in Fig. 1; and

Fig. 3 is a circuit diagram showing one form of interconnecting linkage suitable for connecting the circuit of Fig. 2 to a variable range amplifier recorder so that information derived in the voltage sensing circuit may be used to vary the sensitivity range of the mass spectrometer recording system.

As might be expected, the application of the voltage sensitive circuit of the invention to the field of mass spectrometry is dependent in part upon modification of the collector system in a conventional mass spectrometer. Fig. 1 is a diagram of a modified 180° analyzer type mass spectrometer with a collector system adapted for such application. The mass spectrometer comprises an analyzer tube 10 provided at one end with an ion source 12. Ions are produced at the source by an electron beam 13 developed at an electron gun 14 and directed across the ion source at an electron target 15. An accelerating electrode 16 is positioned intermediate the source 12 and an inlet slit 18 in the analyzer tube and by application of suitable potentials between the source and accelerating electrode and between the accelerating electrode and analyzer tube, respectively, ions originating at the source are collimated and propelled as a heterogeneous beam A into the analyzer tube. In the analyzer tube, under the influence of a transverse magnetic field established by conventional means (not shown), the heterogeneous ion beam A is broken into a plurality of separate beams A1, A2, A3, A4, the ions in each beam being of the same mass-to-charge ratio and differing from the mass-to-charge ratio of the ions forming the other beams. The number of separate homogeneous beams will, of course, be dependent upon the number of components in the sample.

An exit slit 20 in the end of the analyzer tube opposite the ion source gives access to an ion collection system. The collection system includes a collector electrode 22, a metastable ion suppressor electrode 23, shield electrodes 24, 25 and an anticipator electrode 26. The shield elec-

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trodes and the metastable ion suppressor electrode are not essential to the practice of the invention but represent preferred structure.

The anticipator electrode 26 is provided with a slit 26A aligned with and off center with respect to the exit slit 20 in the analyzer tube. Thus ions passing through the exit slit 20 may strike the anticipator target 26 or may pass through the slit 26A therein depending upon the focussing of the beam. In the illustration, the ion beam A1 is out of focus and is discharged at the end wall of the tube. The beam A2 is focussed through the exit slit and slit 26A in the anticipator target to strike the collector electrode 22 while the beam A3 likewise is focussed through the exit slit 20 but onto the anticipator target and the beam A4 has not yet been brought into focus on the exit slit and strikes and discharges on the walls of the analyzer tube. In scanning and spectrum, the ion beams are shifted to the left with respect to the exit slit so that beam A2 will shift out of focus with respect to the exit slit 20, beam A3 will focus through the slit 26A of the anticipator target and beam A4 will be brought into focus through the exit slit 20 and onto the anticipator target.

The exit slit 20 is made just wide enough to receive adjacent masses, while the slit 26A in the anticipator target is narrow enough to resolve between adjacent masses, these relationships being maintained for the highest mass range to be encountered in any given instrument. Thus it is conventional to design a mass spectrometer to analyze materials within a given mass range and in the present instance the exit slit and slit in the anticipator target are proportioned as described and with respect to the highest ion masses to be encountered. Spatial separation between adjacent ion masses is a function of the reciprocal of the ion masses so that resolution of high mass ions automatically insures resolution of lower mass ions.

It is apparent from the foregoing description of the collection system of the mass spectrometer that the ion discharge signals developed at each of the anticipator and collection targets are the same with the collector signal lagging the anticipator signal. This means that by the time the collecting channel recorder has started to record a peak responsive to the discharge of ions of a given mass at the collector electrode, the crest of that same peak must, of necessity, have passed and previously discharged on the anticipator target. This characteristic of the system insures that the top of the peak has reached the anticipator target and that no further signal increases will occur in the anticipator channel until the next peak arrives.

As mentioned above, another characteristic of the collector system, which is important to the use of the circuit of the invention as an anticipator channel, is that all peaks return substantially to zero or to a base level before the arrival of the next peak. This is insured by proper dimensioning of the slit system so that slit 26A will resolve adjacent masses up to the largest mass to be encountered, and exit slit 20 in the analyzer tube will resolve between alternate adjacent masses so that only one mass at a time will strike the anticipator electrode.

Fig. 2 is a diagram of the voltage sensitive circuit of the invention as adapted for use in conjunction with the mass spectrometer shown in Fig. 1. The circuit includes an amplifier 30 with the anticipator target 26 connected to the amplifier input through a dropping resistor 32 to feed a voltage to the amplifier which is proportional to the ion discharge current developed at the anticipator target.

