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Noltingk et al.

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[45] **July 16, 1974**

[54] **METHODS OF AND APPARATUS FOR FLAME MONITORING**

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[52] **U.S. Cl.** **250/208,** 340/228.2

[51] **Int. Cl.** **H01j 39/12**

[58] **Field of Search** .... 250/208, 209, 214 R, 217 F; 340/227, 228.1, 228.2

[56] **References Cited**

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Assistant Examiner—D. C. Nelms
Attorney, Agent, or Firm—Mawhinney & Mawhinney

[57] **ABSTRACT**

For monitoring each individual flame in a multi-burner furnace, two optical light receiving systems each have a photo-sensor on which is focused a narrow beam, the two beams intersecting at a small angle in or near the flame to be monitored. The angular beam widths are less than the angle of intersection. The alternating electrical signals from the photo-sensors due to flicker components in the flame are correlated in a correlator which determines the degree of correlation whereby the presence or absence of a flame in the intersection region only of the two beams is detected.

10 Claims, 2 Drawing Figures

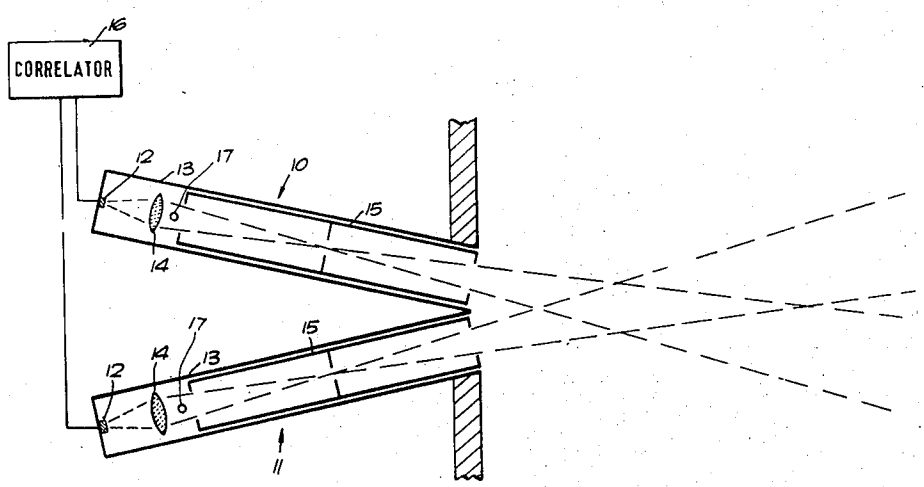
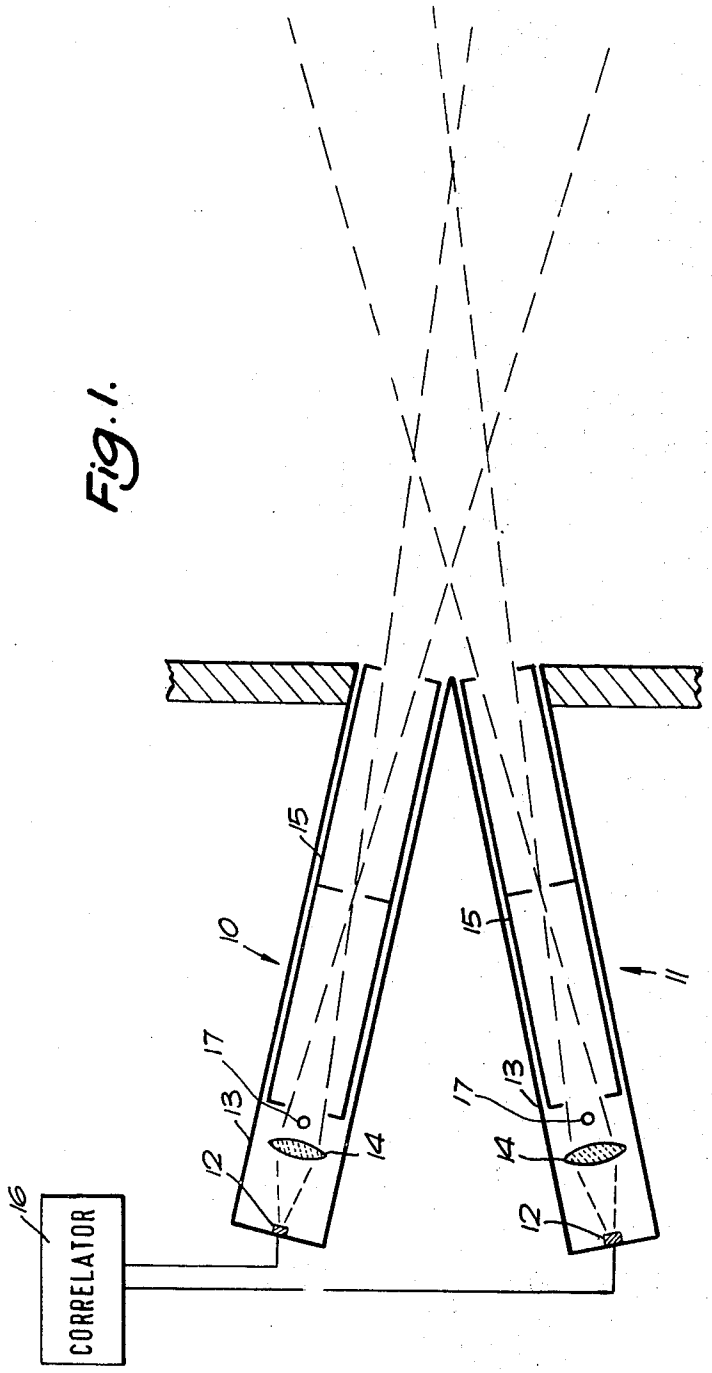


