Dec. 5, 1967 L. KRAUSS ET AL 3,356,895

SPECTRO-CHEMICAL ANALYSIS APPARATUS SUPPLYING SUBSTANTIALLY THE SAME ENERGY TO THE GAP FOR ALL WAVEFORMS

Filed Dec. 30, 1964 3 Sheets-Sheet 1

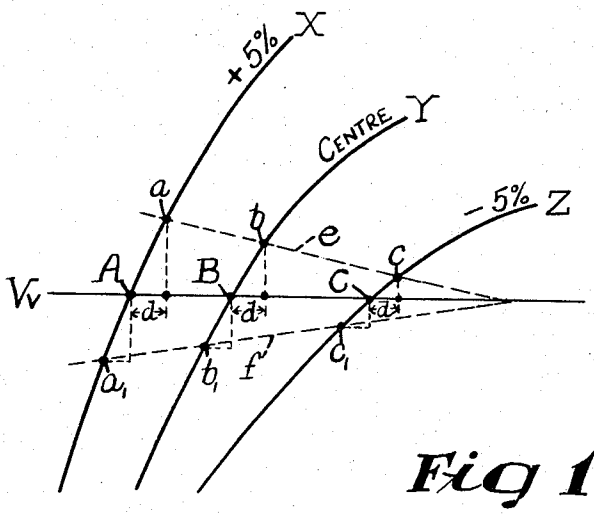


Fig 1.

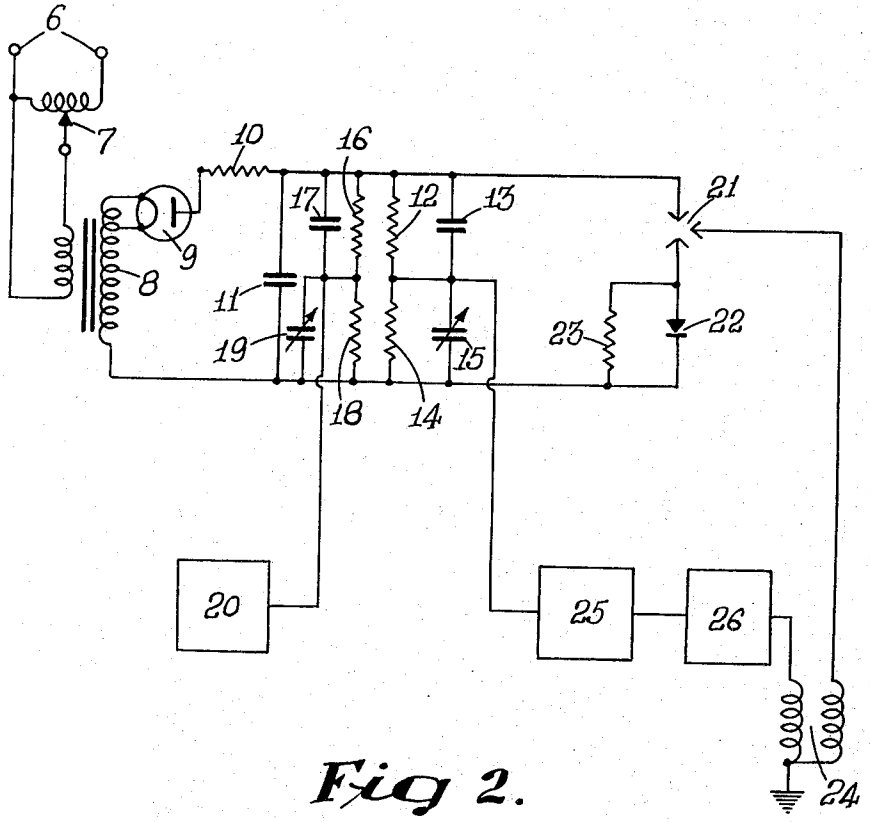


Fig 2.

