Fundamentals of
Flame Safeguard System (F S G)

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Contents

Preface

There have been cases under which explosion accidents by combustion equipment such as combustion furnace, dryer and boiler not only inflicted heavy damage to the operating company but also claimed precious human lives.

The following is the explanation on circumstances that cause the explosion, and on how to prevent these explosion accidents. In addition, this text book explains how to prevent the accident occurrence by means of installing flame safeguard systems with automation of combustion equipment, required roles by the operating company to maintain /secure the safety of combustion equipment, and some precautions to be taken at the time of combustion safety equipment (FSG) installation.

Since this text book quotes partially and describes some fundamental matters on the combustion safety equipment as referred in ? Safety Engineering Directives of Industrial Gas Combustion Equipment ? of The Japan Gas Association (Shi-Ki-0126-85), each quotation and reference are marked with “The Japan Gas Association”.

(1) Explosion Prevention of Combustion Equipment

The following is the description on conditions under which combustion equipment may explode.

1. Causes for explosion

An explosion occurs when the fuel/air mixture having the density within the explosion limit accumulates in a sealed chamber and the ignition source starts to grow.

Air Excess	Explosion Limit*	Fuel Excess

Figure: Density of fuel/air mixture and explosion limit

Note *: · The explosion limit differs depending on fuels. The explosion limit of natural gas (LNG : 13A) is 4.3 to 14.1% (the gas mixture ratio in 100%)
· The explosion limit value differs depending on temperature, the pressure, etc. even with the same fuel.

Namely, an explosion relates to the three(3) elements of fuel, air and ignition source. This is the same as three(3) elements of combustion. The explosion occurs when the ignition starts after the fuel/air mixture accumulation in a combustion chamber, and the normal combustion occurs when the ignition starts before the mixture accumulation.

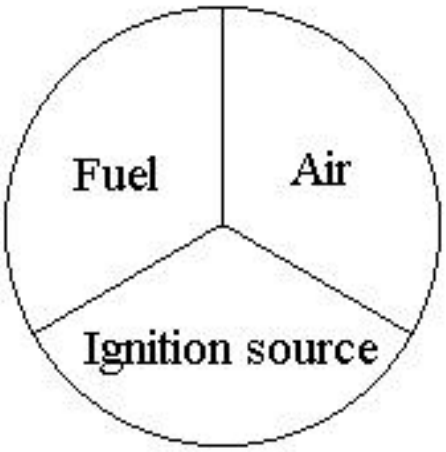
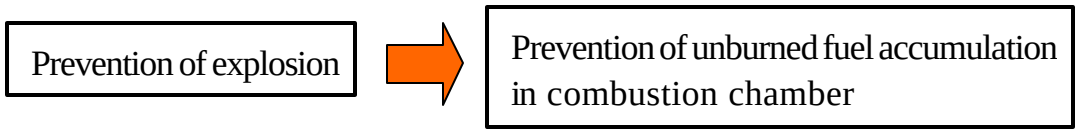


Figure: Three(3) elements of explosion (combustion)

2. How to prevent explosion

In order to avoid an explosion, it is quite acceptable to control at least one out of three (3) elements, namely, fuel, air or ignition source that causes an explosion. However, the control for air or ignition source is not practically easy due to the presence of air anywhere on the ground surfaces entering into a combustion chamber, and the existence of an ignition source because of the constant red heat within the chamber of combustion equipment.

In case the sprayed fuel is not fired or the ignition fails, the fuel supply must be stopped. When the burner firing stops suddenly due to an unknown cause during the normal operation, the fuel supply must be cut off.



The following will give examples of actual application of preventive measures to avoid the fuel accumulation in the combustion chambers..

3. Cases of fuel accumulating in combustion chambers

The followings are some actual cases of the fuel accumulation in the chamber:

1) The burner stops firing suddenly due to an unknown cause during the operation.

2) The safety shut-off valve opens prior to the ignition source at the time of burner ignition.

3) The ignition action is tried for burner but the ignition fails.