Fig. 1.



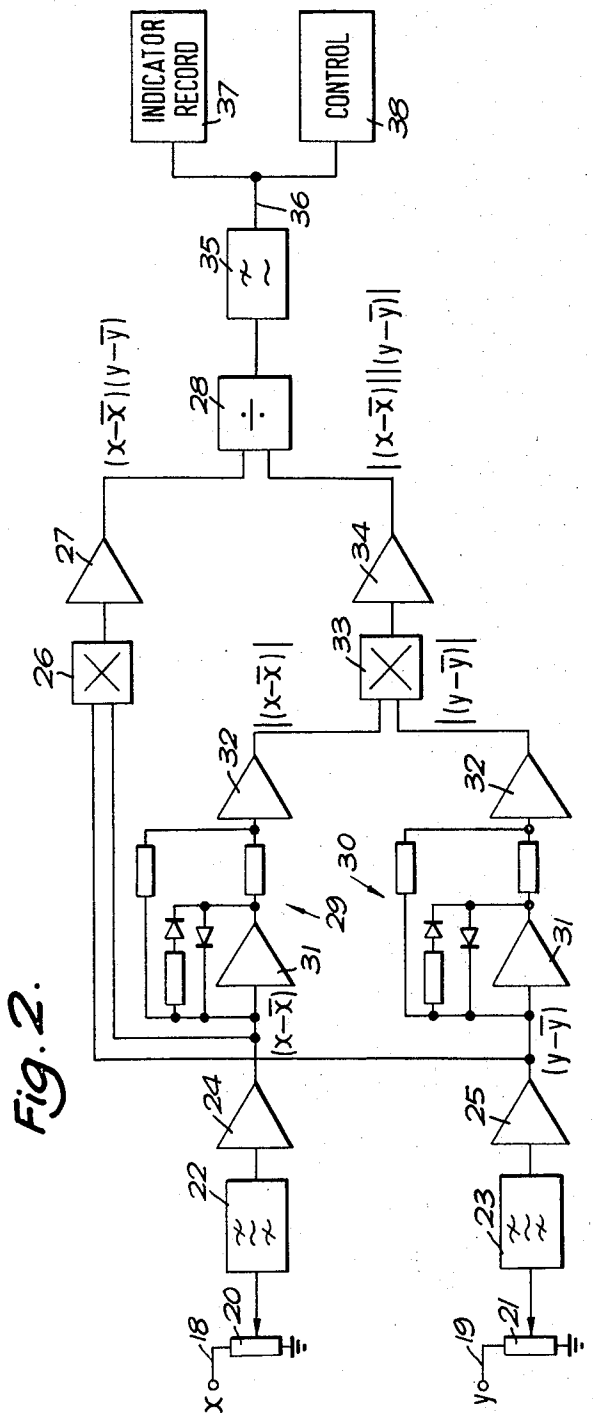

INDICATOR RECORD
37
CONTROL
38
36
35
28
$(x-\bar{x})(y-\bar{y})$
$|(x-\bar{x})||(y-\bar{y})|$
27
34
26
33
$|(x-\bar{x})|$
$|(y-\bar{y})|$
32
32
30
29
31
31
$(x-\bar{x})$
$(y-\bar{y})$
24
25
22
23
18
20
19
21
x_o
y_o

Fig. 2.

METHODS OF AND APPARATUS FOR FLAME MONITORING

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a method of and apparatus for monitoring flames in multi-burner furnaces, such as in boilers for large electrical power generating stations.

2. Prior Art

For a long time the desirability of automatically monitoring flames in a boiler has been recognised. If fuel continues to be supplied to a burner after the flame has been extinguished, the fuel may re-ignite explosively. A human observer can identify a particular flame but continuous human observation is expensive in manpower, even if confined to critical periods. The problem arises particularly with the growing demand for automatic start-up of boilers. Reference may be made to "Flame Monitoring-Important Key to Unit Automation" Power 104 Oct. 1960, "Combustion Monitoring of Large Flames from Flame Spectra" Baumgartel and Hage A.S.M.E. Paper No. 61-WA-299 and "Photo-Electric Supervision of Oil and Gas Burners of Steam Generating Plant" Brinke Tech. Uberwach Vol. 5, No. 4 1964.

Many systems intended for flame detection have been produced. Simple detectors of optical radiation (infra-red, visible or ultra-violet) give false indications that a flame is present when they receive radiation from something else of comparable brightness, such as the furnace walls or part of a neighbouring flame. In a large boiler, there are many burners and it is difficult to have a line of sight through only one flame, particularly bearing in mind that the form of the flame depends on the fuel supply and other factors. For these reasons, although radiation amplitude sensitive devices may work satisfactorily in a single burner furnace, the high level of background radiation precludes the use of such devices in a multi-burner furnace.

Detectors have therefore been proposed to utilise particular properties of a flame. One, for example, is a differential system in which two photo-electric cells are positioned to view dark and light areas of the flame respectively; such a detector is applicable to coal-fired flames in which there is a dark area where the pulverised coal emerges from the burner. Such a detector however is very sensitive to changes in combustion conditions which alter the distance along the flame axis at which the fuel ignites. Also with such a differential flame detector, blocking of one of the viewing tubes could cause a differential signal even when the flame is absent.

Another detection system makes use of the alternating component, known as flicker, which, in all large flames, is superimposed on the steady radiation. Flicker amplitude decreases progressively along the flame axis so that the photo-detection system has to be aimed near the root of the flame. This gives a considerably improved discrimination but, with the wide variation in combustion conditions, as occur for example on start-up and loading changing, it is not possible to achieve a confident distinction between flame-on and flame-off conditions.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide an improved method of and apparatus for monitoring any selected flame in a multi-burner furnace.

According to this invention, a method of monitoring a selected frame in a multi-burner furnace comprises photo-electrically viewing the selected flame along two lines-of-sight which intersect in or near the flame to produce electrical signal outputs and determining the degree of correlation of the alternating components of the two electrical signals.

