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A. LOFT

3,038,306

GAS TURBINE OVERSPEED PROTECTION SYSTEM

Filed Nov. 24, 1959

Fig. 1.

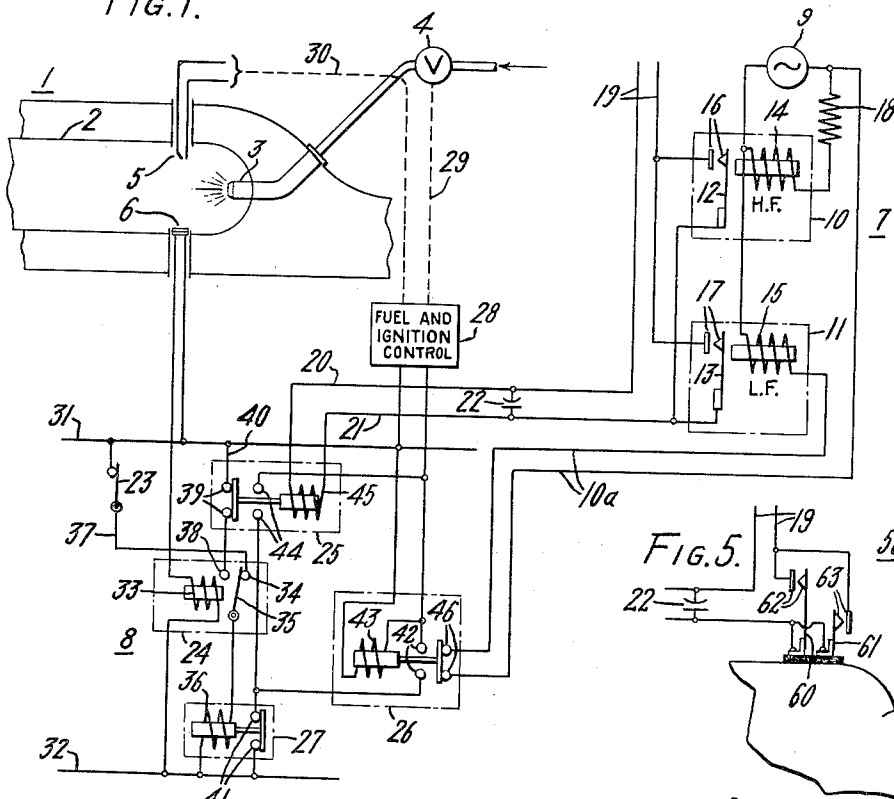


Fig. 2.

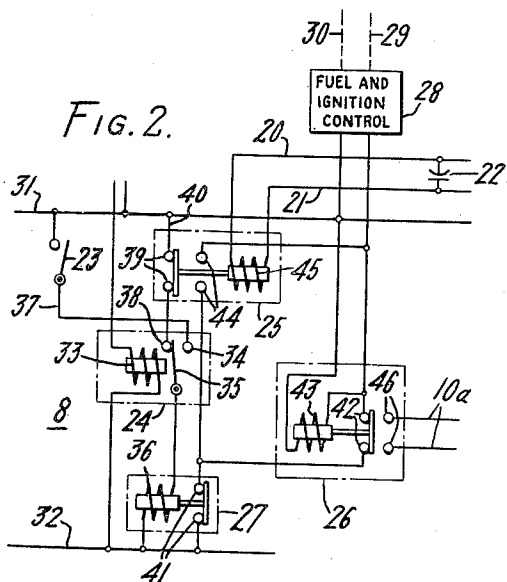


Fig. 5.

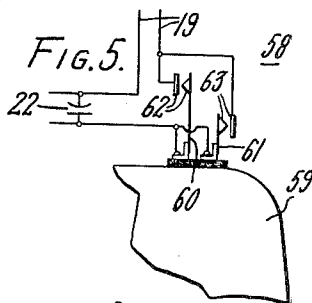


Fig. 3.