4) The burner makes incomplete combustion because of inappropriate fuel/air ratio.

5) The residue gas remains in chamber.

Next, each preventive measure on these five (5) cases is described.

1) The burner stops firing suddenly due to an unknown cause during the operation.

(Preventive Measure)

Supervise the burner flame, close safety shut-off valve at firing failure and stop fuel supply to the combustion chamber. Such a sequence is called "combustion supervision" and "safety shut-off" which can be accomplished with the combination of flame relay, Protectorelay and safety shut-off valve. The three(3) devices fulfill the most important role in the flame safeguard system.

According to the Japan Industrial Standard, JIS B 0113 Industrial Combustion Equipment glossary, the safety shut-off valve is defined as " the valve to be used to stop the ejection of fuel within a short time at emergency and not to return automatically." In other words, the safety shut-off valve must have such a structure to receive the electric power back to operate again after it closes due to an unknown reason, and can not be operated unless the mechanical resetting is manually performed. Or it must have a self-locking circuit as an augmented safety so as not to make the valve open unless the resetting is made.

Furthermore, the above JIS specifies Fuel Shut-off Valve as "the valve to stop the ejection of fuel", but such a valve is classified in this text as safety shut-off valve.

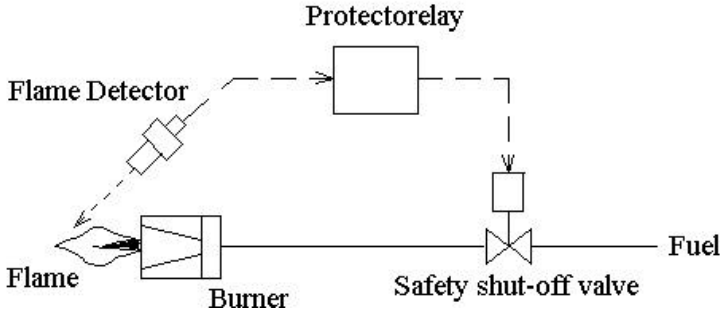


Figure: Fuel supervision and Safety Shut-off

2) The safety shut-off valve opens prior to the ignition source at the time of burner ignition.

(Preventive Measure)

If the safety shut-off valve opens at the time of burner ignition, and shortly provides the ignition source (the same condition as ignition delay), the explosion may occur. As a countermeasure, the ignition sequence is set up so as to make the preparation of ignition source prior to safety shut-off valve opening or at least at the same time when the burner is to be ignited.

The Protectorelay has an embedded sequence circuit so that regardless of an operator's manipulation, the sequence and the timing are always the same to actuate each device. This sequence circuit is said to be "the circuit to actuate devices in pre-set sequence and timing".

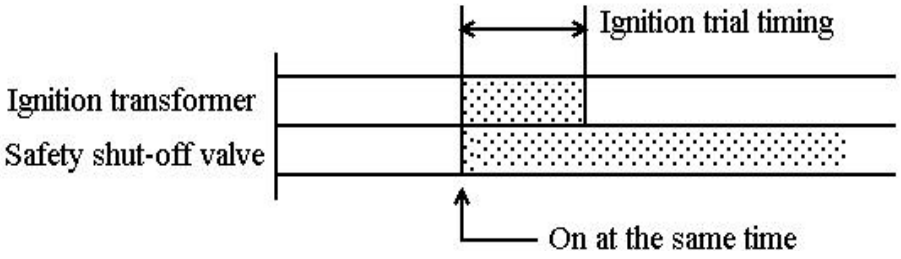
Ignition delay ⇨

[Setting of ignition sequence]
1. Preparation of ignition source
   (Ignition transformer: ON)
2. Fuel supply (Safety shut-off valve: Open)

(The both actions perform at least the same time.*)

* The time chart of ignition below is referred.