According to a further aspect of this invention, apparatus for monitoring a selected flame in a multi-burner furnace comprises two photo-electric pick-ups arranged for viewing the selected flame along two lines-of-sight which intersect in or near the flame, and means responsive to or determining the degree of correlation of the alternating components of the electrical output signals from the two pick-ups.

It is to be expected that the alternating components of signals which arise from sources at the point of intersection will show high cross-correlation while those arising elsewhere in the furnace should be uncorrelated. This technique depends essentially on the existence of alternating components (flicker) in the optical signals from the flame. The origin of such components is not firmly established. They may be attributed to turbulence in the flame or to fluctuations in the fuel supply. At the root of the flame, it is to be expected that turbulence will distort the flame front, giving rise to a large variation in speed and direction of propagation and this may well cause the flame to flicker. Along the length of the flame, the flicker could be influenced by some resonance in the furnace. With large turbulence, some of the unburnt fuel may be carried into the hotter regions of the flame where it suddenly ignites propagating a region of hotter gas along the length of the flame.

As indicated above, one purpose of flame monitoring is to determine if a flame is present. If the flame monitor is used for control purposes, action may be required within a short time, e.g., 1 second, and this would set a lower limit to the frequencies which can usefully be correlated. If action is required within one second, frequencies below 10 Hz would be of little value. More generally however, the pick-ups may be arranged to provide signals over a wide frequency band. Flicker signals can readily be detected up to at least 700 Hz. Filters can be provided for removing electrical signals at frequencies at which correlation is small even when a flame is present. The optimum frequency band may be determined empirically.

The photo-electric pick-ups may be sensitive over a wide range of optical wavelength or may be made selective.

The divergence of the viewing beams may be chosen in accordance with the particular conditions to be monitored. A wide angle beam will give greater light gathering but overlap outside the space occupied by the flame to be monitored will reduce the possible correlation. If too large a region of incoherently flickering flame is observed, the high frequency components of the signals will be relatively smaller.

The angle θ of acceptance of light into each detector and the angle ϕ between their respective optic axes must be considered in relation to one another. There are advantages in keeping ϕ small since it gives a greater length over which correlated signals can arise. Also it makes it possible to have both optical axes pass-

ing through one port in the furnace wall, so simplifying installation. On the other hand ϕ must be greater than θ or the region of overlap between the two viewing beams will extend to infinity. It is thus advantageous for θ to be small provided enough light is gathered so that amplifier noise will not dominate the optical signal.

Alternatively an optical system with a lens or lenses may be used. In the case of a single lens, the diameter of the lens, its focal length, the distance between the lens and an aperture in front of the sensor, and the shape and size of the aperture control the geometry of the light path.

Each pick-up conveniently comprises a photo-sensor mounted in a tube which serves to collimate the light path. In practice, the photo-sensors may be mounted in long metal tubes which extend into the furnace; such a tube may for example be 1–2 metres long to give protection for the sensor and to collimate the light path. A tube with an internal diameter of 16 mm and 1.5 m long will make θ about 1.2°. Two such tubes can be pointed at a flame near its root and set to give maximum correlation.

Correlators for correlating electrical signals are commercially available for giving an output representative of the correlation factor between two alternating input signals. For a simple monitor to indicate the presence or absence of a flame, it is not necessary to measure the correlation factor; it may be adequate to give an output signal which is related to the correlation.

If the two photo-cell outputs, which are functions of time t, are $x(t)$ and $y(t)$ respectively, the correlation coefficient $\rho x\ y$ between the two photo-cell outputs may be defined as

$$\rho xy = \frac{\int_{t-T}^{t} x(\gamma)\cdot y(\gamma)\,d\gamma}{\sqrt{\int_{t-T}^{t} x^2(\gamma)\,d\gamma \cdot \int_{t-T}^{t} y^2(\gamma)\,d\gamma}}$$

where

T is the time period over which the signals are correlated,

γ is a dummy variable of integration representing time, and

x and y are the alternating components of the signals from the sensors having zero average values.