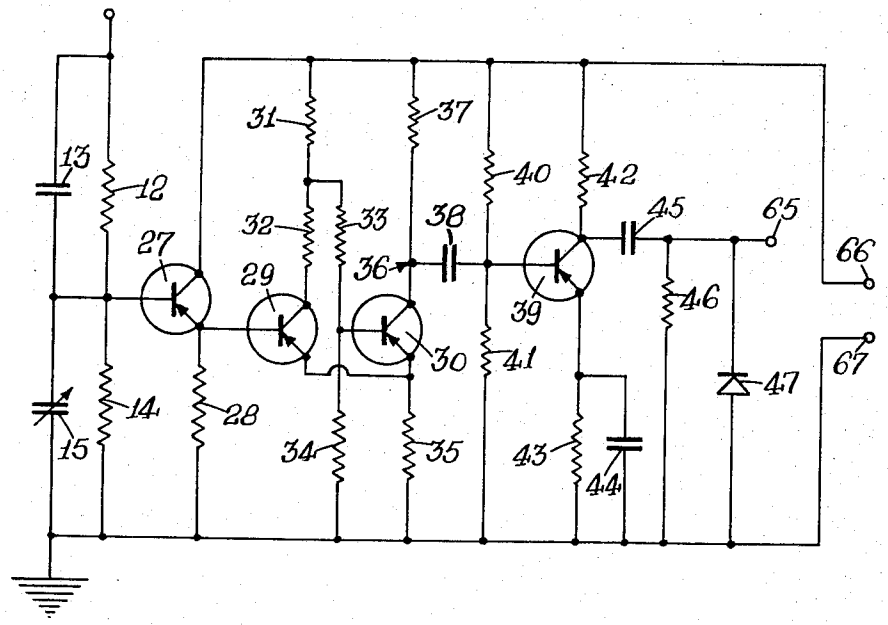

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Fig 3.

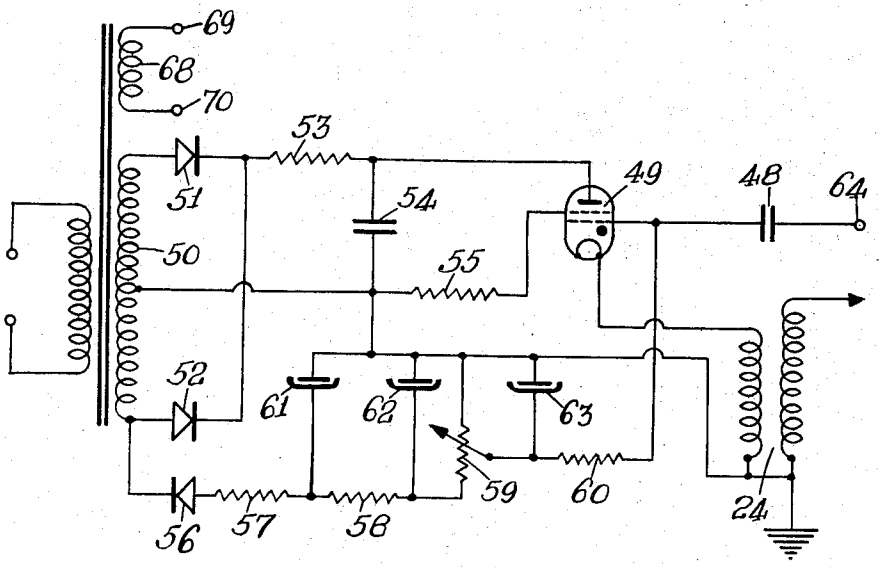

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Fig 4.