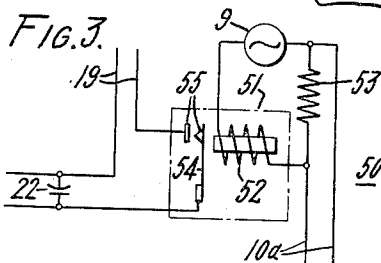
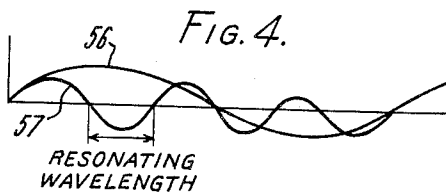


Fig. 4.



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3,038,306

GAS TURBINE OVERSPEED PROTECTION SYSTEM
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This invention relates to an improved control mechanism which effectively integrates the starting circuitry and overspeed and flameout protection for a gas turbine, and more particularly it relates to a means for automatically testing the overspeed protection system each time the turbine commences operation.

Inasmuch as powerplants, such as gas turbines, commonly employ emergency devices to shut down the machine in the event a dangerous overspeed condition takes place, it is desirable to have some means of frequently checking the overspeed protection means in order to reduce the possibility of malfunction.

Moreover, many types of commonly used mechanical overspeed protection systems are subject to accidental actuation by shock or vibration, and are rendered inaccurate by other unpredictable friction and vibration effects. Each time a mechanical overspeed device trips, some wear takes place which eventually affects its accuracy. Therefore, a reliable and accurate overspeed protection device is greatly desirable.

Accordingly, the general object of the invention is to provide an improved overspeed protection system for gas turbine powerplants.

Another object of the invention is to provide means for automatically testing the overspeed circuitry each time the gas turbine is started.

A more specific object is to provide means for initiating combustion at a predetermined turbine speed, and after combustion has taken place, to terminate fuel flow through the same circuitry either when the flame in the combustion chamber goes out or when a predetermined turbine overspeed condition occurs.

The subject matter of the invention is particularly pointed out and distinctly claimed in the concluding portion of the specification. The invention, however, both as to organization and method of practice, together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawing in which:

FIG. 1 is a schematic circuit diagram showing the starting and overspeed protection system prior to startup;

FIG. 2 is a portion of the circuit of FIG. 1 as it appears after the combustion chamber has ignited and during normal operation;

FIG. 3 is a portion of the circuit diagram illustrating a modification of the invention;

FIG. 4 is a graph depicting the method of operation of the modification shown in FIG. 3; and

FIG. 5 illustrates still another modification of the invention.

Generally stated, the invention is practiced by providing the gas turbine with means to generate an electrical signal having a frequency proportional to turbine speed. Frequency responsive relays, calibrated to experience resonance at predetermined frequencies corresponding to given turbine speeds are actuated by the frequency signals to initiate fuel supply and combustion ignition at a low shaft speed, and to terminate combustion, as by interrupting the fuel flow, at a higher shaft speed, or upon loss of flame in the combustion chambers.

Referring now to FIG. 1 of the drawing, a gas turbine combustion chamber is shown schematically at 1 comprising a liner 2 supplied with fuel by a fuel nozzle 3. The flow of fuel to nozzle 3 is controlled by a valve 4. The combustion chamber depicted is only a schematic representation, it being understood that there may be

several combustion chambers supplied by separate nozzles which may be fed by a fuel manifold or by flow metering fuel pumps (not shown). An ignition means 5 is disposed in the liner to ignite the fuel supplied by nozzle 3. A flame detector 6 is also disposed in liner 2 so as to sense the presence of flame in the liner. Flame detector 6 may be either of the photoelectric type as more fully described in U.S. Patent No. 2,797,336, issued on April 9, 1957, or a thermopile, as more fully described in U.S. Patent No. 2,538,642, issued on January 16, 1951, both issued to Arne Loft and assigned to the assignee of the present application. The foregoing description relates to a more or less conventional gas turbine combustion system and it will be understood that the ignition means 5 and the flame detector 6 are provided in one or more of the chambers of a multi-combustor system.

The starting and overspeed protection system which controls the fuel flow and ignition for combustion chamber 1 comprises a speed-responsive signal generating system shown generally at 7 and a combustion control system shown generally at 8. Fig. 2 shows the combustion control portion 8 after combustion chamber 1 has "fired," while omitting the speed responsive signal generating component 7 for sake of simplicity.

