United States Patent

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[31] **8634/68**

[54] **FLAME QUALITY AND PRESENCE MONITOR FOR MULTIBURNER FURNACES**
10 Claims, 3 Drawing Figs.

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[51] **Int. Cl.** **G01j 1/42,** G01j 5/32, G08b 17/06
[50] **Field of Search** .... 340/228.2, 228 S, 228, 227, 409, 210, 214; 356/217, 218, 221, 223; 328/2, 6; 250/83.3 UV, 83.6 P, 200, 206

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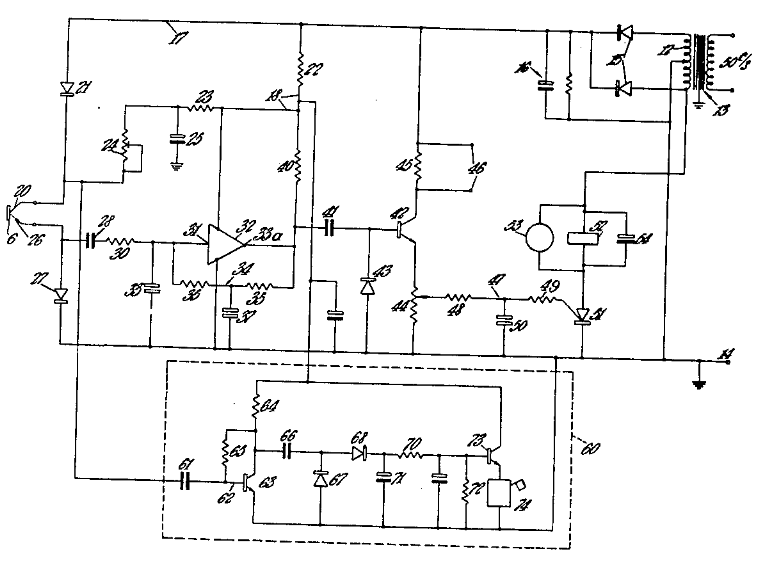
ABSTRACT: Flame-monitoring equipment for indicating the state of a burner flame in the presence of other burner flames is arranged to respond to a range of frequencies higher than those normally utilized in flame-monitoring equipment and which are confined to the root portion of the burner flame. The equipment provides a measure of the flame quality and has a light sensitive element which is arranged to view the root portion of the burner flame and to feed signals to the associated electrical circuitry which determines the flame quality from the number, rather than the amplitude, of the high frequencies present in the electrical output of the element and lying within said range.



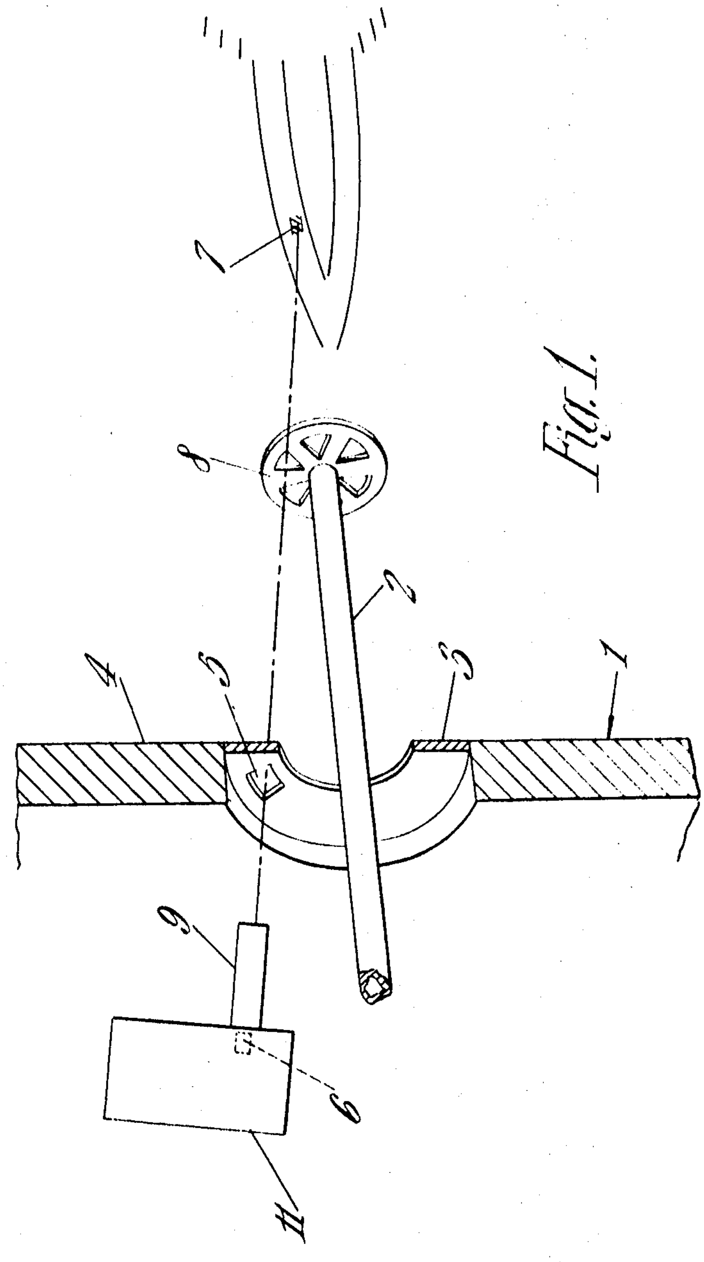


Fig. 1.