The circuit also includes a first contact meter 34 and a second contact meter 35 connected to receive the output of the amplifier 30. The contact meters are essentially identical including, respectively, indicating pointers 34A, 35A, hand set pointers 34B, 35B, indicating coils 34C, 35C and locking coils 34D, 35D. A stepping relay 38 is

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connected to be actuated responsive to the condition of the contact meters and includes a plurality of output channels identified as x1, x3, x10, etc., a plurality of input channels similarly identified and a companion pair of movable contacts 38A, 38B which respectively contact corresponding input and output channels upon movement thereof. The stepping relay 38 is provided with a stepping coil 38D for stepping the contacts 38A, 38B upscale and a resetting coil 38C, the function of which is described in greater detail hereinafter. The hand set arm 34B of contact meter 34 is connected through the coil of a relay 40 to a relay 42, the latter of which operates as an interrupter to continuously make and break the circuit between the indicating arm 34A and contact arm 34B when the current supplied to the indicating arm 34A is sufficient to carry it into contact with the hand set arm 34B.

A pen-operated micro-switch 44 is connected to govern the application of an output signal from the stepping relay and the resetting of the stepping relay in the proper sequence and at the proper time with relation to the condition of the main recording channel. The switch 44 includes a cam 44A driven in opposite directions responsive to upscale and downscale movement of the recording pen on a variable-range amplifier and recorder 45 (see Fig. 3), say of the type disclosed in U. S. 2,656,498, micro-switches 44B, 44C and a lever 44D, which is normally urged toward a neutral position between micro-switches 44B and 44C by a spring 44E. The recording pen is coupled to rotate the cam 44A through mechanical link 44F (see Fig. 3). The cam is arranged so that the micro-switch 44C closes as the recording pen approaches the base line or zero, i. e. at the tail end of a peak. As explained below, this causes the recording amplifier to change to the sensitivity selected by relay 38. The micro-switch 44B closes to reset the relay 38 as the recording pen leaves the base line to record a peak. As explained below, this occurs after micro-switch 44C has closed and reopened, and the operation of the micro-switch 44B to reset relay 38 does not disturb the recording amplifier. The lever is operable responsive to movement of cam 44A to actuate switch 44C as the recording pen moves downscale, and to actuate switch 44B as the recording pen moves upscale. The switch 44C is connected in series between voltage source 46 and contact 38B of relay 38 and switch 44B is connected in series between the voltage source and reset coil 38C of relay 38.

The hand set arm 35B of the second contact meter is connected through the coil of a relay 48, which in turn is connected in series with contacts 48B to the negative side of the source 46. When arm 35B contacts arm 35A, it is connected through coil 35D and contacts 48C to ground and to the positive side of the potential source 46. When the arms thus make contact, while contacts 48B are closed, the coil 48 is energized as also is the locking coil 35D.

The operation of the circuit of Fig. 2 can be better understood after a brief description of Fig. 3 which shows means for using the information obtained from the circuit of Fig. 2 to vary the range of a variable range recording amplifier. Briefly, the stepping relay 38 in Fig. 2 steps to one of the several output channels x1, x3, x10, etc., dependent upon the magnitude of the voltage introduced to the amplifier 30. The designations x1, x3, etc., as applied to various contact points and connecting leads in the circuits of Figs. 2 and 3 signify that correspondingly identified elements are component parts of separate channels which are appropriately selected in a manner hereinafter explained to control the magnitude of the full scale voltage across the balancing potentiometer found in a recording amplifier of the type previously described. Thus the channel represented by the several elements labeled x3 is connected, when energized, to increase automatically the voltage across such a balancing potentiometer by a factor of 3. The sensitivity of the recording amplifier circuit will, as a result, be altered by the recip-

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rocal of this factor. The means of altering this sensitivity responsive to the setting of the stepping relay 38 is shown diagrammatically in Fig. 3.

Referring to this figure, the automatic attenuation system includes a panel selector switch 60 by means of which attenuation may be selected manually, and also includes a contact labeled auto "auto." which connects the circuit for automatic selection. The stepping relay 38 as shown in Fig. 3 constitutes only that portion of the relay comprising the output channels. The variable range amplifier and recorder 45 includes a potentiometer (not shown), the movable tap of which is mechanically connected to a bi-directional stepping relay 60 including ganged contact wafers 62, 63 an upscale drive coil 64 and a downscale drive coil 65.