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SPECTRO-CHEMICAL ANALYSIS APPARATUS SUPPLYING SUBSTANTIALLY THE SAME ENERGY TO THE GAP FOR ALL WAVEFORMS
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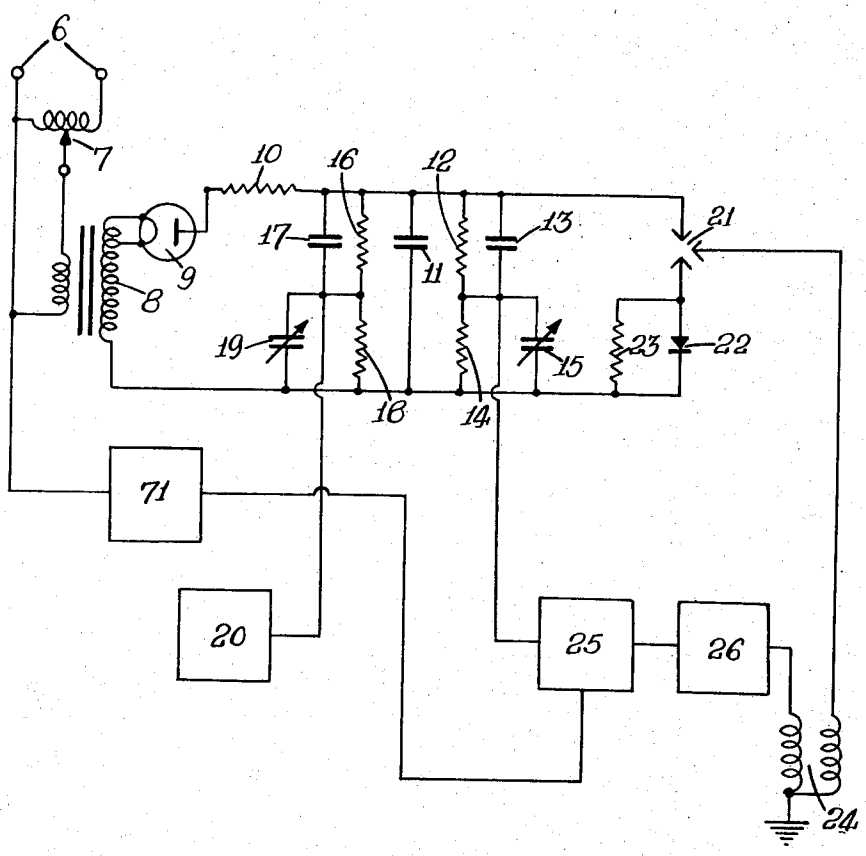


Fig 5.

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3,356,895

SPECTRO-CHEMICAL ANALYSIS APPARATUS SUPPLYING SUBSTANTIALLY THE SAME ENERGY TO THE GAP FOR ALL WAVEFORMS

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4 Claims. (Cl. 315—199)

This invention relates to the stabilizing of firing voltages in discharge gaps where spark, arc or other light sources are initiated.

In spectro-chemistry, for instance, a spark or arc discharge is used for the analysis of material. In this case, the vaporization of a sample of the material is brought about by the arc or spark as a prerequisite to the analysis. Where accurate analysis is required, the stability of the firing voltage in the discharge gap is usually of cardinal importance and for this purpose various forms of equipment are available. However, such equipment is generally costly and an object of the present invention is to provide a novel method for stabilizing the firing voltage which may be exercised by the use of comparatively inexpensive apparatus. A further object of the invention is to provide apparatus for practicing the method.

According to the invention, apparatus is provided for insuring a substantially constant firing voltage in a discharge gap, the voltage being derived from an alternating or interrupted direct current supply. Said apparatus comprises sensing means responsive to the occurrence of a selected voltage level in the supply, and means for triggering the initiation of a discharge in the gap on signals received from the sensing means, a passive network connecting the sensing means to the operating voltage source and operable to produce an advance of time corresponding to the time delay between the initiation of the sensing signal and the instant of firing.

Further according to the invention the apparatus includes means to signal the action of the passive network. Also according to the invention the apparatus includes means to vary the action of the passive network. In a preferred form of the invention the means to vary the action of the passive network responds substantially to signals from the signal means.

In order to illustrate the invention some examples are described hereunder with reference to the accompanying drawings in which:

FIGURE 1 shows a series of voltage waves all of which have the same frequency but differing amplitudes, and the diagram serves to illustrate the problem with which the present invention is involved;

FIGURE 2 is a circuit diagram of one form of apparatus for practicing the method of the invention;

FIGURE 3 is a circuit diagram of the form of sensing means used in the example of FIG. 1;

FIGURE 4 is a circuit diagram of the form of triggering means used in the example of FIG. 1; and

FIGURE 5 is a circuit diagram of a second form of apparatus for practicing the method of the invention.

Apparatus adapted to initiate a discharge in a gap between electrodes may be classified as efficient or inefficient according to the speed with which the discharge is effected on the occurrence of the voltage in question. With expensive equipment the time delay is small and the variation in the actual firing voltage in the gap is reasonably stable. On the other hand, with inexpensive equipment, the variation in the actual firing voltage can reach substantial proportions because of the time delay

involved between the step of sensing the occurrence of the selected voltage and the triggering of the discharge initiating device. It is all a question of the inherent time delay in the equipment and this delay is related to cost. In practice the supply voltage may often vary in the range plus or minus 5% about a mean value and the purpose of FIG. 1 is to show how these changes can substantially effect the voltage level in the gap at which a discharge is initiated.