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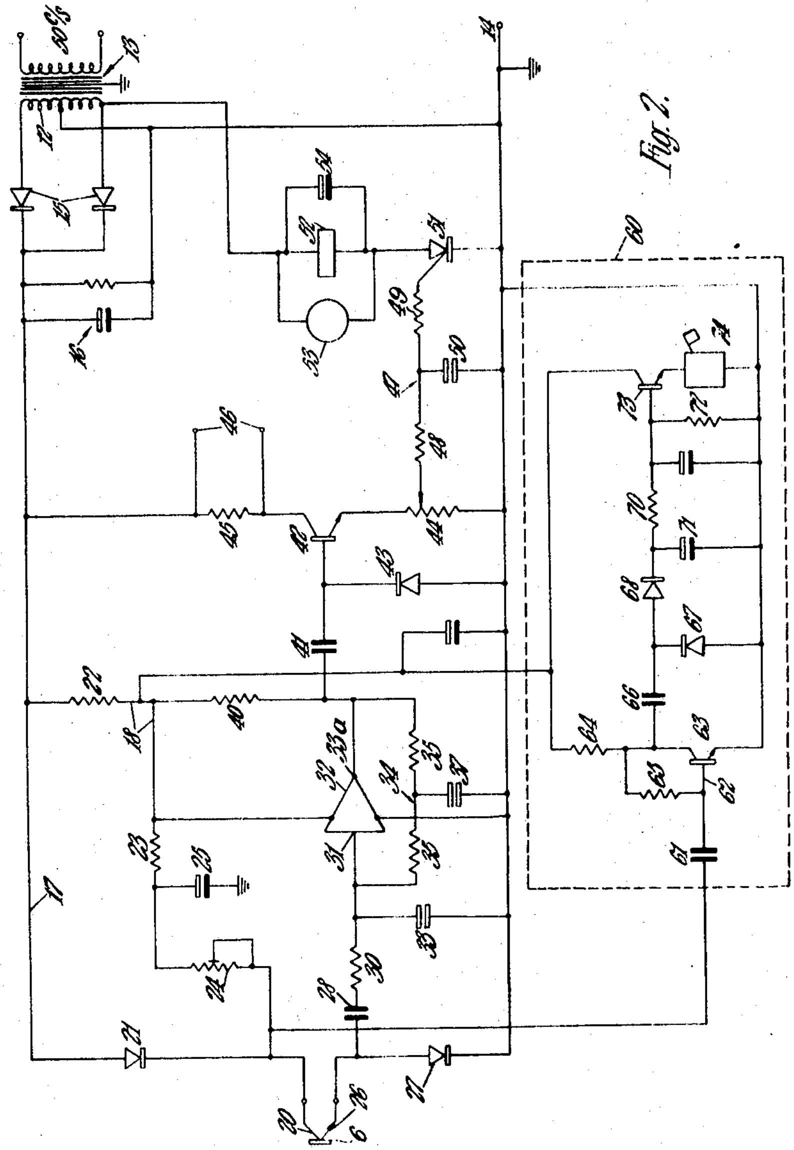

Fig. 2.

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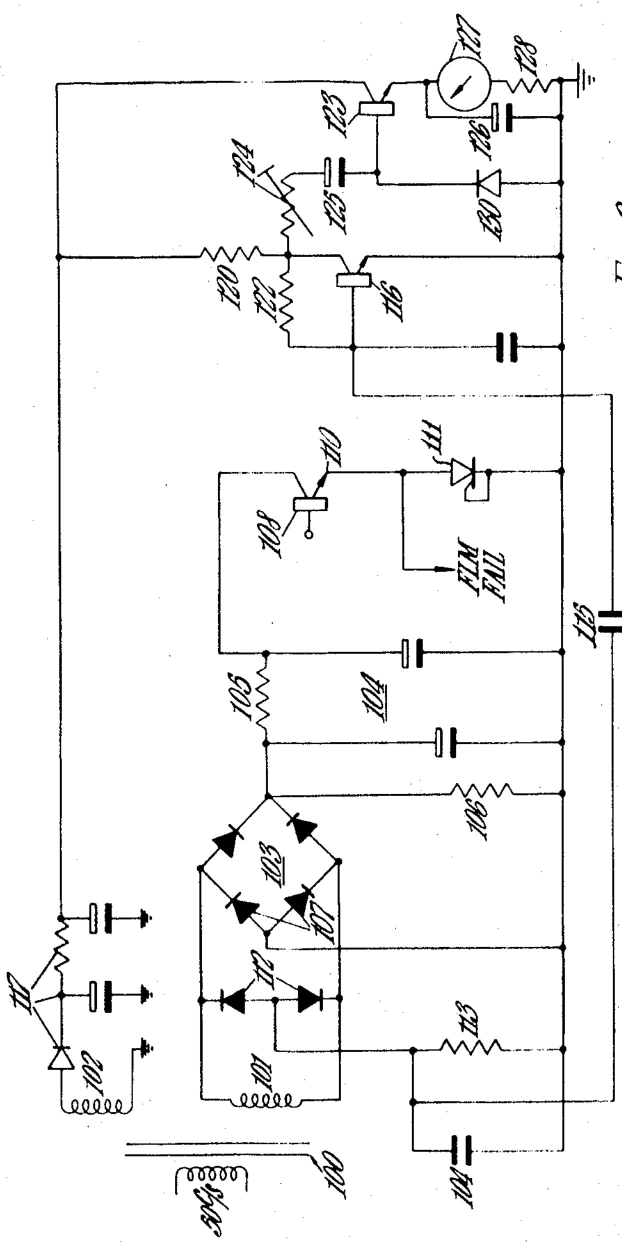

Fig. 3.