A source of voltage, say the source 46 of Fig. 2, is connected through the panel selector switch when in the auto. position illustrated and the stepping relay to one of the common buses designated x1, x3, x10, etc., interconnecting the contact points of the relay wafers 62, 63. The wafers 62, 63 are arranged so that they will home to the maximum position attained by the stepping relay 38 for each distinct discharge signal received at the anticipator target.

The two wafers 62 and 63 are composed of conductive material and are ganged together by linkage 66 so that they rotate in the same direction. The wafers 62 and 63 are driven respectively by solenoids 64 and 65 through mechanical links 70. When the solenoid 64 is energized, it causes the wafers to rotate in a clockwise direction. When the solenoid 65 is energized, it causes the wafers to rotate in a counter-clockwise direction. Another mechanical linkage 66A is interconnected with the variable range amplifier and recorder 45, providing a mechanical coupling between the homing switch and the variable range amplifier and recorder so that the voltage across the balancing potentiometer can be varied in response to movement of the homing switches. Each of the solenoids is connected in series with a normally closed breaker contact 69. Cams 67 on the shafts which support the wafers actuate these contacts through mechanical linkages 68. By the cam's action of breaking the solenoid's current, the solenoid is energized in a step-wise manner, and the wafer is caused to rotate. For each step the rotation of the wafer is equal to the angular spacing between the brushes which contact the outer periphery of the wafer, and the cams are spaced on the shafts so as to interrupt the contacts with such frequency that the movement with each step is equal to that angular distance, as between contacts x1 and x3.

The operation of the circuit of Fig. 3 will be best understood after a detailed description of the operation of the circuit of Fig. 2 which follows:

The D. C. amplifier 30 has as its input the signal developed at the anticipator target 26 across the dropping resistor 32. The output of the amplifier is a voltage whose amplitude is directly proportional to the input current. As the ion current to the anticipator target increases during the scan of a mass peak, the amplifier output voltage increases in a negative direction. At a predetermined level of output voltage, say a level corresponding to approximately 15% of full scale on the most sensitive range of the main recorder 45, indicating pointer 34A of contact meter 34 contacts the hand set contact pointer as a result of current flow through indicating coil 34C. When contact is established between the indicating and hand set pointers, current will flow through coil 34D and its associated circuit. The two pointers are thus magnetically locked together so that the indicating pointer is independent of signal current in the indicating coil. The coil of relay 40 is connected across a capacitor 40A in series with the locking coil 34D. The relay 40 is a necessary element of the circuit because the meter contacts can not carry sufficient current to operate reset coil 38C of relay 38. The contacts of relay

40 are connected between the reset coil 38C of the relay 38 and ground and are arranged to open-circuit the reset coil when relay 40 is energized by establishment of contact in meter 34. The relay 40 therefore prevents reset of relay 38 when there is a significant signal at the auxiliary target.

Relay 42 is connected in series with both the relay 40 and the locking coil 34D of contact meter 34. The relay 42 is urged by a tension spring 42A to complete the circuit through the coil of relay 42 so that it operates as a low frequency interrupter or buzzer, and periodically open-circuits the locking coil for short intervals. During such interruptions, the resulting collapsing field in the locking coil will kick the indicator pointer away from the contact pointer. As long as the signal applied to the indicating coil 34C from the amplifier is above the level set on the hand set pointer, the indicating pointer will return immediately to re-establish contact with the hand set pointer. The condenser 40A connected across the coil of relay 40 is made large enough so that the short interruptions caused by the alternation of relay 42 will not actuate the contacts of the relay 40. For this reason the reset mechanism is rendered inoperative whenever the ion signal at the auxiliary target is at a value representing more than 15% of full scale on the most sensitive recording range. However, when this ion signal falls below 15% full scale, the indicating pointer is not brought back into contact with the hand set pointer after interruption by relay 42 and the relay 40 is de-energized. At this point one condition necessary to actuation of the reset mechanism of relay 38 will obtain.