[Time chart of the Protectorelay at ignition trial]



3) Case of a burner not making firing despite of ignition trial for the burner (Preventive Measure)

When the burner is not ignited despite of ignition trial, the unburned fuel starts filling in the combustion chamber under continuous fuel ejection to create a very hazardous moment due to the spark of ignition transformer as an ignition source. In order to prevent this possibility, an ignition timing for the burner is set. When the ignition can not be accomplished within this timing, the ignition transformer operation is stopped, and the safety shut-off valve is closed.

Ignition failure ⇨

1. Limit ignition time *
2. Ignition is not made within the specified timing
   ⟶ Fuel shut-off

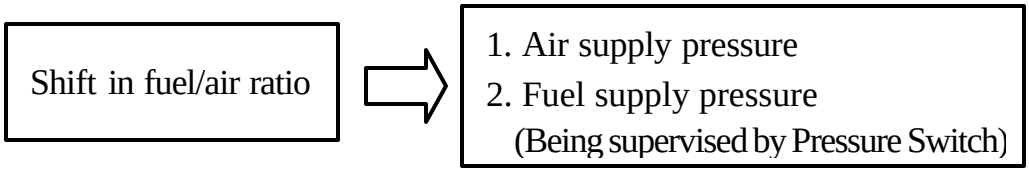
*: Refer to the above time chart.

4) In case of incomplete combustion of burner due to an inappropriate fuel/air ratio

(Preventive Measure)

The fuel/air ratio may change at trial run or at maintenance because of the following cases despite of its adjustment conducted for combustion equipment. **(Refer to the combustion system examples of Page 21)**

a. When the change in air supply pressure and fuel supply pressure occurs, the fuel/air ratio may change. To cope with this possibility, a Pressure Switch is mounted to supervise the air supply pressure and makes the firing stop by sending a signal to the switch. However, this method can not distinguish small change in fuel/air ratio.



b. The fuel/air ratio may change during operation by a loose screw of linkage unit which connects air control valve and fuel control valve, and holds fuel/air ratio at a fixed value. There is no clear solution for the change unless a periodic checking to find if the linkage screw becomes loose.

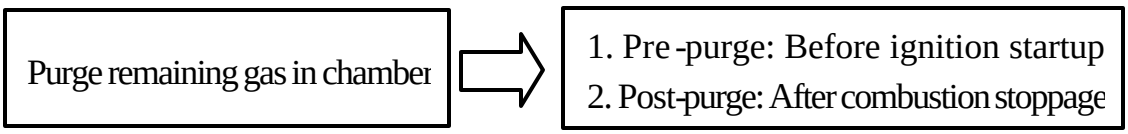
5) Case under which the residual gas remains

(Preventive Measure)

There are following cases in which the unburned gas remains in the chamber.

a. The fuel passing from fuel supply pipe to safety shut-off valve does not burn completely but remains partially as unburned gas. (The oil becomes also gasified under heat.) Furthermore, the unburned fuel is accumulated in the chamber as a result of fuel leakage from the safety shut-off valve due to the functional attenuation during combustion toppage.

To cope with this situation, only air is blown into the chamber by a blower prior to ignition operation of the burner to make positive air circulation (pre-purging) and to purge the remaining gas. On the other hand, purging the remaining gas is called "Post purge" to make the air circulation after combustion stoppage.



b. Fuel leaks out from safety shut-off valve due to the functional attenuation of safety shut-off valve caused by galling of foreign particles and the failure of closing mechanism.

The following measures can be taken to secure necessary functions for this kind of situation:

(1) The system increases the safety by installing a double shutdown arrangement with two (2) safety shut-off valves in series so that either one of them can prevent the fuel leakage despite of a failure of either valve.

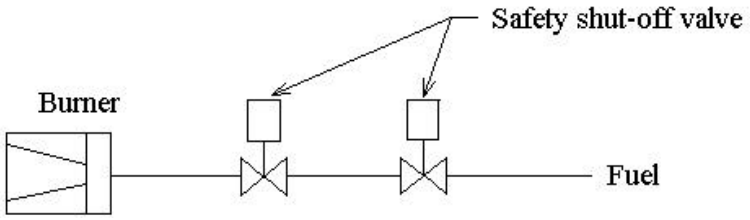


Figure: Double shut-off arrangement of fuel flow

(2)The function can be secured by periodical leakage check of safety shut-off valves.