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FLAME QUALITY AND PRESENCE MONITOR FOR MULTIBURNER FURNACES

This invention relates to flame-monitoring equipment for use with multiburner furnaces and more specifically is concerned with equipment devised to operate effectively over a wide range of burner flame intensities and with negligible risk of the equipment failing to respond to the extinction of a particular flame as a result of the masking effect of neighboring flames.

There is an increasing demand in modern steam-generating apparatus and similar apparatus for the flames of burners feeding a furnace to be individually monitored so that an immediate warning is given should one of the flames falter or extinguish itself. Various techniques have been devised for monitoring individual flames of burners but they all suffer from practical disadvantages and none of them, as far as the applicants are aware, are capable of operating without risk of paralysis over a wide range of flame intensities or for monitoring the flames of a furnace having oppositely directed burners. The use of oppositely directed burners in furnaces is now becoming more common and is a combustion technique in which the burners are arranged in opposed pairs and direct fuel towards one another so that an extremely hot fireball is formed between the pairs by the coalesced flame fronts.

One of the more successful forms of flame monitoring equipment uses a photosensitive element which views the flame front of a particular flame being monitored and provides an electrical output signal having an alternating component whose magnitude is dependent upon the quality of the flame. This system relies on the fact that a burner flame front has a substantial low frequency alternating component of its light output of the order of 100cycles per second or less (hereinafter referred to as the 100 c.p.s. component for convenience), whose presence and magnitude may be used to signify, respectively, whether a burner is alight and the quality of the flame produced by it. Although light frequencies other than 100 c.p.s. are known to occur to lesser extents in the burner flame front, the component frequencies of the order of 100 c.p.s., apart from the flame-fluctuation frequency which is normally about 10 c.p.s., predominate and are naturally used to provide a measure of the flame quality of the burner. However, the relative magnitude of the 100 c.p.s. flame-fluctuation signal is large as compared with the 100 c.p.s. component present in the flame front so that there is a strong tendency for swamping of the photocell output by the constant value components and the 10 c.p.s. signal when monitoring high-temperature flames, with consequent difficulties in detecting the relatively weak 100 c.p.s. signal.

Although the above-described flame-monitoring equipment is widely used nowadays it has certain limitations which make it virtually unusable with opposed burners and seriously impair its usefulness in monitoring one of a multiplicity of closely spaced burners. One of these limitations stems from the fact that the burner flame being monitored may well have a relatively large range of desired operating temperatures. The light output fed to the photosensitive element is not only that of the flame but also that of the often-incandescent refractory material of the furnace lining viewed through the flame, as well as portions of adjacent flames.

In practice, there is towards the high-temperature range of burner operation a high level of background illumination on the photosensitive element which reduces the relative strength of the 100 c.p.s. alternating component of the photocell output signal. For example, perhaps 99 percent of the light falling on a photocell emanates from sources other than the 100 c.p.s. component. The internal resistance of the photocell is naturally reduced by the high level of background illumination so that fluctuations in the internal resistance produced by the 100 c.p.s. component provide relatively small electrical output signals. Also, the load of the photocell, being constant, means that there is always a mismatch between the photocell and the load at one or other ends of the range of burner operation. For example, if the burner is required to be monitored accurately at low-firing rates, or through a dirty window, then the photocell must be able to provide a good signal when its resistance is relatively high as a result of the low light intensity falling upon it. For this to occur the load connected to the photocell must have a high resistance. If the burner is operating at maximum firing rate then the light incident on the photocell is of high intensity so that its resistance is relatively small compared with the load resistance, and the mismatch between the photocell and load resistance results in a considerable loss of useful signal level derived from the 100 c.p.s. component.

A second limitation stems from the fact that although the detection of the 100 c.p.s. component.

A second limitation stems from the fact that although the detection of the 100 c.p.s. alternating component of a flame front is generally considered to be sufficient to distinguish one flame from a neighboring flame, this does not apply when the burners are oppositely directed as for practical reasons it is not possible to view the flame front of a burner flame without also viewing the flame front and thus the 100 c.p.s. component of the oppositely directed burner. The conventional system is thus quite incapable of distinguishing the 100 c.p.s. component of one burner flame which is not operating correctly, from the 100 c.p.s. component present in the flame front of the opposed burner which may be functioning correctly.

A third limitation of the above-described equipment is that for burners required to operate over a wide range of firing rates, the difference in light intensities falling on the photocell is commonly such that unless compensating measures are taken by reducing the light on the photocell at the upper end of the range of temperatures, paralysis of the equipment can occur. Although automatically operated diaphragms have been proposed for cutting down the light incident on the photocell at higher temperatures, they have the same effect as dirt on the window through which the photocell views the flame. The position can arise, therefore, that deposition on the window is interpreted as a poor quality flame. To remove this disadvantage complex systems have been devised for controlling the diaphragm position in accordance with the background radiation which produces a unidirectional output from the photocell. However, such arrangements increase the cost and complexity of the flame monitoring equipment.

An object of this this invention is the provision of improved flame-monitoring equipment.

In accordance with the broadest aspect of the invention there is provided flame-monitoring equipment for indicating the state of a burner flame in the presence of other burner flames by responding to the range of relatively high pulsation frequencies (as herein defined) present in the light output of the root portion of the flame to be monitored, such equipment including a light-sensitive element for viewing the flame root to provide an electrical signal containing components at said frequencies, and electrical circuitry receiving said components and providing an output whose magnitude is a function of the frequencies present in the electrical signal and is a measure of the flame quality.