The automatic attenuation function of the circuit is accomplished by the second contact meter 35 and the associated stepping relay 38. Starting in the most sensitive region (x1 scale) an increasing signal will cause the indicating pointer 35A of this meter to swing upscale because of current flow through the indicating coil 35C. When the indicating pointer reaches approximately 95% of full scale, contact is made with the hand set pointer and they are locked together by current flow through the locking coil 35D in a manner similar to that described with reference to contact meter 34. Relay 48, associated with contact meter 35, is a combination control and interrupting relay. Contacts 48B, 48C of relay 48 are urged by tension spring 48D to the position shown in Fig. 2. When the indicating and hand set pointers of the meter 35 make contact, current flows through both the coil of relay 48 and the locking coil 35D of the meter. The time constant of the coil and relay 48 and of an associated condenser 48A connected across the coil is adjusted to give a small delay to the operation of the relay contacts to insure good contact of the meter pointers. When the contacts of relay 48 to the energized position, one set 48C interrupts the locking current in the meter to give the indicating pointer a kick down scale by reason of the decay of the field in the locking coil and at the same time energizes the stepping coil 38D of the stepping relay. The stepping relay is thus advanced from the assumed x1 position to the x3 position, the contacts 38A, 38B moving simultaneously to the two positions. The other set of contacts 48B on the relay 48 opens the circuit on the other side of the locking coil 35D to eliminate any current flow from the voltage source 46 through the indicating coil 35C in the reverse direction.

The aforementioned time constant of the relay 48 serves the additional function of keeping the relay in the energized position long enough for the stepping relay 38 to be driven one step forward even though the locking current in the contact meter 35 has been interrupted. During the time the stepping relay is being actuated, the indicating pointer 35A of the meter 35 is being pulled back towards zero by the internal spring action of the meter because the signal current has been removed from the indicating coil by contacts 48C. As soon as the relay 48 returns to its de-energized position, the signal current

will again position the indicating pointer 35A according to the signal magnitude, and the drive mechanism of the stepping relay will return to its quiescent position to await the next step. If the ion signal current as amplified in the amplifier 30 is large enough to drive the indicating pointer 35A to 95% of full scale on the x3 range, the above process repeats to drive the stepping relay to the x10 position. It should be noted that with each step of contact 38A of the stepping relay, the sensitivity of the contact meter 35 is reduced by reason of the resistance added to the circuit between the amplifier and the contact 38A. The stepping process continues until an "on scale" reading is achieved on the contact meter 35. This reading will lie between 30% and 95% of full scale on the meter regardless of the range, with the possible exception of the x1 range when the initial signal may be less than 30% of full scale.

As the maximum value of the ion discharge signal is passed, and the signal decreases in magnitude, the indicating pointer 35A will follow the signal back to zero following interruption of the locking coil circuit. However, at this condition the position of the stepping relay will remain unchanged as there is no means by which it can be stepped in the reverse direction. Thus the stepping relay remains at its maximum value even though the signal drops below 15% of full scale on the x1 range and the contact meter 34 will allow reset by reason of the de-energization of relay 40. A second preventative feature is provided by the pen operated switch 44. The micro-switch 44B is in series with the reset coil 38C of relay 38 and is kept open until the range selected by the relay is transferred from the contacts x1, x3, x10, etc. to the homing switch in Fig. 3 through micro-switch 44C. Once the main recording amplifier is set to the new attenuation range, the micro-switch 44B closes due to the upscale movement of the pen and completes the circuit through the reset coil 38C, whereupon the stepping relay is returned to the x1 position to await the incidence of the next succeeding peak on the anticipator target.

The micro-switch 44C opens due to pen upscale movement prior to the closure of the micro-switch 44B. For this reason resetting of the stepping relay 38 to the x1 position does not disturb the setting of the wafers 62 and 63, and hence the attenuation range of the amplifier 60 is not affected by the resetting operation. This control action of the micro-switch 44C will be apparent from an inspection of Fig. 3 of the drawings.

Thus, the stepping switch 38 is actuated during each period when an ion beam impinges upon the anticipator target 26, and the information as to the desired recording level is transferred to the homing switches 62, 63 when the recording pen of the pass spectrometer approaches its base line so that the pen operated micro-switch 44 causes the contacts 44C to close. The position of the homing switches 62, 63 and hence the attenuation range of the amplifier 60, is not changed again until the recording pen records the next peak and again approaches its base lines. In this manner, the homing switches 62, 63 store the information as to each desired recording level until the respective ion beams traverse the collector electrode 22 of the mass spectrometer.

The stepping switch 38 is reset when the recording pen of the mass spectrometer begins to record a peak because at that time the pen operated micro-switch 44 first causes the contacts 44C to open and then the contacts 44B to close. Since the setting of the switch 38 is not transferred to the homing switches 62, 63 until the recording pen of the mass spectrometer completes the recording of the peak, the recording level is not changed until after the peak is recorded.