In FIG. 1, portions of three voltage waves are shown and these waves are referred to respectively by the references X, Y, and Z. These waves are characterized in that they are of the same frequency but of differing amplitude and of different slopes in their leading edges. The middle or center wave Y is taken as the mean voltage wave at electrodes spanning a discharge gap and the flanking waves X and Z are assumed to represent the anticipated maximum and minimum voltage waves. In the case of wave X, the peak voltage in this wave will be higher than that of the mean wave Y and in the case of the wave Z its peak voltage will be lower than that of the mean wave. On the assumption that a discharge in a gap is to be initiated on the occurrence of a voltage V then a line joining points A, B and C on the waves will be a straight datum line V_V, the points A, B and C representing voltage V. If expensive equipment having virtually no time delay were involved then firing of the discharge would occur practically simultaneously with the appearance of the selected firing voltage V. In these circumstances, the problems with which this application is concerned hardly arise, but their recognition has enabled applicant to proceed using vastly cheaper equipment.

On the other hand the voltage sensing means and the discharge triggering means may have a material time delay before the required end response occurs, i.e. firing of the discharge. In these circumstances, at a given setting of the voltage sensing means, the voltage at the electrodes flanking a discharge gap will rise during the constant time delay period before the triggering means has actually triggered the discharge; so that in the case of the X curve the voltage will rise to the value represented by reference *a* before firing takes place. In curves Y and Z the corresponding points are *b* and *c*, all of which are on the sloping line *e*. The horizontal distance represented by the reference *d* is the time delay between the appearance of the selected sensing point, namely voltage V, and the end response of the ionization means. The actual voltage at which the discharge occurs is, of course, dependent on the magnitude of this delay which is fixed, and the slope of the wave, which varies in correspondence with the input mains changes.

In accordance with the invention, there has been devised an arrangement which triggers whenever a given selected voltage appears on any waveform passing through it, and insures that a substantially stable firing voltage occurs in the discharge gap regardless of which waveform in the range X to Z is involved. By means of this arrangement, it is possible to employ comparatively cheap equipment and yet maintain the performance hitherto usually associated with expensive equipment.

The apparatus of the invention, as exemplified in the circuits shown in the drawings is designed to fire, at constant voltage, an operating discharge gap **22**. This discharge gap **22** is connected via a switching gap **21** to a storage capacitor **11**. The storage capacitor **11** obtains its charge from a charging resistor **10**, rectifier **9** and the transformer **8** which is connected to the power source **6**. The stored energy in capacitor **11** discharges in the firing gap **22** whenever the switching gap **21** is actuated. In spectro-chemical analysis, it is essential to have a source of constant energy and since the energy released in the

firing gap is related to the voltage across capacitor **11** according to:

$$\text{Energy}=\frac{\text{Voltage}^2\cdot\text{Capacitance}}{2}$$

the need for having a constant firing voltage becomes obvious.

The trigger electrode of the switching gap **21** is connected to the circuit through a passive network comprising elements **12, 13, 14, 15**, sensing unit **25**, triggering circuit **26** and ignition coil **24**. The processing of the signal picked up by the sensing circuit and passed through the triggering circuit and ignition coil occupies a time period *d*, and accordingly a time delay *d* occurs between the sensing of the triggering signal and the actual operation of the gap **21** (i.e. the instant of firing). This time delay *d* affects the firing voltage which is developed across the capacitor **11** in the manner described earlier such that the actual voltage when the discharge occurs in gap **22** will have increased by an amount corresponding to the time period *d* (see FIG. 1).

As the sensing circuit **25**, trigger circuit **26** and the spark from the ignition coil **24** at the switching gap **21** will always produce delay *d*, the voltage at which the discharge occurs in discharge gap **22** is higher than the voltage at the time of the sensing by the sensing circuit **25** and, since the delay depends on the components used, this delay is fixed. The greatest part of the delay *d* occurs in the ignition coil **24**.