Signal system 7 comprises a tachometer generator 9 and two vibrating reed relays 10, 11. The tachometer generator 9 is connected or geared to the turbine shaft in any suitable manner so that the generator 9 will provide an alternating current whose frequency is proportional to the turbine speed. The vibrating reed relays 10, 11 comprise reed elements 12, 13 actuated by coils 14, 15 to close a circuit with contacts 16, 17 respectively at resonance in a manner well known to those skilled in the art.

Vibrating reed relay 11 is selected and calibrated to experience resonance at a much lower frequency than relay 10. The frequency at which relay 11 resonates, thus closing contacts 17, is that corresponding to turbine shaft speed at a suitable time for commencing combustion. It will be understood that the turbine is initially started by a separate driving means to bring it up to a "firing speed," at which the compressor (not shown) is functioning to supply the appropriate flow of air to combustor 1.

Relay 10, on the other hand, is selected and calibrated to experience resonance at a frequency which corresponds to a pre-selected maximum shaft speed in excess of the rated speed of the turbine. Thus relay 10 will experience resonance and reed 12 will vibrate to close contacts 16 when the turbine reaches a predetermined overspeed point.

In the embodiment shown, relay 11 is calibrated to vibrate at 61 cycles per second corresponding to a shaft speed of 25% of rated r.p.m., while relay 10 "resonates" at 267 cycles per second, corresponding to a shaft speed of 110% of rated r.p.m. The absolute values are unimportant since the generator gearing and wiring may vary. The examples given are merely to illustrate the relative magnitude of the selected frequencies.

A resistor 18 is connected in series with the coil 14 of relay 10 so as to attenuate any undesirable harmonics in the current generated by tachometer generator 9. A suitable D.C. source 19 causes a current to flow along the conductors 20, 21 to supply a speed-responsive signal when either of the parallel connected contacts 16 or 17 are closed and a capacitor 22 serves to stabilize the signal and dampen out the pulsations.

The combustion control system 8 in FIG. 1 is greatly simplified as many other starting devices and protective relays not pertinent to the invention herein detailed have been omitted for the sake of clarity. Such starting devices are collectively represented by a simple off-on switch 23. The control system 8 also includes a "flame detection relay" 24, a "shaft speed relay" 25, a "circuit sealing relay" 26 and a "firing signal relay" 27. A fuel and ignition con-

trol mechanism 28 is shown schematically for furnishing fuel control signals to valve 4 and ignition signals to igniter 5, these signals being represented by dotted lines 29, 30 respectively.

The combustion control system 8 is supplied by a suitable source of D.C. electricity represented by supply lines 31, 32. The flame detector 6 is connected in series with the coil 33 of flame detector relay 24. Relay 24 has normally closed contacts 34, 35 which are connected in series with starting switch 23, and the coil 36 of firing signal relay 27. These elements of the system, connected across the supply lines 31, 32 form a "starting circuit" 37.

Relay 24 also has normally open contacts 35, 38 which are connected together in series with coil 36 and the normally closed contacts 39 on the shaft speed relay 25. These elements of the system comprise an "operating circuit" 40.

It will be apparent that when switch 23 is closed and flame detector relay coil 33 is de-energized, the coil 36 of the firing signal relay 27 will be energized by starting circuit 37. Likewise, an alternate method of energizing coil 36 is provided by "operating circuit" 40 through contacts 35, 38 when flame detector relay coil 33 is energized and when contacts 39 are closed. Thus either the "starting circuit" 37, or the "operating circuit" 40 will hold the firing signal relay contacts 41 closed as shown in FIGS. 1 and 2 respectively.

Contacts 41 on firing signal relay 27 together with contacts 42 on circuit sealing relay 26 comprise a "firing circuit" which initiates fuel and ignition signals and which maintains combustion by supplying current to the mechanism 28. The activating coil 43 on circuit sealing relay 26 is connected in shunt across this "firing circuit" so that relay 26 "seals" itself in when contacts 42 are closed, as shown more clearly in FIG. 2.

In order for relay 26 to "seal" itself in, contacts 44 on the shaft speed relay 25 are connected in parallel with the "firing circuit." Thus when coil 45 of the relay 25 is energized by a signal from signal system 7, contacts 44 will be momentarily closed to complete the "firing circuit" and cause relay 26 to close contacts 42 to maintain the "firing circuit."