As described above, cam 44A and lever 44D are so arranged that micro-switch 44C is closed as the recording pen approaches zero after recording a peak. By this time relay 38 has been set at the proper attenuation level for the succeeding peak and this information is transferred

to the recorder when micro-switch 44C is closed. As the recording pen moves upscale to record the new peak, micro-switch 44C is opened and micro-switch 44B is closed. This completes the circuit through reset coil 38C of relay 38 and allows the relay to be reset whenever relay 40 is de-energized.

Referring now to Fig. 3, the setting of the stepping relay 38 on any of the x_1 , x_3 , x_{10} , etc., positions closes the circuit through micro-switch 44C between the voltage source 46 and one of the homing switches 62, 63 so that the latter homes to a position corresponding to the setting of the stepping relay. In so doing the homing switch operates to vary the full scale voltage across the balancing potentiometer of the variable range amplifier 45. In the x_1 position shown in Fig. 3 there is no current flow through either of the homing switches 62, 63, and hence there is no flow through their respective associated actuating coils 64, 65. Now if the stepping relay moves to the x_3 position for a different ion peak a circuit is completed through the x_3 bus to homing switch 62 and the actuating coil 64, the latter being thereupon energized to rotate switch 62 and the ganged switch 63 clockwise until the circuit through the switch 62 is broken. If the stepping relay then steps to the x_{10} position for a third peak a circuit is completed through bus x_{10} and the switch 62 to again actuate the driving coil 64 to rotate the switches one step. In this procedure the contact wafer of switch 63 will rotate clockwise to the position where it makes contact with x_1 , x_3 contact. If on the next peak the stepping relay reaches the x_3 position only, the homing switch drive will be through the downscale drive switch 63 and its driving coil 65 to reverse the direction of rotation of the homing switches as that attenuation of the amplifier will be at the x_3 instead of the x_{10} level.

This process is kept up through the entire mass spectrum so that the main recording amplifier will scan each peak in turn at the proper attenuation setting. The time constants, etc., are established for the critically adjacent mass peaks which are the largest masses likely to be encountered in the particular instrument. The entire circuit is made fast enough to respond to these masses without impairing its performance at the opposite end of the mass range where the peaks are much farther apart in time.

Referring again to Fig. 1, the exit slit 20 of the mass spectrometer should be just wide enough to receive the two most closely spaced ion beams which the apparatus is designed to record. Since the exit slit 20 and the slit 26A in the anticipator target 26 are offset, only one ion beam is allowed to impinge upon the anticipator electrode at a time. With such an arrangement the recording level of the apparatus is set in accordance with the intensity of only one ion beam at a time.

To facilitate interpretation of the resultant record it is convenient to include some type of coding means to identify on the record in juxtaposition to each peak the attenuation range at which that peak was recorded. One such recording circuit is described in U. S. 2,656,498.

The pen operated micro-switches 44B, 44C act as an interlock to prevent premature transfer of information from the anticipator to the recording channel and also to prevent resetting of the anticipator channel before the information is transferred. Other interlock means may be employed as for example the arrangement described in U. S. 2,629,056.

We claim:

1. A voltage sensitive circuit comprising a stepping relay having a stepping winding and a resetting winding, a contact meter connected to the stepping winding of the relay and sensitive to the magnitude of an input voltage to step the relay in accordance therewith, a source of voltage connected to the relay to be delivered thereby through one of a number of separate channels selected by the relay, and a second contact meter connected to

the resetting winding of the relay for resetting the relay responsive to decay of said input voltage.

2. A voltage sensitive circuit comprising a stepping relay, a contact meter sensitive to the magnitude of an input voltage to step the relay in accordance therewith, means for decreasing the sensitivity of said contact meter for each upscale step of the stepping relay, a source of voltage connected to the relay to be delivered thereby through one of a number of separate channels selected by the relay, and means for resetting the relay responsive to decay of said input voltage.

3. A voltage sensitive circuit comprising a stepping relay, a first contact meter sensitive to the magnitude of an input voltage to step the relay in accordance therewith, means for decreasing the sensitivity of said contact meter for each upscale step of the stepping relay, a source of voltage connected to the relay to be delivered thereby through one of a number of separate channels selected by the relay, and a second contact meter operable to reset the stepping relay responsive to decay of said input voltage below a predetermined value.