The apparatus operates in the zone of the line V*v* in FIG. 1 and the basic requirement is that the datum line is below the peak voltage of the wave Z. The position of the line V*v* is determined by experience of the voltage fluctuations of the current supply used. If the initiating signal or pulse was received at a time when the voltage level is V*v* then due to the delay *d* firing in the gap **22** would occur on the line *a, b, c*, depending on the particular form of the wave. This is undesirable. Therefore the sensing device **25** is supplied with a voltage advanced in phase from the voltage across the capacitor **11** of the discharge circuit which is the discharge voltage, and if this phase adjustment is equal and opposite to the delay *d* firing in the gap **22** will occur along the line A, B, C, and is at constant voltage V*v*.

The phase advance is effected by adjusting the passive network comprising resistors **12** and **14**, and capacitors **13** and **15**. For various purposes the capacitor **15** is adjustable to enable it to be set to suit the components of the apparatus and the selected firing voltage. During operation no adjustment of the capacitor is necessary. Adjustments may be required from time to time to compensate for changes which might occur in the physical properties of the components of the circuit.

Depending on which curve of FIG. 1 represents the existing voltage form, the apparatus will become operative along the line *f* at the appropriate point to insure that firing at the gap **22** occurs at the voltage V*v*. It will be understood that a_1, b_1, and c_1 are different voltage levels and the sensing device **25** is responsive to a fixed selected voltage level, the level being sensed by the sensing circuit at a point between resistors **12** and **14** of the passive network (FIG. 3). The phase of the discharge voltage across the capacitor **11** is not altered by the passive network insofar as the firing voltage is of concern, but only the phase of the voltage fed into the sensing device **25** is shifted.

The desired firing of the discharge gap **22** on the line A, B, C at constant voltage V*v* is brought about by a phase advance of the waveform corresponding to waveforms X, Y, Z, which are picked up by the sensing circuit through the passive network. When the arrangement is operating on the Y curve the sensing device will pick up a voltage proportional to the appearance of the voltage across the capacitor **11** at the level of the point b_1 so that firing in the gap will occur when the waveform reaches B at the required voltage level of V*v*. Should the voltage now rise to the X curve then the sensing device will be initiated when the voltage across the capacitor is at the level of a_1 volt so that once again firing will take place at the V*v* level. In the case of the Z curve sensing will take place when the capacitor **11** voltage is at c_1 volts.

The arrangement of the invention thus is one in which the voltage picked up by the sensing circuit **25** through the phase shifting passive network is advanced a fixed time interval *d* in such a manner that the sensing of the triggering signal to gap **21** is advanced a fixed time period *d*, and that because of the different slopes of the waveforms X to Z the discharge voltage across the capacitor **11** is allowed to rise during this fixed time interval *d* by an amount proportional to the slope of the particular waveform X through to Z which is involved. Because the advance of time is fixed by an amount equal to *d* the sensing of the triggering signal occurs at different discharge voltage levels a_1, b_1, and c_1, however, the advancement in phase of the voltage to the sensing device only insures that this latter device, which is responsive to a fixed voltage, operates at this fixed level.

The constancy of the firing voltage at A, B, C may be observed by connecting an oscilloscope across capacitor **11**, and if necessary may be corrected by adjusting capacitor **15**.

A suitable circuit for insuring stable firing conditions in the discharge gap is shown in FIG. 2. In this figure, reference **6** represents the mains input terminals and reference **7** is a form of variable transformer frequently called a Variac. The latter device is used artificially to create mains variations with the object of testing the performance of the spark generator. The Variac could be replaced by any suitable device which would enable the user of the equipment artificially to simulate operating conditions through the range of waves shown by curves X to Z in FIG. 1.

Reference **8** in FIG. 2 is a high voltage transformer and has, say, a normal peak voltage of 17 kilovolts and the reference **9** indicates a rectifier tube which is associated with a heater winding forming part of transformer **8**. The tube **9** could be arranged to produce wave pulses corresponding to the positive portions of the supply wave, or, alternatively, the negative portions of the supply wave could be rectified to produce a continuous wave having the appearance of joined positive half waves. Furthermore, the tube **9** could be replaced by solid state rectifiers suitably connected to produce the desired waveform.