(Periodical maintenance)

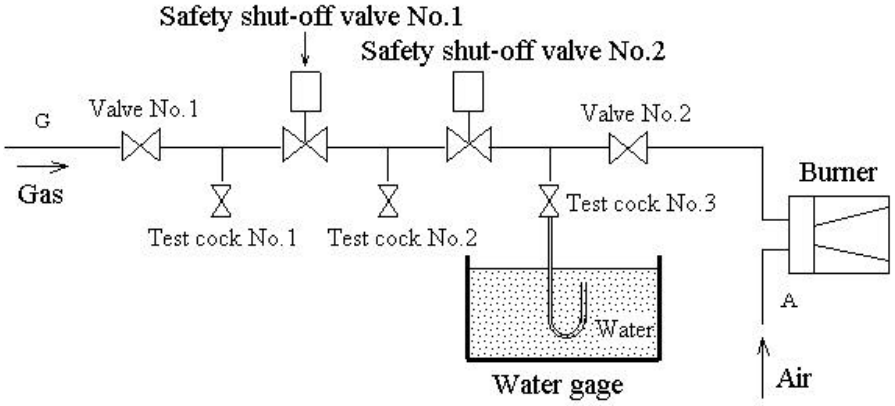


Figure: Checking method of fuel leakage

Fuel leakage	⇨	1. Double shut-off arrangement 2. Periodical check and maintenance

Out of the above diagram, it will be necessary to combine appropriate devices (combustion safety equipment) and use them in order to prevent equipment explosion, namely, to prevent accumulation of unburned fuel in the combustion chamber.

Next, the basic structures of combustion equipment are described, and some precautions are given in the applications and on the functions of relevant component devices.

(2) Outline of Flame Safeguard System

1. Basic structure of flame safeguard system

The basic structure of a flame safeguard system is shown in the following block diagram:

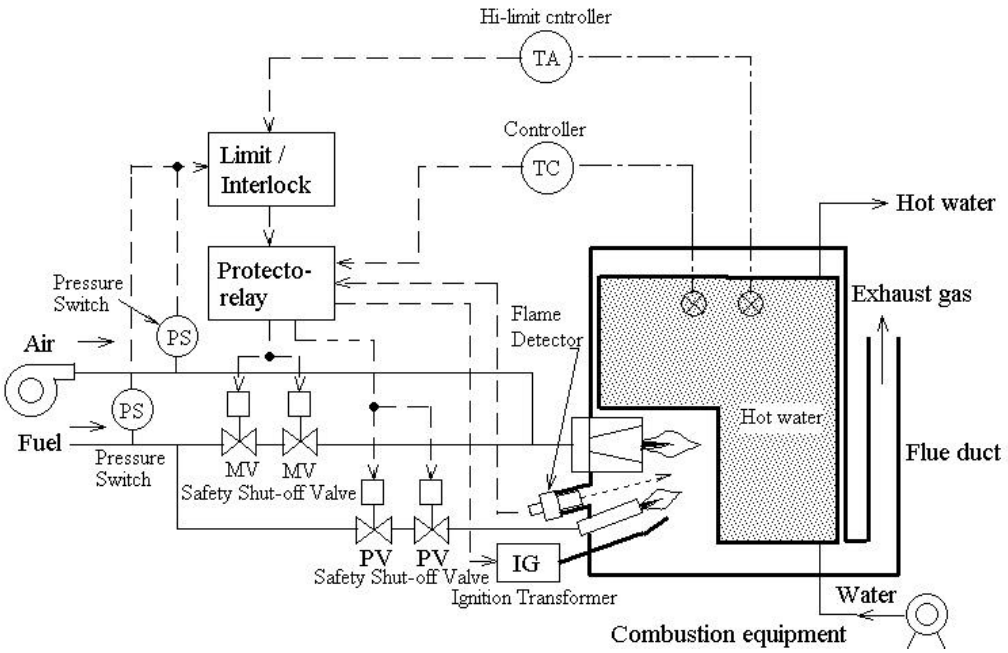


Figure: Basic structure of flame Safeguard system (an example of small type hot water boiler)

2. Component devices and the functions of flame safeguard system

The flame safeguard system is composed of the devices shown hereunder.