Commercial instruments are available which operate on two inputs x and y to give an output of $\rho\ x\ y$. Thus a commercial correlation instrument might be used, the two photo-sensor outputs being used as the x and y inputs respectively. If either $x(t)$ or $y(t)$ continues at zero, the above expression for the correlation coefficient becomes indeterminate and thus it would be necessary to check that a finite signal $x(t)$ and $y(t)$ was present in the respective channels. However for a simple monitor to detect the presence of a flame, the numerator of the above expression could be used by itself. The fact that it exceeded some threshold value would be taken as an indication that a flame was present.

In effecting the computation using analogue techniques, considerable saving in cost can be made by making a simpler computation given an approximate measure of correlation. In one form of the invention, the means for determining the degree of correlation between the signals from the line photo-sensors comprises a processor coupled to the photo-sensors to process the signals therefrom and arranged effectively to give the quotient:

$$\frac{(x-\bar{x})(y-\bar{y})}{|(x-\bar{x})||(y-\bar{y})|}$$

the output of the processor being smoothed by a low pass filter (typically with a time constant of 0.5 seconds), $\bar{x}$ and $\bar{y}$ being mean values of x and y respectively. This circuit employs only two multipliers and a divider. No square rooting operations are employed. The use of a low pass filter, i.e., a smoothing circuit, with a single time lag in effect provides a continuous average so avoiding any necessity for sampling. This processor is independent of signal amplitudes but gives an approximate measure of correlation since the circuit only compares the instantaneous polarity of the input signals. The errors introduced however are not substantial and can be discounted for flame monitoring because, in the correlated case, the two waveforms will be identical in shape because they come from the same source.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagrammatic plan view of a flame monitoring apparatus for a multi-burner furnace; and

FIG. **2** is a block diagram illustrating signal correlating means used in the apparatus of FIG. **1.**

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. **1,** there are shown two optical image forming systems **10, 11** each arranged to form, at a photo-sensor **12,** an optical image of a flame front. Each image forming system comprises a tubular mount indicated diagrammatically at **13** which supports the photo-sensor **12,** a line **14** and a tubular light stop system **15.** This tubular light stop is arranged to give a light acceptance angle of just over 1°. Typically for a large furnace the tube is about 1.5 metres long and 15–20 mm in diameter. The two tubes are mounted in an aperture in the furnace wall at an angle to one another, which angle must be larger than the acceptance angle of the tubes, such that they both accept light from the same portion of a particular flame which is to be monitored.

For clarity in FIG. **1,** the acceptance angles of the two image forming systems **10, 11** and the angle between their axes have been greatly exaggerated and the overlap region of the two acceptance regions has been made close to the ends of the tubes. It will be seen that the overlap region, by making the angle between the axes small, can be made to have an appreciable depth into the furnace. The position of a burner flame in a furnace depends on the air/fuel ratio and fuel supply. The image forming systems are arranged so that the overlap region covers the required range of possible positions of the flame to be monitored. It will be noted, however, that the proportion of the light acceptance regions which overlap decreases towards the inner and outer limits of overlap region and hence the degree of correlation of viewed flames will decrease towards these limits.

For pulverised coal or oil fired burners, the flames are appreciably opaque. In these cases, the flame front is readily observed. A silicon photo-voltaic photo-sensor having a wide optical bandwidth is conveniently employed with such flames. For a natural gas flame, it is preferred to utilise the longer wavelength radiation, particularly in the infra-red region of the spectrum, where the flame is sufficiently opaque to prevent light interference from flames behind the flame being viewed. For such flames, lead sulphide or indium antimonide photo-conductive elements could be used to give output signals dependent more particularly on the infra-red radiation.