The current flows from the anode of rectifier tube **9** through resistor **10** into condenser **11**, and the elements **10** and **11** involve a time constant adapted to prevent a too rapid re-discharge of condenser **11** in circumstances where the discharge has taken place very early in the cycle. Clearly the values of elements **10** and **11** will depend on the spark or discharge conditions chosen. If the value of element **11** is large, the spark will have a greater energy and vice versa; a common practical value for element **10** would be about 400-kilo-ohms and for the element **11** about 6 nanofarads.

Across the condenser **11**, a passive network consisting of resistor **12**, condenser **13**, resistor **14** and condenser **15** is placed, condenser **15** being of a variable nature. The network comprising elements **12, 13, 14** and **15** constitutes in itself a well known compensated network which acts to divide the voltage appearing across the condenser **11** for further use. At the same time, it insures that there will be no phase lag or phase lead between the input and the output of the network if the time constants formed by resistor **12** and condenser **13** are equal to the time constants formed by resistor **14** and condenser **15**. If, however, the network is detuned, as for instance in the preferred version by the variable condenser **15**, the phase relationship between the input and output of the network can be made lagging or leading. In the arrangement under consideration, the concern is with a phase lag caused by the discharge triggering mechanism involved, and this lag

is the cause of bad regulation in a circuit such as that depicted in FIG. 2. By adjusting condenser **15** the network may be given a phase characteristic adapted to balance the lag resulting from the trigger circuit. It is through condenser **15** that the phase lag can be nullified and the desired operation of the discharge device be obtained.

There is also a network consisting of resistor **16**, condenser **17**, resistor **18** and condenser **19** across condenser **11**. This network serves the purpose of providing the means whereby the performance of the circuitry may be checked or signalled. In other words, it is through this aspect of the circuitry that the operator is able to determine whether in fact constant firing voltage conditions are being maintained in so far as the discharge is concerned. This additional network is tuned to zero phase lag and its output goes to a suitable monitoring device **20**.

The passive network may be arranged to vary its action automatically in response to signals from the checking or signalling circuit (reference **20**).

It will be apparent that the regulation of the spark generator is brought about by the adjustment of passive devices, so that once the adjustment is made it is unlikely that the performance of the spark generator will fall away. This assumption is on the basis that the parts involved are of suitable manufacture with respect to stability and high voltage performance.

Across the condenser **11** there are two spark gaps carrying the references **21** and **22**. Spark gap **21** is a control gap and contains an ionization needle which is linked to an ignition coil **24**. In parallel with the gap **22** there is a resistor **23** of the value of, say, 100 kilo-ohms to 1 meg-ohm which serves the purpose of offering the trigger spark a ground potential to which it can jump. Gap **22** is an analytical gap containing on its ground side the sample to be analyzed. In order to alter the analytical spark characteristics it is desirable to insert resistances or inductances in, for instance, the line leading to gap **21** or by inserting resistances or inductances between analytical gap **22** and ground.

There are many similar methods of achieving the spark action in the gap **22**, but in this case the gap **21** is used as a switch to switch the energy contained in condenser **11** into gap **22**. A sensing device **25** together with a triggering device **26** produce in conjunction with the ignition coil **24** the desired ignition in gap **21** which as mentioned previously acts as a switch for gap **22**.

Clearly all the components involved must be able to stand the high voltages which are ltikely to be experienced in devices of this nature.

FIGURE 3 shows the circuitry of the sensing means **25** as used in the embodiment under consideration. The function of the sensing means is to sense the apperance of a selected voltage level for the purpose of initiating the discharge in the gap **21**. Network **12**, **13**, **14** and **15** gives rise on its output side to a voltage proportional to the dividing factor of the network. The voltage thus achieved at the base of transistor **27** varies with the wave form across condenser **11** from, say, 0 to 10 volts, whereas the voltage on condenser **11** varies from, say 0 to 10 kilovolts. The action of condenser **15** as shown in FIG. 3 has already been explained with reference to FIG. 2.