1) Controller

This is used to control the temperature and the pressure of combustion equipment for certain target values (set values). Generally, a temperature controller and a pressure controller are used to make ON-OFF control for a small type hot water boiler of the above diagram and a small type stream boiler.

A temperature controller is used to control the temperature of hot water boiler, combustion chamber, dryer, etc. A pressure controller is used to control the pressure of steam boilers. The ON contacts mean the operation start, and the OFF contacts give a stop signal. In addition to the controllers of ON-OFF control, there are controllers to operate an electric Modutrol Motor and a Butterfly Valve for proportional control in an application to comparatively large size combustion equipment.

2) Limit and Interlock

a. Limit

This is used as a device to prevent in advance an abnormal condition and a hazardous condition that will possibly occur. For example, when a temperature controller in the combustion chamber fails, the temperature in the chamber gradually increases to a set point limit at which a signal from high limit controller is sent to the Protecotorelay to make the combustion stop. Generally, the temperature controller of ON-OFF control and the pressure controller are used as Limit with the contacts ON at normality and OFF at abnormality.

b. Interlock

There are two (2) categories of the Interlock being used in combustion equipments, namely, Startup Interlock and Operation Interlock.

The interlock is meant to make relevant devices the startup or operation safety after the necessary conditions are satisfied with all the contacts of devices being turned on.

- **Start Interlock**

This is the name of device used for checking the completion of combustion equipment startup condition.

Generally, limit switches are used for this kind of an application but the Limit Switches are used as start interlock to see if the opening of a damper in stack for air circulation is positively completed. Also a limit switch is operated as start interlock to check the complete closing of Safety Shut-off Valve prior to the starting of combustion equipment.

- **Running Interlock**

This is used as the name of device to check the completion of combustion equipment operation condition.

Generally, pressure switches are used for this application. For example, during the normal operation a pressure switch sees if the air for combustion and supply pressure are normal or not. The switch contacts are in ON position to continue the operation with the operation condition being met. When the condition is not satisfied, the switch contacts become OFF and the combustion operation is stopped by a signal to be sent from the Protectorelay.

3)Flame Detector

This flame detector acknowledges the presence of burner flame and sends a converted electrical signal to the Protectorelay.

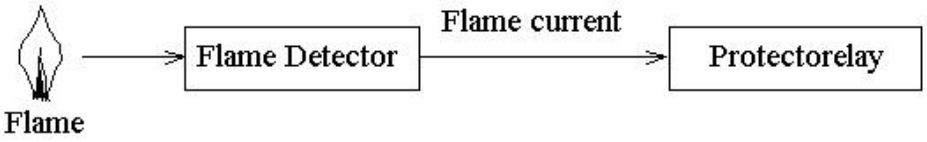


Fig. Function of Flame Detector

Generally, the direct current is applied as electrical signal that is called "flame current". When a flame detector detects the burner flame, it sends out a few micro-amperes of flame current to the Protectorely.

? Precautions in Use ?

a. Selection of Flame Detectors

Depending on flame detectors, there are some cases in which the gas burner flame or oil burner flame may not be detected. When a detector is to be used, make sure to confirm the functions.

b. False detection prevention of ignition sparks

Depending on flame detectors, some may detect not only burner flame but also ignition spark at the same time. When the flame detector is installed on the burner unit, it is necessary to position the flame detector in such a way not to sense the presence of sparks by ignition transformer.