In accordance with a second aspect of this invention flame-monitoring equipment includes a light-sensitive circuit containing a photosensitive element for providing an electrical output signal containing alternating frequency components corresponding to pulsation frequencies of light incident on the element from a root portion of a burner flame to be monitored; a processing circuit connected to receive the alternating frequency components from the light-sensitive circuit and to amplify those above a predetermined range of lower frequencies to substantially the same amplitude, irrespective of their relative amplitudes above a predetermined minimum magnitude, to provide an output train of pulses of substantially the same magnitude and generated at a rate dependent on the relatively high pulsation frequencies (as herein defined) of the components above said predetermined range of lower frequencies in the signal input to the processing circuit; and a pulse counting and analogue converter circuit connected to receive the output train of pulses from the processing circuit and to derive from them an electrical flame-measuring signal significant in magnitude of the pulse repetition rate in the train of pulses and which is an indication of the flame quality being monitored.

In accordance with a third aspect of the invention flame-monitoring equipment includes a photosensitive element whose electrical resistance varies with the intensity of light incident thereon, a nonlinear impedance load substantially matched to the element so that its impedance varies in sympathy with the element resistance to provide an output voltage signal across the load which varies as a logarithm, i.e. function, of the load current, a coupling circuit transferring alternating components of the voltage signal to input terminals of high-gain limiting amplifier, preferably an integrated circuit amplifier, a negative feedback loop extending from the output terminals of the amplifier to its input terminals and incorporating a shunt path for removing signals at relatively high pulsation frequencies (as herein defined) and above a prearranged lower range of input signal frequencies so that said lower frequency range of signal components is degeneratively amplified to progressively greater extents with diminishing frequencies, a differentiating and detecting circuit converting the limited output signals from the amplifier into a train of unidirectional pulses, a pulse-counting circuit for receiving the pulses and providing an output signal fluctuating with the rate of pulse generation by the amplifier, a potentiometer adjustable to select a desired proportion of the output signal in order to set the equipment to a predetermined threshold frequency, and an analogue converter circuit operating a flame indicator and controlled by the output signal from the potentiometer.

The underlying principle of the invention is based on the discovery by the applicants that a range of light frequencies considerably above those hitherto used for flame monitoring purposes and through this specification referred to, for convenience, as "relatively high pulsation frequencies" is produced in the root portion of the burner flame and can be used to operate flame-monitoring equipment. Moreover, this range of frequencies produced in the root portion increases with increasing quality of the burner flame so that, by counting the frequencies produced, rather than by taking a measurement of their magnitude, an excellent indication of the flame quality can be obtained which is localized to the burner flame being monitored. The lower range of frequencies beneath the relatively high pulsation frequencies and which have formed the basis of prior art flame-monitoring equipment are not used in the applicants' invention and they fall within the aforesaid prearranged range of lower frequencies. By using the relatively high pulsation frequencies present in each burner flame root to operate the flame-monitoring equipment associated with the burner, individual burners arranged for opposed firing can be monitored independently and without the risk that frequencies generated by one burner will mask the correct reading of the equipment monitoring invention opposed burner. In practice, the relatively high pulsation frequencies used in the applicants' invention range upwardly from frequencies of the order of 1,000 c.p.s. and are suitably above 3,000 c.p.s. upwards, frequencies of 10,000 c.p.s. and above being particularly useful in carrying out the applicants' invention as they are found to be very localized to a particular region of the flame root.

In carrying out the second aspect of the invention it is naturally preferable that the load for the photosensitive element should have a logarithmic impedance characteristic substantially matched to the impedance characteristic of the photosensitive element which may be a photosensitive transistor, a photocell or a photoresistor. A suitable form of load comprises a forward biased silicon diode connected to provide across it a voltage which varies logarithmically with the current through it. Preferably the photosensitive element in such an arrangement comprises an NPN phototransistor.

The processing circuit of the second aspect of the invention suitably includes a high-gain amplifier, preferably as integrated circuit amplifier, having low-frequency degenerative characteristics for suppressing the lower range of frequencies, that is to say those beneath about 1,000 c.p.s. A convenient way of obtaining low-frequency suppression is by using a negative feedback loop between the output and input to the amplifier and arranging for a shunt circuit to earth to be effective to prevent the feed back of frequencies above the lower range which is to be suppressed. The amplifier is preferably a limiting amplifier having a high gain so that virtually all input signals are limited to substantially the same value in the output. A detecting circuit following the limiting amplifier may then be used to convert the output from the amplifier into a stream of pulses of substantially the same magnitude and polarity. The pulse repetition rate is a function of the frequencies present in the light incident on the photosensitive element and this, in turn, has been found by the applicants to be indicative of the flame quality.

An advantage of the third aspect of the invention is that by arranging for the load on the photosensitive element to have a characteristic which substantially matches the characteristic of the element, a satisfactory match between the resistance of the element and the impedance of its load can be maintained so that the range of light intensities over which the equipment is capable of operating can be considerably extended as compared with conventional flame-monitoring equipment using a constant load. In this way the flame-monitoring equipment is suitable for use with current burners designed to operate with a very wide range of load, without risk of paralysis.

Preferably the detector circuit of the third aspect of the invention includes a diode arranged between the base of an NPN transistor and a capacitor. The capacitor and the diode serve to provide the base of an NPN transistor connected into an emitter follower circuit, with a bias which fluctuates with the pulse repetition rate in the output of the amplifier. The load of the emitter follower circuit suitably takes the form of a potentiometer across which a voltage is generated fluctuating in accordance with the pulse repetition rate. A proportion of this voltage may be applied through a delay circuit to the gate of a silicon-controlled rectifier to switch the current through a relay and flame indicator lamp. The advantage of such an arrangement is that the point of operation of the relay is determined by the setting of the potentiometer of the emitter follower circuit. The voltage tapped off the potentiometer is a function of the frequencies incident on the photosensitive element and thus the point at which the relay operates in relation to the pulse repetition rate can be determined by the potentiometer setting.