It only remains to be noted that relay 26 also includes normally closed contacts 46 which are connected in series with the vibrating reed relay 11, so that when relay 26 is energized, the contacts 46 are opened and the low frequency reed relay 11 will be thus removed from the circuit.

The operation of the starting and overspeed protection system will now be outlined. The turbine rotor is turned by suitable starting motor means (not shown) and starting switch 23 is closed. Since there is no flame in the combustion chamber 1, coil 33 of flame detector relay 24 is not energized and the circuitry appears as shown in FIG. 1, with coil 36 of firing signal relay 27 energized to close contacts 41. Contacts 41 must remain closed in order for combustion to take place or in order for combustion to continue after it has taken place. This is true, whether coil 36 is energized by the "starting circuit" 37 or by the "operating circuit" 40.

At a predetermined shaft speed, which causes generator 9 to generate a frequency at which vibrating reed relay 11 experiences resonance, the reed member 13 will close contacts 17 to energize coil 45 of the shaft speed relay 25. Relay 25 causes contacts 44 to close momentarily and contacts 39 to open, as the shaft speed reaches the point at which combustion is to commence. When contacts 44 are closed, the "firing circuit" is completed which actuates the fuel and ignition control mechanism 28. Mechanism 28 sends a fuel signal 29 to the fuel control valve 4 causing it to open and supply fuel to the nozzle 3. Mechanism 28 also sends a signal 30 to energize the ignition means 5 to initiate combustion. Contacts 44 also energize coil 43 of circuit sealing relay 26 to close contacts 42, which provide an alternate path for supplying current to the mechanism 28. Moreover, circuit sealing relay 26 is "sealed"

in and the speed relay 25 may now return to its previous position.

In order to positively remove the reed relay 11 from the circuit, contacts 46 are opened by the relay 26.

As the fuel and spark are supplied to combustion chamber 1, ignition takes place and the flame is sensed by flame detector 6 to energize coil 33 of the flame detector relay 24. This causes the "operating circuit" 40 to be completed and coil 36 of the firing signal relay 27 is now energized via the operating circuit 40 thus maintaining the supply of fuel to the combustion chamber 1 by means of the mechanism 28.

It will be understood by those skilled in the art that "overlapping contacts" are necessary on relay 25 in order to insure that contacts 44 are made before contacts 46 are broken. Likewise, overlapping contacts may be provided on relay 24 to insure that coil 36 remains energized while the flame detector relay 24 is shifting from the "starting circuit" 37 to the "operating circuit" 40. After firing has taken place, the starting switch 23 is opened, either manually or by suitable automatic devices not shown because not pertinent to the present invention.

The combustion control system 8 is now in the condition shown in FIG. 2. It is to be particularly noted that control system 8 comprises the same circuitry that will shut the turbine down in case of overspeed. Thus the above-described starting process has acted to "exercise" the circuits and associated relays to insure their ability to act properly upon overspeed.

In the event the turbine starts to overspeed, the generator 9 generates a frequency which causes vibrating reed member 12 of relay 10 to close contacts 16 and to again energize coil 45 of shaft speed relay 25. Solenoid 45 opens contacts 39, which de-energizes coil 36 of the firing signal relay 27. This permits contacts 41 to open the firing circuit which, in turn, causes fuel and ignition control mechanism 28 to stop the flow of fuel to combustion chamber 1. At the same time, coil 43 of the circuit sealing relay 26 is de-energized and this relay returns to the position that it occupied in FIG. 1.

This control system will also act if the flame goes out in combustion chamber 1. Flame detector 6 senses this and the circuit containing coil 33 is de-energized opening contacts 35, 38. The coil 36 of relay 27 is consequently de-energized which interrupts the firing circuit. This causes mechanism 28 to shut off the fuel.

The resonant reed relays 10, 11 are standard articles of commerce which are quite reliable and may be accurately calibrated to resonate at a preselected shaft speed. Thus relay 10 provides a reliable overspeed protection device which is not subject to mechanical wear or inaccuracy due to mechanical shocks, friction, etc., as in the case of conventional mechanical speed sensing means.