Flame Detector	Burner flame sensing		Main application	Ignition spark detection
	Gas	Oil		
Ultravision	?	?	Industrial combustion chamber Dryer, Boiler, etc.	?
Flame rod	?	-	Gas fired small boiler, Small type dryer, etc.	-
Cd S	-	?	Oil fired small type boiler, etc.	-

c. Performance of pilot turndown test

When a burner system with separate pilot method is adopted to ignite the main burner after the pilot burner is ignited and the flame is detected by a flame detector, the flame detector should not be mounted in a position to sense a small pilot burner flame without resulting in the positive firing of the main burner because a large amount of unburned fuel is accumulated in the combustion chamber and possibly creates the danger of explosion.

In order to avoid such an explosion, it is necessary to perform so called "Pilot turndown test" in which repeated adjustment is made to generate an appropriate pilot flame size with the manual valve, and to correct flame viewing angle of the flame detector for the positive ignition of the main burner.

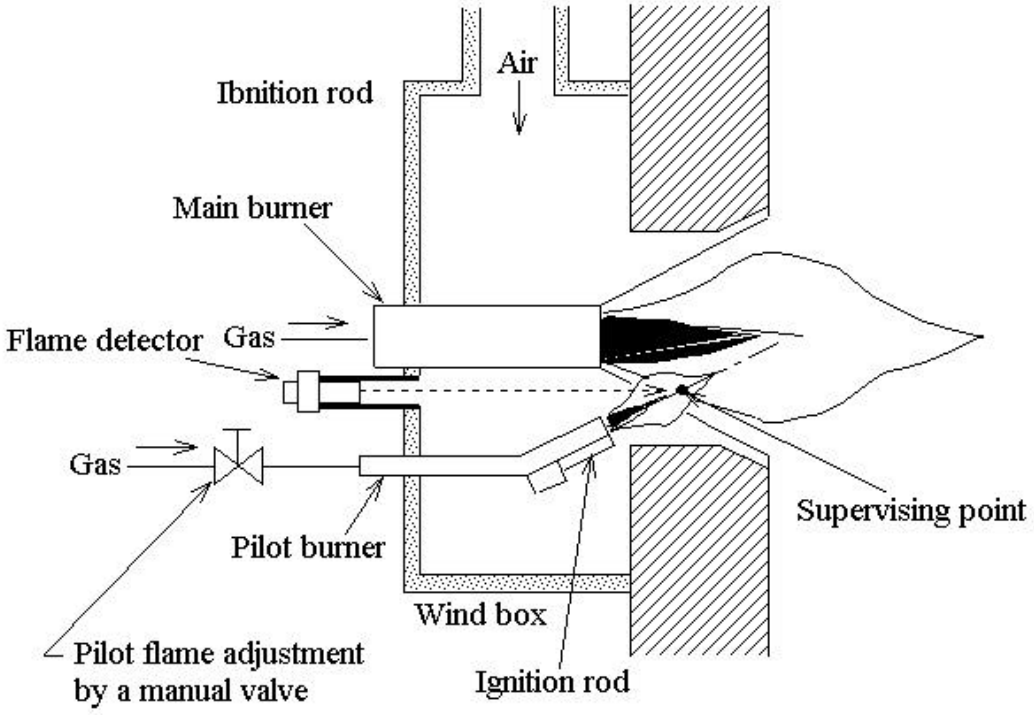


Figure: Pilot turndown test

4) Protectorelay

The following functions are embedded in Protectorelays

a. Combustion monitoring and safety shutdown

These objectives can not be fulfilled by the Protectorelay only but are achieved by the combination of Flame Detector, Protectorelay and Safety Shut-off Valve. (Refer to the diagram below.)

While the burner is firing, the flame current of several micro-amperes is flowing into the Protectorelay which in turn amplifies the current and makes the flame relay on (Flame detecting relay). Through the relay contacts the electric power is supplied to the safety shut-off valve for opening.