Transistor **27** acts as an emitter follower to provide a low impedance source for the sensing circuit and it will be noted that a resistor **28** is placed between element **27** and ground. Transistors **29** and **30**, and resistors **31**, **32**, **33**, **34**, and **35** form together a so-called Schmitt circuit. If a certain voltage on the incoming wave form is reached on the base of transistor **29**, the Schmitt circuit will change its potential abruptly on the collector of transistor **30**. The transistor **30** conducts in advance of the appearance of the specific voltage on the base of transistor **29** so that the junction **36** of the resistor **37** and condenser **38** is therefore at a potential nearer to ground. When the voltage on the base of transistor **29** reaches the specific chosen value, the potential at the junction **36** of resistor **37** and condenser **38** abruptly assumes a value nearer to the supply voltage.

If the voltage on the base of transistor **29** falls again, the potential on the junction **36** of resistor **37** and condenser **38** reverts again to the original state. Thus, for a varying input wave form, whether of sine wave form or a pulsating direct current, the output of the Schmitt circuit will provide a square-wave form.

Condenser **38** couples the output of the Schmitt circuit to an amplifier which consists of transistor **39**, resistors **40**, **41**, **42** and **43** and condenser **44**. This stage is a normal amplifying stage with feedback through condenser **44**. The collector of transistor **39** then provides an amplified and inverted signal which is fed to condenser **45**. Condenser **45** and resistor **46** form a differentiating network in order to provide sharp pulses for the following network which constitutes the triggering device shown in FIG. 4. As only the positive pulses from the differentiating network are used, the negative pulses are shorted to ground by the diode **47**. The output of the total sensing circuit is then fed to the trigger device of FIG. 4 through terminal **65**.

In the example under consideration, the sensing device is powered through terminals **66** and **67** by, say, a negative 15 volt power supply in the case of negative wave forms and PNP transistors are used. If positive wave forms are to be used, the device must be provided with NPN transistors and with a positive supply voltage. The amplitude of the output pulses in this case is about 8 volts. In all examples the power supply used for powering the sensing device should be properly stabilized.

The pulses obtained from the output of the sensing means is fed through terminal **64** and condenser **48** to the grid of thyratron **49** of FIG. 4. Thyratron **49** is switched on on receiving this pulse and passes a heavy current through the primary of ignition coil **24**. The voltage on the output of the ignition coil is then used to trigger the discharge in spark gap **21**. Transformer **50**, rectifiers **51** and **52**, resistor **53** and capacitor **54** form the voltage source for the heavy current passed through the thyratron **49**. Resistor **55** is usually fixed by the form of thyratron used. The resistor **53** and condenser **54** form a time constant which determines the frequency at which the thyratron **49** can be refired. Thus, if higher frequencies are used the time constant must be reduced.

Diode **56**, resistors **57**, **58**, **59** and **60** together with condensers **61**, **62** and **63** form a negative supply in order to bias off the grid of thyratron **49**. The positive pulse coming from the sensing means overcomes this bias and thyratron **49** fires.

The ignition coil **24** may be a conventional motor car ignition coil or even the smaller forms of coils used in vehicles such as various motor cycles. The output of this coil is a pulse which has a duration in the order of tens of micro-seconds and of an amplitude of about 20 kilovolts or more. It is advisable therefore to see that the cable from the output of the ignition coil **24** to the trigger gap **21** is well insulated and is of low capacity.

With respect to the transformer **50**, it is possible to use the same transformer for supplying both the sensing device and the trigger. In the case under consideration the additional winding **68** of the transformer **50** could be coupled to the terminals **69** and **70** of the sensing device through a suitable rectifying device. It is also possible to replace the thyratron **49** by a thyristor, a silicon controlled rectifier or similar device.

For the purpose of assisting in the clear understanding of the circuitry of the example, a parts list is set out below of the components involved in a test circuit which operated efficiently:

9—Rectifier valve RCA 8020
10—Resistor, 300 kilo-ohm, 20 watt
11—Condenser, 6 nanofarad, 40 kilovolts peak
12—Resistor, 15 meg-ohm, high stability, in araldite
13—Condenser, 25 picofarad, 24 kilovolt, in araldite