Although vibrating reed relays 10, 11 are very dependable components, a more complete check of the overall speed protection system during start-up can be had by use of the modification illustrated in FIG. 3 of the drawing. Here the portion of FIG. 1 designated collectively as the speed responsive signal generating system 60 has been replaced by a modified speed responsive signal generating system 50, the remaining components of the system being the same as in FIG. 1. Signal system 50 employs only one vibrating reed relay 51 actuated by tachometer generator 9. The coil 52 of relay 51 is connected by circuit 10a with contacts 46 of circuit sealing relay 26 (FIG. 1). An impedance 53 is connected in parallel with contacts 46. The reed member 54 closes contacts 55 when it resonates to provide a signal for energizing coil 45 either for the purpose of initiating combustion or for overspeed protection.

The operation of the single reed relay 51 as in FIG. 3 depends upon the fact that the tachometer generator 9 generates a fundamental frequency as well as many harmonics thereof. This is illustrated more clearly by ref-

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erence to FIG. 4 of the drawing, where a sinusoidal curve 56 represents the fundamental frequency generated by the generator 9 at a low predetermined shaft speed. The curve 57, in turn, represents the third harmonic of the fundamental frequency represented by curve 56. Other harmonics than the third harmonic may also be present, but are not shown. The harmonic signal has a lower amplitude than the fundamental signal 56, but is sufficiently strong to vibrate the reed 54. Impedance 53 has no effect on this weak signal since the current can flow through closed contacts 46. When the turbine is at a predetermined low speed, the relay 51 is responsive to the harmonic signal. Thus the harmonic signal 57 is employed to actuate relay 51 so that it serves to initiate combustion so as to perform the function of the reed relay 11 in FIG. 1.

After combustion occurs, and the contacts 46 of relay 26 are opened by activation of the firing circuit, the impedance 53 will then act to attenuate any weak harmonic signals of the fundamental signal. Thus if an overspeed condition is reached, and the turbine shaft and generator 9 are turning three times as fast as when the relay was activated by the harmonic in the example shown, the fundamental frequency generated by generator 10 will have a wave length equivalent to curve 57. The reed is calibrated so that this frequency corresponds to a predetermined overspeed condition, and when this shaft speed is reached coil 45 of relay 25 again will be energized, this time to shut off the fuel supply and to shut down the turbine.

Thus in the starting cycle, a harmonic of the signal generated by the tachometer generator 9 is used to initiate combustion and test the circuit, while in normal operation the circuitry is conditioned so that the fundamental signal produced by generator 9 shuts down the turbine in case of overspeed.

It will be appreciated that the third harmonic was selected only for purposes of illustration. The harmonics appear in odd numbers, 3, 5, 7, etc., and any one having strength enough to vibrate the reed can be utilized. Of course, the fundamental frequency to which the reed responds must correspond to the desired overspeed setting and the selected harmonic must correspond to a suitable speed for initiating combustion.

As in the embodiment shown in FIG. 1, the use of a single combustion control circuit 8 both to initiate combustion and to terminate combustion upon overspeed will be appreciated, since an automatic check is made of the circuitry every time the turbine commences operation. The only portion of the overspeed circuitry which is not checked during start-up by the circuit shown in FIG. 1 is the vibrating reed relay 10 which is generally a very reliable item.

In the embodiment shown in FIG. 3, however, even the vibrating relay 51 is tested during start-up, thus giving maximum reliability by automatically "exercising" every component of the overspeed protection system each time the starting sequence is performed.

A modification of the speed responsive signal generating system, shown as 7 in FIG. 1 and as 50 in FIG. 3, is illustrated generally as 58 in FIG. 5. Instead of using a tachometer generator to produce a speed responsive signal, the vibration of the turbine casing, a portion of which is seen at 59, is utilized. A low frequency reed member 60 and a high frequency reed member 61 are mounted directly to casing 59 so as to sense the vibrations characteristic of each rotor speed. Contacts 62, 63 are connected in parallel to D.C. source 19 and are closed by reeds 60, 61 respectively when the reeds vibrate. Closing of either contacts 62 or 63 energizes relay coil 45 shown in FIG. 1.

The operation of FIG. 5 is as follows. Reed 60 is calibrated to sense a rotor speed suitable for initiating combustion through the vibrations of casing 59. Contacts 62

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close and combustion is initiated as previously described in connection with FIG. 1.