In an assumption of sudden burner shutdown, it is clear that the flame detector does not send any flame current thus making the flame relay become off.. Consequently, the flame relay contacts open so as to make the electric power shutdown for safety shut-off valve. The enclosed spring safety-shut off valve automatically closes the valve by its own power thus shutting down the fuel supply to the burner to prevent in advance the accumulation of unburned fuel in the combustion chamber.

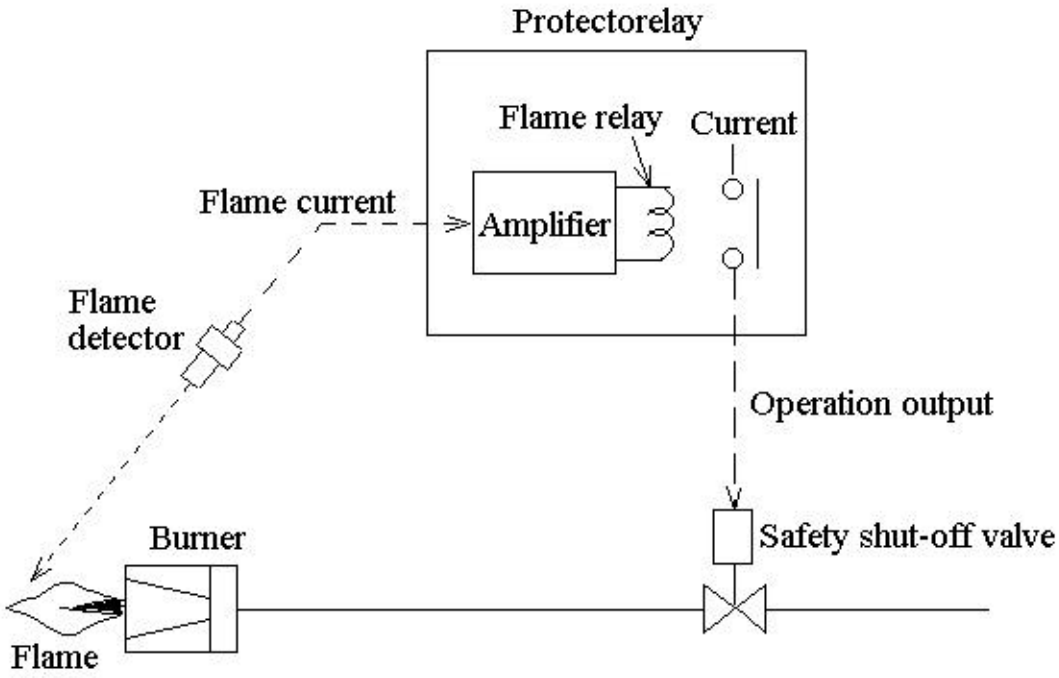


Figure: Combustion supervising and safety shutdown

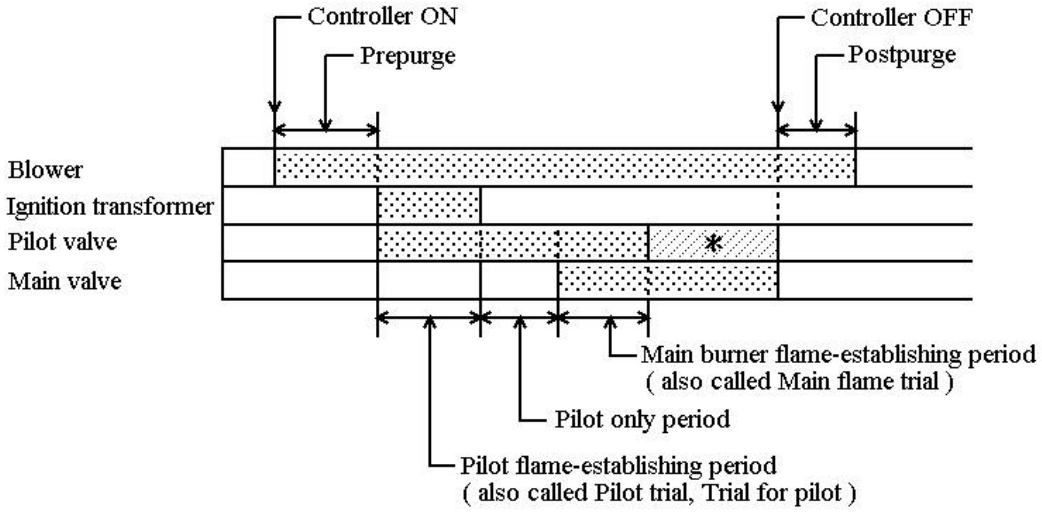
b. Start-up operation and combustion equipment stoppage by safety sequencing