Conveniently the equipment is arranged to provide an output signal if the intensity of light on the photosensitive element is less than a predetermined valve. This may be effected by providing the photosensitive element with two power supplies one of which provides a low current at a unidirectional steady voltage to the element and the other of which provides a larger current at a unidirectional voltage on which a ripple frequency is superimposed. A switching means is adapted selectively to connect the power supplies to the element in accordance with the current passing through it. A frequency sensitive circuit which responds to the ripple frequency may be suitably connected to a supply terminal of the element so as to respond to operation of the switching means by providing an output signal signifying that the light intensity on the photosensitive element has fallen beneath a predetermined minimum. In this way the equipment can provide an indication that the sight glass or transparent screen, through which the photosensitive element views the flame, needs cleaning. The invention will now be described in more detail, by way of example only, with reference to the accompanying drawings, in which:

FIG. 1 is a diagrammatic view of a portion of a furnace having a burner the flame of which is to be monitored by flame-monitoring equipment;

FIG. 2 is a circuit diagram of the monitoring equipment; and,

FIG. 3 shows a brightness circuit providing an analogue output.

Referring to FIG. 1 a furnace partially shown at **1** has a number of burners arranged for opposed firing and one of which is shown at **2**. The burner **2** is arranged in a port **3** formed in a wall **4** of the furnace. Also associated with the port **3** is a sighting window **5** through which an optical arrangement **9** incorporating a phototransistor **6** is able to view a segment of a root portion **7** of a burner flame. The line of sight of the arrangement **9** is shown diagrammatically and it passes across the edge of an impeller plate **8** surrounding the discharge end portion of the burner barrel. The transistor forms part of an electrical circuit diagrammatically illustrated by the box **11** and which provides outputs significant of the quality of the flame and also the cleanliness of the sighting window **5** which can be impaired by dust deposition on its optical components.

The circuit **11** of the equipment is shown in more detail in FIG. **2** and it receives its power from a center tapped secondary winding **12** of a transformer **13**. The center tap of the transformer secondary winding is earthed at **14** and a conventional full-wave rectifier **15** and smoothing circuit **16** are arranged to provide a 10 volt supply line on which is superimposed a 1 volt 100 c.p.s. ripple obtained from the full-wave rectifier **15**. This supply is connected through two supply circuits **17, 18** to the collector **20** of the photosensitive NPN transistor **6** on which light from the root portion of a flame being monitored is incident.

One of the circuits **17** comprises a simple rectifier **21** providing switching means and having its cathode connected to the collector **20** of the transistor **6** and across which a half volt drop occurs. The supply fed to the collector of the transistor via the rectifier **21** has superimposed upon it the 100 c.p.s. ripple. The other supply circuit **18** to the collector is arranged in parallel with the rectifier and comprises three serially connected resistors **22, 23, 24** of values, respectively of 47 ohms, 220 ohms and a preset 100 kilohm. The junction of the 220 ohm resistor **23** and the 100 kilohm resistor **24** is connected through a smoothing capacitor **25** of 320 microfarads to earth so that the 100 c.p.s. ripple does not appear on the transistor collector when the second supply circuit **18** formed by the resistors is in use. However, the 100 kilohm resistor in the circuit results in the current it is capable of providing to the collector **20** being very limited and if the light intensity falling on the photosensitive transistor **6** is such that the junction of the 100 kilohm resistor and the transistor collector **20** falls beneath 9.5 volts, the rectifier **21** in the other supply circuit **17** is forwardly biased and supplies the transistor collector **20** with current drawn from the 10 volt supply having the 100 c.p.s. ripple on it.

The transistor emitter **26** is connected to earth through a load circuit provided by a silicon diode **27** so connected by forward biasing that the voltage drop across it is proportional to the logarithm of the current through it.

Alternating current components of the voltage signal across the silicon diode **27** are fed through a coupling capacitor **28** of 0.01 microfarads in series with a 4.7 kilohm resistor **30** to an input terminal **31** of a high-gain integrated circuit amplifier **32** connected to have low-frequency degenerative characteristics and to operate as a limiter. The input terminal **31** of the amplifier is connected to earth through a 1,000 picofarad capacitor **33** providing protection from possible sources of high-frequency interference such as a powerful radio transmission. The input terminal **31** of the amplifier **32** is also connected to the output terminal **33*a*** through a negative feedback T-filter network **34** composed of two serially connected resistors **35** each of 150 kilohms having their common junction connected to earth through a 0.33 microfarad capacitor **37** providing a shunt for relatively high pulsation frequencies as above-defined. In consequence, lower frequency signals produced at the output terminal **33*a*** of the amplifier **32** are fed back negatively to the input terminal **31** to provide the amplifier **32** with degenerative low frequency characteristics whereas a large proportion of the relatively high pulsation frequency signals which enter the feedback network **34** is bypassed to earth through the capacitor **37**. The integrated circuit amplifier **32** receives a positive voltage supply from the junction of the 220 ohm resistor **23** and the 47 ohm resistor **22** in the aforesaid supply circuit **18**, the other side of the integrated circuit being connected to earth.

The high-gain characteristics of the integrated circuit amplifier **32** together with the degenerative low frequency feedback loop results in the amplifier selectively amplifying the high-pulsation frequencies above a predetermined lower range of frequencies and subsequently limiting them so that output pulse signals of substantially the same amplitude are provided at the terminal **33*a*** irrespective to the relative magnitudes of the input signal frequencies of the amplifier **32** provided that such input signal frequencies lie above a predetermined threshold value. The output terminal **33*a*** of the amplifier is connected through a 3.3 kilohm load **40** across which the limited pulses are produced.