The reed 61 is calibrated to vibrate when the rotor is turning in excess of rated speed. Contacts 63 are closed to shut off the fuel. Thus the operation of speed responsive signal generating system 58 is exactly like system 7, with the exception that mechanical vibrations, rather than electrical coils are used to make the reeds vibrate.

It can be seen, therefore, that a very reliable gas turbine starting and overspeed system has been provided, which is free from many of the difficulties of other types of mechanically actuated or hydraulic overspeed devices. The reliability of the vibrating reeds as overspeed devices together with the automatic testing provisions, greatly decrease the possibility of malfunction of the overspeed protection system.

The system is not limited to alternating current signals, of course, since a pulsating direct current furnished by rotating contacts on the shaft might also be used to actuate a frequency-responsive device.

These and many other advantages will be apparent to those skilled in the art and while there has been described what is at present considered to be the preferred embodiment of the invention, it is desired to cover in the appended claims all such modifications as fall within the true spirit and scope of the invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. In a thermal powerplant having a combustion chamber, the combination of means responsive to a speed condition in the powerplant generating a first signal at a first relatively low speed and generating a second signal at a higher preselected maximum speed, means for initiating combustion and supplying fuel to the combustion chamber when actuated by a firing signal, flame detection means adapted to sense the presence of flame in the combustion chamber, and combustion control means including a starting circuit supplying a firing signal to said combustion initiation means when actuated by the first speed signal, said combustion control means also including an operating circuit for sustaining said firing signal provided the flame detecting means is actuated by flame in the combustion chamber and for interrupting the firing signal either when actuated by the second speed signal or when the flame is extinguished, said first speed signal also acting to interrupt the operating circuit for testing before there is flame in the combustion chamber.

2. In a gas turbine having a combustion chamber, the combination of means responsive to turbine speed generating a first signal at a first relatively low turbine speed and generating a second signal at second higher preselected maximum turbine speed, means for initiating combustion and supplying fuel to said combustion chamber when activated by a firing signal, flame detection means adapted to sense the presence of flame in the combustion chamber, and combustion control means comprising a firing signal relay adapted to furnish a firing signal to said combustion initiation means, a starting circuit energizing said firing signal relay when there is no flame in the combustion chamber, an operating circuit energizing said firing signal relay provided there is flame in the combustion chamber, and means to open said operating circuit when energized by said second preselected maximum turbine speed signal, whereby the fuel flow to the combustion chamber will be terminated either when the flame is extinguished or when the turbine reaches the second preselected speed, said means also opening said operating circuit for testing when energized by the first speed signal before there is flame in the combustion chamber.

3. In a gas turbine having a combustion chamber, the combination of means to initiate combustion and supply fuel to said combustion chamber when actuated by a firing signal, combustion control means including a starting circuit which is closed when there is no flame in the combustion chamber and an operating circuit which is closed

when there is flame in the combustion chamber, said combustion control means also including a firing circuit which is energized by either said starting or said operating circuit, shaft speed relay means connected to seal in the firing circuit and to interrupt the operating circuit when energized, means for generating a fluctuating current having a frequency proportional to turbine speed, frequency-responsive relay means responsive to a selected first frequency corresponding to a first turbine speed and also to a selected second frequency corresponding to a second higher turbine speed, said frequency-responsive relay means being connected to energize said shaft speed relay means at said first and second turbine speeds, whereby combustion will be initiated at the first turbine speed when there is no flame in the combustion chamber by closing the firing circuit and combustion will be terminated at the second turbine speed by opening the operating circuit.

4. In a gas turbine having a combustion chamber and means for supplying fuel thereto, the combination of means responsive to turbine speed for generating a signal having a frequency proportional to turbine speed, vibrating reed relay means connected to said generating means and responsive to a first frequency corresponding to a turbine speed suitable for initiating combustion and also responsive to a second frequency corresponding to an overspeed condition of the turbine, flame detection means to sense the presence of flame in said combustion chamber, and means controlling the supply of fuel to said combustion chamber connected to be activated by said vibrating reed relay means at the first frequency and arranged to interrupt said fuel supply when actuated either by loss of flame as sensed by the flame detecting means or an overspeed condition as sensed by said vibrating reed relay means at the second frequency.