The electrical outputs from the two photo-sensors **12** are fed to a signal correlator **16** which is illustrated in further detail in FIG. **2.**

Although simple image forming systems have been shown in FIG. **1,** it is possible to use more complex telescopes, for example Newtonian or Cassegrain systems to give the required narrow acceptance angle.

In the image forming system, an air supply may be applied to a bleed hole **17** to give a small air flow through the tube into the furnace to keep the optical system clear. Other known techniques however may be employed to reduce or prevent the ingress of any smoke and solid particles from the furnace into the tube.

It will be appreciated that the two image forming systems may be arranged in any place such that they can have acceptance regions overlapping in the position of the flame to be monitored. Separate systems would be provided for each flame in the furnace which is to be monitored.

The signal correlator of FIG. **2** is an amplitude insensitive correlator. It includes a simple processor which processes the instantaneous values and moduli of the two inputs and which effectively gives the quotient:

$$\frac{(x-\bar{x})(y-\bar{y})}{|(x-\bar{x})||(y-\bar{y})|}$$

where x and y are the photo-sensor inputs and where $\bar{x}$ and $\bar{y}$ are their mean values. The output of this processor is smoothed by a low pass filter, with a time constant, in this embodiment, of 0.5 seconds.

In FIG. **2,** the inputs x and y from the photo-sensors are fed via leads **18** and **19** and scaling potentiometers **20, 21** respectively to two band-pass filters **22, 23** which typically have a pass band of 20–1000 Hz. The signals from these band pass filters are fed respectively to two separate amplifiers **24, 25** to produce outputs having amplitudes $(x-\bar{x})$ and $(y-\bar{y})$. These two signals are fed, in the first place to a signal multiplier **26** which multiplies the amplitudes of the two signals and which is followed by a scaling amplifier **27** to give the signal $(x-\bar{x})(y-\bar{y})$. This in turn is fed to one input of a divider or ratio determining circuit **28.** The outputs from the amplifiers **24, 25** are also separately fed to two linear full wave rectifier circuits **29, 30,** each consisting of two operational amplifiers **31** and **32,** to provide outputs $|(x-\bar{x})|$ and $|(y-\bar{y})|$. The amplifier **31** forms a rectifier giving the modulus of the input signal and the amplifier **32** is a scaling amplifier. From the amplifier **31,** the two signals are multiplied in a multiplier **33** and thence passed via a scaling amplifier **34** to the second input of the divider **28.** The output of the divider **28** is smoothed by a low pass filter circuit **35** with a time constant of 0.5 seconds to give the required output on a lead **36.** The signal may be fed to an indicator and/or recorder as indicated at **37.** More typically however it would be used for control purposes as indicated at **38,** e.g., to shut-off the fuel supply if the cessation of a flame is detected.

It will be seen that this correlation circuit employs only two multipliers. No squaring or square-rooting operations are required.

It is found that with a circuit such as is shown in FIG. **2,** it is possible to distinguish, by means of the level of the output signal, not only whether there is a normal flame or no flame but also the intermediate condition of an abnormal flame. This can arise, because, as previously explained, the degree of correlation will depend on the position of the flame. The flame position depends, for example, on the air to fuel ratio and hence an abnormal flame due to an incorrect air to fuel ratio may give a magnitude of output on lead **36** intermediate between substantially complete correlation and no correlation. Provision may be made therefore for operating an alarm or control device if an output signal is an intermediate amplitude range.

Other circuits could also be employed giving outputs related to the correlation coefficient between the two signals, for instance a digital processor incorporating zero-crossing detectors and a logic circuit which produces a positive voltage level if the signs of the input signals are the same and an equivalent negative voltage level if the signs of the input signals are not the same. These voltages from the logic circuit would be stabilised by a digital-to-analogue converter and then integrated by a low-pass filter.

We claim:

1. A method of monitoring a selected flame in a multi-burner furnace comprising photo-electrically viewing the selected flame along two lines-of-sight which have a region of intersection in the flame to produce two electrical output signals each having alternating components corresponding to the varying intensity of the radiation from the flame and determining the degree of phase correlation of the alternating components of the two electrical signals.