The stream of limited pulses from the load **40** are fed through a 3,300 picofarad capacitor **41** to the base of an NPN transistor **42** and also to the cathode of a detector rectifier **43** having its anode connected to earth. The base of the transistor is thus biased positively by an amount which varies with the pulse repetition rate at the output terminal **33*a*** of the amplifier **32**.

The transistor **42** provides at its emitter a current which fluctuates in accordance with the base potential. The emitter of the transistor is connected through a 5 ki kilohm potentiometer load **44** so that the transistor **42** behaves as an emitter follower with a 5 kilohm The collector of the transistor is also connected to the 10 volt supply line through a 1 kilohm resistor **45** across which meter test points **46** are arranged.

The voltage tapped off from the wiper of the potentiometer **44** is fed through the arms of a delay T-circuit **47** formed by two 1 kilohm resistors **48** having their common junction connected to earth through a 2,500 microfarad condenser **50**. The other end of the delay circuit is connected to the gate of a silicon-controlled rectifier **51** having its cathode connected to earth and its anode connected through a relay operating coil **52** to one side of the secondary winding **12** of the supply transformer **13**. The relay **52** is shunted by a flame indicator lamp **53** and also by a 125 microfarad capacitor **54** providing a holdon circuit for the relay **52** during the half cycles when the silicon-controlled rectifier **51** is not conducting.

The flame monitoring equipment is provided with a flame-brightness indicator circuit shown within the broken outline box **60** in order to warn an operator that the light level incident on the photosensitive transistor **6** is lower than a prearranged value determined by the setting of the 100 kilohm preset resistor **24** in the resistive supply line **18** to the collector **20** of the photosensitive transistor **6**. During starting up of the furnace the brightness indication will obviously be low. However, if the furnace is functioning normally and the brightness indication is low it may indicate that the sighting window **5** of FIG. **1** and through which the photosensitive transistor **6** views the flame root portion **7** should be cleaned.

The brightness indicating circuit is connected between the collector **20** of the photosensitive transistor **6** and earth. It comprises a 1 microfarad coupling condenser **61** through which the 100 c.p.s. ripple present at the photosensitive transistor collector is fed to the base **62** of an NPN transistor **63** having its collector connected through a 3.3 kilohm load **64** to the same positive supply terminal as the integrated circuit amplifier. The working point of the transistor is stabilized by a 220 kilohm resistor **65** connected between its collector and base.

The output signal from the collector of the transistor is fed through a 1 microfarad coupling capacitor **66** to a junction between a pair of rectifiers **67, 68** one of which has its anode connected to earth and the other via a 33 kilohm detector load resistor **70** and 250 microfarad capacitor **71** to earth. The fluctuating voltage developed across the detector load resistor **70** is fed via a second 33 kilohm resistor **72** to the base of a second NPN transistor **73** the emitter of which is connected through a small magnetic flag type indicator **74** to earth while its collector is connected to the same power supply as feeds the integrated circuit.

The above-described equipment operates in the following manner. During normal operation the overall intensity of the light on the phototransistor **6** results in it drawing too much current for the smooth resistive supply circuit **18** to provide, so that the second supply circuit **17** containing the rectifier **21** functions to feed the collector of the photosensitive transistor **6** with a unidirectional voltage supply on which is superimposed a 100 c.p.s. ripple. This ripple at the transistor collector **20** is fed through the coupling capacitor **61** to the brightness circuit **60** and is amplified in the first transistor **63** to provide a signal which is rectified by rectifier **68**, and smoothed before being applied as a positive bias to the base of the second transistor **73** which therefore conducts to operate the magnetic indicator **74**. This is true whether or not the burner **2** being viewed is alight, provided the furnace is running and the viewing window **5** is not too dirty.

The high-frequency variations in current flowing through the photosensitive transistor **6** as a result of the high-frequency light components present in the flame root portion **7** also flow through the silicon-diode load **27** which provides a voltage signal, significant of the logarithm of the current in transistor **6**, to the input terminal **31** of the integrated circuit amplifier **32**. The aforesaid lower range of frequencies at the input terminal **31** are suppressed as a result of the degenerative action of the feedback loop whereas the range of relatively high pulsation frequency signals which range upwards from 10,000 c.p.s. are transmitted through the amplifier **32** and are amplified and limited as a result of its high gain. The amplifier output signal pulses are differentiated by resistor **40** and capacitor **41** and are detected by rectifier **43** to provide a bias on the base of the transistor **42** connected as an emitter follower, so as to vary the current through the potentiometer **44** in its emitter circuit. The voltage tapped from the potentiometer **44** is a function of the pulsating frequencies present in the light incident on the phototransistor **6** and is fed through the time delay circuit **47** to the gate of the silicon-controlled rectifier **51** to fire it in accordance with the presetting of the potentiometer **44** and the voltage tapped off it.

If the voltage applied to the gate of the silicon-controlled rectifier **51** falls below a certain value (typically 0.7 volts) the silicon-controlled rectifier **51** will fail to conduct resulting in the relay **52** open circuiting its contacts to sound an alarm or carry out some other duty which is to be performed if the high-frequency content of the root portion of the burner flame being monitored falls beneath a preset value determined by the potentiometer **44** setting.