5. In a gas turbine having a combustion chamber, means to initiate and maintain combustion in said combustion chamber when a firing signal is received by said means, flame detection means to sense the presence of flame in the combustion chamber, a flame detector relay connected to be energized by said flame detector means when there is flame in the combustion chamber, said flame detector relay having first normally closed and second normally open contacts forming a portion of starting and operating circuits respectively, whereby a loss of flame will interrupt the operating circuit, a firing signal relay connected to be energized either by the starting circuit or the operating circuit and including normally open contacts forming a portion of a firing circuit, shaft speed relay means including normally closed contacts arranged to interrupt the operating circuit and normally open contacts arranged to complete said firing circuit, means to seal in the firing circuit when the shaft speed relay is energized, means to generate a signal proportional to turbine speed, frequency-responsive relay means connected to be responsive to said speed signal to energize said shaft speed relay at a first turbine speed, whereby combustion will be initiated and the firing circuit will be sealed in, said frequency-responsive relay means also being connected to energize the shaft speed relay when actuated by said speed signal at a second higher turbine speed, whereby the operating circuit is interrupted upon the occurrence of a turbine overspeed condition.

6. In a gas turbine having a combustion chamber, means to initiate and maintain combustion in said combustion chamber when a firing signal is received by said means, flame detection means to sense the presence of flame in the combustion chamber, a flame detector relay connected to be energized by said flame detector means when there is flame in the combustion chamber, said flame detector relay having first normally closed and second normally open contacts forming a portion of starting and operating circuits respectively, whereby a loss of flame will interrupt the operating circuit, a firing signal relay connected to be energized either by the starting circuit or the operating circuit and including normally open contacts forming a portion of a firing circuit, shaft

speed relay means including normally closed contacts arranged to interrupt the operating circuit and normally open contacts arranged to close said firing circuit, means to seal in the firing circuit when the shaft speed relay is energized, generator means arranged to turn at a speed proportional to turbine speed so as to generate an alternating current having a frequency proportional to turbine speed, first and second vibrating reed relays each having a coil connected in parallel with said generator means and each having contacts connected in parallel to said shaft speed relay, said first vibrating reed relay being responsive to a frequency corresponding to a first turbine speed and said second vibrating reed relay being responsive to a frequency corresponding to a second higher turbine speed, whereby the first vibrating reed relay will energize the shaft speed relay at the first turbine speed to initiate combustion and seal in the firing circuit, and the second vibrating reed relay will energize the shaft speed relay at the second higher turbine speed to interrupt the operating circuit and shut down the turbine.

7. In a gas turbine having a combustion chamber, the combination of means to initiate combustion and supply fuel to said combustion chamber when actuated by a firing signal, combustion control means including a starting circuit which is closed when there is no flame in the combustion chamber and an operating circuit which is closed when there is flame in the combustion chamber, said combustion control means also including a firing circuit which is energized by either said operating circuit or by said starting circuit, shaft speed relay means connected to seal in the firing circuit and to interrupt the operating circuit when actuated, generator means arranged to turn at a speed proportional to shaft speed so as to generate an alternating current having a fundamental frequency proportional to shaft speed which includes at least one harmonic frequency, said fundamental frequency corresponding to a preselected turbine overspeed condition, frequency-responsive relay means connected to said generator and responsive to one of said harmonic frequencies at a first relatively low turbine speed, and impedance means connected to attenuate the harmonic at a speed in excess of said first turbine speed, whereby the harmonic signal will initiate combustion at said relatively low shaft speed and the fundamental frequency will terminate combustion upon occurrence of said turbine overspeed condition.

8. In a thermal powerplant having a heating device and means generating a signal proportional to a speed condition in the powerplant, the combination of first control means to initiate and discontinue operation of the heating device, electric generator means driven at a speed proportional to said speed signal and producing an alternating electrical signal having a frequency proportional to said speed condition and including a fundamental frequency corresponding to a first relatively high speed condition and a harmonic frequency corresponding to a second relatively lower speed condition, impedance means connected to attenuate said harmonic frequency at speeds in excess of said second speed condition, and frequency responsive relay means connecting said generator to said first control means whereby the harmonic frequency actuates the first control means to initiate operation of the heating device at said second speed condition and the fundamental frequency actuates the control means to discontinue operation of the heating device at said first speed condition.

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