2. Apparatus for monitoring a selected flame in a multi-burner furnace comprising two photo-electric pick-ups arranged for viewing the selected flame along two lines-of-sight which have a region of intersection in the flame, each pick-up including a photo-sensor producing an electrical output signal having alternating components corresponding to the varying intensity of the radiation from the flame, and signal processing means connected to said photo-sensors to be responsive to said output signals and arranged to determine the degree of phase correlation of said alternating components of the electrical output signals from the two pick-ups.

3. Apparatus as claimed in claim **2** wherein said each of said photo-electric pick-ups comprises a photo-sensor mounted in a tube, and two tubes being arranged to collimate the respective light paths with angles of acceptance at the photo-sensors smaller than the angle between the tubes.

4. Apparatus as claimed in claim **3** wherein each said tube contains at least one optical element to form an optical image forming system.

5. Apparatus as claimed in claim **4** and having an air supply source and air bleed means in said tube to cause a flow of air over said at least one optical element.

6. Apparatus as claimed in claim 2 wherein said signal processing means comprises means determining, over a time period, the fraction of the total time for which the two output signals have the same polarity relative to their respective mean values.

7. Apparatus for monitoring a selected flame in a multi-burner furnace comprising two photo-electric pick-ups arranged for viewing the selected flame along two lines-of-sight having a region of intersection in the flame, said photo-electric pick-ups each including a photo-sensor said photo providing an electric output signal corresponding to the intensity of radiation incident on the pick-up, a processor coupled to said photo-sensors to process the signals therefrom the arranged to give the quotient:

$$\frac{(x-\bar{x})(y-\bar{y})}{|(x-\bar{x})||(y-\bar{y})|}$$

where x and y are the amplitudes of the output signals from the photo-sensors, and $\bar{x}$ and $\bar{y}$ are the mean values of x and y, and a low pass filter for smoothing the output of the processor.

8. Apparatus as claimed in claim 7 wherein said processor comprises a pair of amplifiers coupled respectively to the two photo-sensors to produce the outputs $(x-\bar{x})$ and $(y-\bar{y})$ respectively, a pair of full wave rectifiers coupled respectively to said amplifiers to produce the signals $|(x-\bar{x})|$ and $|(y-\bar{y})|$ respectively, a first multiplier coupled to said amplifiers to provide an output proportional to the product of the outputs of the amplifiers, a second multiplier coupled to said full wave rectifiers to produce an output proportional to the product of the outputs of the rectifiers, and a divider coupled to said multipliers to the output proportional to the ratio of the products.

9. Apparatus as claimed in claim 7 wherein said processor comprises a pair of filters and amplifiers coupled respectively to the two photo-sensors to produce the signals $(x-\bar{x})$ and $(y-\bar{y})$ respectively, a pair of zero crossing detectors to produce voltages corresponding to the sign of $(x-\bar{x})$ and the sign of $(y-\bar{y})$ respectively, a logic circuit to produce one output if these voltages are of similar sign and a different output if they are of dissimilar sign, a digital-to-analogue converter to stabilise these outputs from the logic circuit and low-pass filter to integrate these stabilised outputs.

10. A method of monitoring a selected flame in a multi-burner furnace comprising photo-electrically viewing the selected flame along two lines-of-sight which have a region of intersection in the flame to produce two electrical output signals, each having alternating components dependent on the varying intensity of the radiation from the flame, and determining, over a time period, the fraction of the total time for which the two output signals have the same polarity relative to their respective mean levels.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,824,391 Dated July 16, 1974

Inventor(s) BERNARD EDWARD NOLTINGK, et al

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In the Heading of the Patent should appear

--Foreign Application Priority Data
May 22, 1972 Great Britain 24037/72--

Signed and sealed this 15th day of October 1974.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents

FORM PO-1050 (10-69)

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