If, during use, the sighting window **5** through which the flame root portion **7** is viewed becomes obscured, the light incident on the photosensitive transistor **6** diminishes so that the current through it diminishes also. If the current falls to a value such that it can be provided by the resistive supply circuit **18** in preference to the parallel supply circuit **17** containing the rectifier **21**, this occurring when the transistor collector voltage rises above 9.5 volts, the rectifier **21** ceases to conduct and the collector **20** receives its current, instead, from the smoothed supply circuit **18**. In consequence the 100 c.p.s. ripple is absent and the 1 microfarad blocking capacitor **61** at the input end of the brightness circuit **60** removes the input signal from it so causing the brightness indicator **74** to operate.

One of the advantages of the above-described circuit is that it is virtually impossible to overload and therefore it is possible to observe the very high frequency components in the flame which otherwise might not be observed because of the masking effect produced by the general background glare within the furnace. This stems from the substantial match maintained between the current-impedance characteristic of light-sensitive element **6** and the similar characteristic of the forwardly biased silicon-controlled load rectifier **27** together with its logarithmic characteristic.

It will be noticed that in the circuit described, only a trip signal is derived from the brightness amplitude, the trip signal occurring when the current through the phototransistor **6** has fallen to such a low value that it can be drawn from the smoothed supply **18** from which the 100 c.p.s. ripple is absent. If the brightness analogue is required it may be obtained by reconnecting the 'brightness' AC amplifier in the following way described with reference to FIG. 3.

FIG. 3 shows a mains transformer **100** provided with two secondary windings **101, 102**. The first secondary winding **101** is connected across a bridge rectifier circuit **103** providing full-wave rectification between its positive and negative output terminals. The unidirectional current output from the bridge contains a 100 c.p.s. ripple component assuming a 50 c.p.s. mains, which is smoothed by a π-filter **104** formed by a resistor **105** capacitively coupled at opposite ends to the negative terminal of the bridge. A continuous light load is maintained on the bridge by a high-value resistor **106** connected between the bridge output terminals to ensure that a minimum current of a few microamperes always flows in the bridge circuit. This current provides a voltage drop across one pair **107** of alternately conducting rectifiers of the bridge **103** of at least several hundred millivolts. The smoothed output voltage from the bridge is applied to a variable load formed by a phototransistor **108** on which light from the furnace is incident and having its emitter **110** connected in series with a forwardly biased silicon-controlled rectifier **111** selected to have a logarithmic current impedance characteristic which matches the characteristic of the phototransistor **108** for reasons already stated in the above-described embodiment. A signal for a flame failure circuit **60'** as above described is taken from the emitter **110** of the phototransistor **108**.

Connected across the alternating terminals of the bridge are a reference pair of similar rectifiers **112** connected anode-to-anode with the junction connected through a bias resistor **113** to the negative terminal of the bridge circuit. The bias resistor **113** has developed across it a voltage proportional to the voltage difference between the volt drop across each of the reference pair of rectifiers **112** and the volt drop across each of said one pair **107** of rectifiers of the bridge. The rectifiers and their loads are so arranged that when there is no light incident on the phototransistor **108** the voltage drop across the bias resistor **113** is zero, but increasing illumination of the phototransistor **108** increases the current through the bridge circuit **103** so that the volt drop across its component rectifiers **107** is increased.

The voltage signal developed across the bias resistor **113** with increasing illumination is at a frequency of 100 c.p.s. High parasitic frequencies which may be developed in the secondary winding **101** of the transformer are decoupled by a capacitor **104** shunting the bias resistor.

The signal generated across the bias resistor **113** is fed through a coupling capacitor **115** to the base of an NPN transistor amplifier **116**. The transistor amplifier **116** is energized by a smoothed unidirectional current obtained from the second secondary winding **102** of the transformer by way of a smoothing and rectifying circuit **117**. The collector of transistor **116** is connected through a load resistor **120** to one end of the second winding **102** whose other end is connected with the emitter of the transistor **116** to earth. The transistor amplifier **116** is required to amplify alternating signals at 100 c.p.s. and is provided with a high degree of degenerative feedback by a resistor **122** connected between its collector and base. The transistor amplifier is thus very stable indeed and amplifies the base signals which increase logarithmically with increase in intensity of illumination of the photo transistor **108**.

The output from the transistor amplifier **116** is fed to the base of an instrument driver amplifier **123**, by way of a preset resistor **124** providing a sensitivity control and in series with a coupling capacitor **125**. The instrument driver **123** is also an NPN transistor having its collector connected to the smoothed positive supply from the transformer secondary winding **102**, and its emitter connected to earth through a decoupling capacitor **126** shunting a milliammeter instrument **127** serially connected with a current limiting resistor **128**. The decoupling capacitor **126** prevents rapid fluctuations of the instrument.

The base of the driver transistor **123** is connected to the cathode of the rectifier **130** having its anode earthed and providing a detector circuit.

In operation of the above-described circuit variations in brightness of light incident on the photosensitive transistor **108** vary the amplitude modulation of the 100 c.p.s. signal across the bias resistor **113** as previously mentioned. The bias resistor voltage is amplified in the alternating current amplifier transistor **116** and then detected by rectifier **130** and fed to the base of the instrument driver amplifier **123**. The reading of the milliammeter **127** associated with the instrument amplifier **123** therefore provides a measure of the light-intensity incident on the photo transistor **108**.

It will also be appreciated that the circuit may be adapted to respond to any particular wavelength of light emitted from the burner flame. For example, by using filters, the ultraviolet light content of the flame may be projected onto the phototransistor.