14—Resistor, 6.5 kilo-ohm, high stability
15—Condenser, 38–40 nanofarad, variable switched
16—Resistor, 20 meg-ohm
17—Condenser, 5 picofarad
18—Resistor, 20 kilo-ohm
19—Condenser, 500 picofarad
21—Control gap, 4–6 mm, tungsten electrodes, with igniter tip
22—Analytical gap, spectro-chemical electrode stand
23—Resistor, 100 kilo-ohm
24—Ignition coil, 6 v., Lucas, sports car or Boach 6 v., Moped
27—Transistor, Philips BCZ 11
28—Resistor, 3.9 kilo-ohm
29—Transistor, Philips BCZ 11
30—Transistor, Philips BCZ 11
31—Resistor, 1.2 kilo-ohm
32—Resistor, 1.2 kilo-ohm
33—Resistor, 1 kilo-ohm
34—Resistor, 560 ohm
35—Resistor, 1 kilo-ohm
37—Resistor, 1 kilo-ohm
38—Condenser, 0.1 microfarad
39—Transistor, Philips BCZ 11
40—Resistor, 3.9 kilo-ohm
41—Resistor, 50 ohm.
42—Resistor, 6.8 kilo-ohm
43—Resistor, 150 ohm
44—Condenser, 2 microfarad
45—Condenser, 0.1 microfarad
46—Resistor, 22 kilo-ohm
47—Diode, Sesco 14J2.
48—Condenser, 1 nanofarad
49—Thyratron, Philips 2D21
50—Mains Transformer, 300–0–300.
51—Diode, Philips OA211
52—Diode, Philips OA211
53—Resistor, 10 kilo-ohm 5 watt
54—Condenser, 1 nanofarad
55—Resistor, 10 kilo-ohm
56—Diode, Philips OA211
57—Resistor, 100 kilo-ohm
58—Resistor, 100 kilo-ohm
59—Potentiometer, 20 kilo-ohm
60—Resistor, 680 kilo-ohm
61—Condenser, 32 microfarad
62—Condenser, 25 microfarad
63—Condenser, 50 microfarad

In FIG. 5 an alternative example is illustrated. On the discharge generating side of the transformer **8** the same components are to be found as in the case of the example of FIG. 2. The control of the sensing device in this case is, however, brought about by a connection from the mains transformer input through a rectifying device **71**. The voltage in this case is applied to the sensing means **25** in an inverted sense in order to satisfy the requirements discussed with reference to FIG. 1. This form of control of the sensing means is a voltage control, whereas in the preferred version discussed with reference to FIGS. 2, 3 and 4 the control is a phase control effected by a proper setting of condenser **15**, to nullify the effect of the

time delay caused by elements **25**, **26** and **24**. Where voltage control is involved it is usually necessary to employ more components than is the case with phase control.

Both the embodiments shown with reference to the main FIGS. 2 and 5 operate on the same fundamental principles. Sensing means **25** is adapted to sense the appearance of the selected voltage level at some point up to the analytical gap and a signal from means **25** then acts to initiate the required discharge through triggering mechanism **26**. In view of inevitable variations in the mains supply, the passive network circuitry is employed to vary the level at which the sensing means responds in order to insure stability of voltage in the analytical gas during discharge.

We claim:

1. For use with a source of power having varying characteristics supplying voltage waveforms which differ at least in the slope of their respective leading edges; apparatus for spectro-chemical analysis comprising first means defining an analytical gap, second means for controlling the initiation of a spark in said analytical gap, energy storage means coupled to said source and adapted for supplying energy to said gap, trigger means coupled to said second means to trigger a spark in said analytical gap, sensing means to actuate said trigger means upon sensing a predetermined voltage magnitude, said sensing and trigger means at least partly causing a determinable delay between the sensing of said voltage magnitude and the triggering of a corresponding spark which delay affects the energy accumulated by said energy storage means in accordance with the particular slopes of the voltage waveforms supplied, and delay compensation means to compensate for said delay and responsive to said waveforms to advance the operation of said sensing means by said determinable delay whereby the energy supplied to said gap is substantially the same for all waveforms.

2. Apparatus as claimed in claim **1** wherein said second means includes means defining a spark gap in series with said analytical gap and coupling the latter with said energy storage means.

3. Apparatus as claimed in claim **2** wherein said delay compensation means includes a variable capacitor coupled to said source and said sensing means and applying to the latter voltages related to said voltage waveforms.

4. Apparatus as claimed in claim **1** comprising a passive network coupled to said energy storage means and a monitoring device coupled to said network.

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