4. A voltage sensitive circuit comprising a multi-channel stepping relay including a stepping coil and a reset coil, a voltage source connected to the stepping relay for delivering a voltage signal through one of said channels as determined by the setting of the stepping relay, a first contact meter adapted to receive a current proportional to the voltage input to said circuit and to make contact when the voltage input reaches a predetermined value, means preventing energization of said reset coil when contact is established in said first contact meter, a second contact meter adapted to receive a current proportional to the voltage input to the circuit, means for varying the proportionality between the current to the second contact meter and the input voltage for each step of the stepping relay, and means operable to energize said stepping coil when contact is established at said second contact meter.

5. A voltage sensitive circuit comprising a multi-channel stepping relay including a stepping coil and a reset coil, a voltage source connected to the stepping relay for delivering a voltage signal through one of said channels as determined by the setting of the stepping relay, a first contact meter adapted to receive a current proportional to the voltage input to said circuit and to make contact when the voltage input reaches a predetermined value, means preventing energization of said reset coil when contact is established in said first contact meter, an interrupter relay adapted to intermittently break the circuit through said first contact meter, a second contact meter adapted to receive a current proportional to the voltage input to the circuit, means for varying the proportionality between the current to the second contact meter and the input voltage for each step of the stepping relay, and means operable to energize said stepping coil when contact is established at said second contact meter.

6. A voltage sensitive circuit comprising a multi-channel stepping relay including a stepping coil and a reset coil, a voltage source connected to the stepping relay for delivering a voltage signal through one of said channels as determined by the setting of the stepping relay, a first contact meter adapted to receive a current proportional to the voltage input to said circuit and to make contact when the voltage input reaches a predetermined value, means preventing energization of said reset coil when contact is established in said first contact meter, an interrupter relay adapted to intermittently break the circuit through said first contact meter, a second contact meter adapted to receive a current proportional to the voltage input to the circuit, means associated with the stepping relay to vary the proportionality between the current to the second contact meter and the input voltage for each step of the stepping relay, and means operable

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to energize said stepping coil when contact is established at said second contact meter.

7. Apparatus according to claim 6 wherein the means for varying the proportionality between the current to said second meter and the input voltage comprises a bank of resistors connected in series with the input voltage, an adjustable slider connected to the input of said second meter, and means causing said slider to tap off an additional resistor for each upscale step of said stepping relay.

8. In a mass spectrometer having a source of ions, means for segregating the ions in accordance with their mass-to-charge ratio, a collector electrode, means for successively focusing ions of differing mass-to-charge ratio on the collector electrode, a variable range amplifier and recorder, an automatic sensitivity selection circuit comprising an anticipator electrode positioned to receive ions in advance of the collector electrode, an amplifier connected to amplify discharge signals developed at the anticipator electrode, a stepping relay, a contact meter sensitive to the magnitude of the output of said amplifier to actuate and step the stepping relay in accordance with the magnitude of the amplifier output, means for decreasing the sensitivity of the meter for each upscale step of the relay, a source of voltage connected to the relay, and means for varying the adjustment of the variable range amplifier and recorder in accordance with the setting of said stepping relay.

9. In a mass spectrometer having a source of ions, means for segregating the ions in accordance with their mass-to-charge ratio, a collector electrode, means for successively focusing ions of differing mass-to-charge ratio on the collector electrode, a variable range amplifier and recorder, an automatic sensitivity selection circuit com-

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prising an anticipator electrode positioned to receive ions in advance of the collector electrode, an amplifier connected to amplify discharge signals developed at the anticipator electrode, a stepping relay, a contact meter sensitive to the magnitude of the output of said amplifier to actuate and step the stepping relay in accordance with the magnitude of the amplifier output, means for decreasing the sensitivity of the meter for each upscale step of the relay, a source of voltage connected to the relay, means for varying the adjustment of the variable range amplifier and recorder in accordance with the setting of said stepping relay, means for resetting said stepping relay, and control means for timing the variation of the variable range amplifier and recorder adjustment and resetting of said stepping relay in accordance with the condition of said recorder.

10. Apparatus according to claim 9 wherein said control means comprises a pair of micro-switches, a first one of said switches being connected in series with said means for resetting said stepping relay, and the second of said switches being connected in series with said means for varying the adjustment of variable range amplifier and recorder, and means operable responsive to movement of the recorder to close said second switch and to open said first switch as the recorder approaches "zero" and to reverse the switch positions as the recorder leaves "zero."

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