I claim:

1. Flame-monitoring equipment comprising a light-sensitive element, means directing an image of a peripheral portion of a burner flame root onto said element, an electrical load through which current from said element varying with the intensity of light falling thereon passes, said load having an impedance-current characteristic similar to said element; circuit means detecting from the number of pulsation frequencies above flicker frequencies in the signal output of said element a measure of the flame quality, and means indicating said measure.

2. Equipment as set forth in claim **1**, including a first current supply circuit to said element and an alternative second current supply circuit to said element; back-biasable switching means in said first current supply circuit for transmitting to said element a DC level having a superimposed ripple frequency; resistive means limiting the current through said second supply circuit and capacitive means for removing therefrom said ripple frequency; and a brightness indicating circuit connected to said element and including means responsive to the presence and absence of said ripple frequency to signify the monitored flame brightness being above and beneath, respectively, a predetermined value.

3. Equipment as set forth in claim **1**, including first rectifying means feeding said light-sensitive element from a rectified source of alternating current; second rectifying means conducting simultaneously with said first rectifying means and connected to said source; constant load means for said second rectifying means, and means providing a signal significant of the analogue brightness from the volt drops across said first and second rectifying means.

4. Flame-monitoring equipment including a light-sensitive circuit; a photosensitive element in said circuit providing an electrical output signal containing alternating frequency components corresponding to pulsation frequencies of light incident on the element; an optical arrangement for directing onto said element light emanating from a root portion of a burner flame to be monitored; a processing circuit connected to receive the alternating frequency components from said light sensitive circuit; amplifying means in said processing circuit amplifying to the same amplitude those components present which have a frequency above the range of flicker frequencies to provide an output train of pulses; pulse counting and analogue conversion circuitry connected to receive the output train of pulses from the processing circuit; and indicating means deriving a measure of the flame quality from the pulse repetition rate of said pulse train.

5. Equipment as set forth in claim **4**, in which said amplifying means comprises an integrated circuit high-gain amplifier having a degenerative feedback network provided with a bypass circuit for bypassing to earth signals in said feedback network above said range of frequencies.

6. Equipment as set forth in claim **5**, including two unidirectional current supply circuits to said element, one such supply circuit including a rectifier for transmitting a direct current level on which is superimposed a ripple frequency, and the second supply circuit containing a chain of resistors and ripple suppression circuitry to provide said second current supply circuit with limited current carrying capacity, ripple frequencies present at the element being detected and amplified by an amplifier to provide a bias voltage for a second amplifier controlling with its output a brightness indicating device having two states indicating, respectively, the brightness incident on the element being above or beneath a predetermined threshold value.

7. Equipment as set forth in claim **4**, including analogue brightness indicating circuitry comprising a source of alternating current, a full-wave bridge rectifier providing from said source a unidirectional current available at output terminals of the bridge rectifier, a high-value load resistor connected across the output terminals of said bridge rectifier, a second circuit connected across said bridge-rectifier output terminals, and including said light-sensitive element formed by a phototransistor connected in series with a load having a similar impedance-current characteristic as the transistor; a second rectifier circuit connected across said source of alternating current, a biasing resistor connected from a midpoint of said second rectifier circuit to one direct current output terminal of said bridge rectifier, a connection extending from said bias resistor and providing to an amplifier a signal significant of the volt drop difference across rectifiers of said bridge and said second rectifier circuit, and an instrument driver stage fed by a bias provided by the output of said amplifier, said instrument having means representing the analogue brightness.

8. Flame monitoring equipment comprising a phototransistor, a forwardly biased silicon-controlled rectifier connected in series with the current circuit through said transistor and having an impedance-current characteristic similar to said phototransistor, a limiting high-gain amplifier having degenerative characteristics for flicker frequencies and connected across the transistor load, output terminals to said amplifier and connected through a negative feedback loop to said input terminals, a shunt path in said feedback loop removing to earth signals above the flicker frequencies so that said flicker frequencies are suppressed, a differentiating and detecting circuit connected to receive output signals from said amplifier and to provide therefrom a train of pulses, a circuit providing a signal instantaneously significant of the rate at which pulses are received from said differentiating and detecting circuit, a potentiometer adjustable to select a desired proportion of the varying output signal to set the equipment to a predetermined threshold frequency, and an analogue converter circuit operating a flame indicator and controlled by the output signal from the potentiometer.

9. Equipment as set forth in claim **8**, including first and second current supply circuits to said phototransistor; a black-biasable diode in one of said circuits; a resistance chain in the second of said circuits; a full-wave bridge rectifier providing direct current with a superimposed ripple to said circuit; a filter in said second circuit for removing said ripple; a brightness indicator circuit supplying a signal at the frequency of said ripple, from said photo transistor collector to a brightness indicator circuit; an amplifier and detecting circuit providing from said ripple frequency signal a bias voltage which is absent in the absence of said ripple; a driver stage switched between a conducting and a nonconducting condition by the presence and absence, respectively, of said bias; and, a brightness indicator by the output of said driver.

10. Equipment as set forth in claim **8**, including a transformer, a secondary winding to said transformer feeding a full-wave bridge rectification circuit and a half-wave rectification circuit in parallel, a bias resistor connected between the center point of said half-wave rectification circuit and a direct current output terminal of the same polarity of the bridge, a resistor connected across direct current output terminals of the bridge, a filter circuit through which said bridge supplies direct current to said phototransistor and said load, the center

point of the half-wave rectification circuit being connected to an amplifier transistor for amplifying the difference in volt drop across rectifiers of the half-wave rectification circuit and the bridge, a detecting circuit providing a bias level which fluctuates in accordance with the magnitude of said difference, a driver amplifier controlled by said bias stage, and a meter operated by said driver stage and providing an output which is an analogue of the brightness of light incident on the phototransistor.