A Protectorelay has a sequence (operating procedure) to safely start, operate and stop the combustion equipment with each timing fixed for securing the safety. The sequence is as follows:

This sequence is a typical one of Protectorelay with the timing chart given hereunder in the operation of combustion equipment. There are two types of Protectorelay, namely, the type to combine with a small type ultravision detector to detect the ignition sparks, and the other type to combine a flame rod not detecting the ignition sparks. The difference is that the former one is provided with ? Pilot only period ? in the sequence.

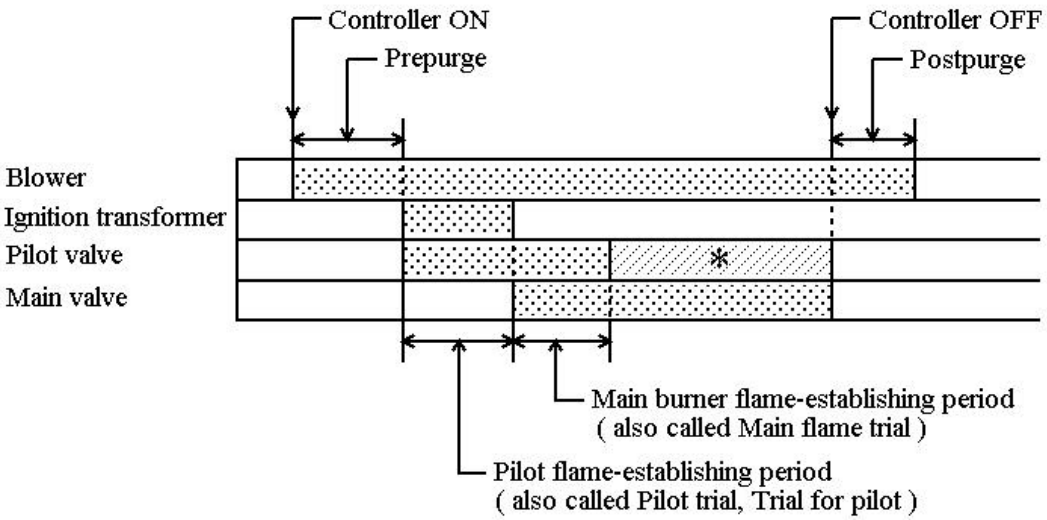
This is the timing to confirm the normal ignition of pilot flame with the flame detector so that it does not detect the presence of sparks and open the main valve in case of pilot ignition failure even though the supervising angle of the small type ultravision detector is adjusted to detect the ignition spark.

? Protectorelay to combine with small type ultravision detector?



✻ : Close in case of interrupted pilot. Open in case of intermittent pilot.

? Protectorelay to combine with flame rod?



* : Close in case of interrupted pilot. Open in case of intermittent pilot.

c. Safe start check

In the startup of combustion equipment, the Protectorelay performs a shelf-checking to see if the flame detecting circuit and the safety switch heater are not in any abnormal state. It starts to operate under the normal condition and prevents to operate under abnormality.

? Flame detector and flame detecting circuit are in abnormality

When a false flame signal exists, an equivalent signal as the flame presence is sent to the Protectorelay. If this happens, the combustion equipment actually starts to operate with this false signal, and the safety shutdown can not be achieved even when the burner flame dies out.

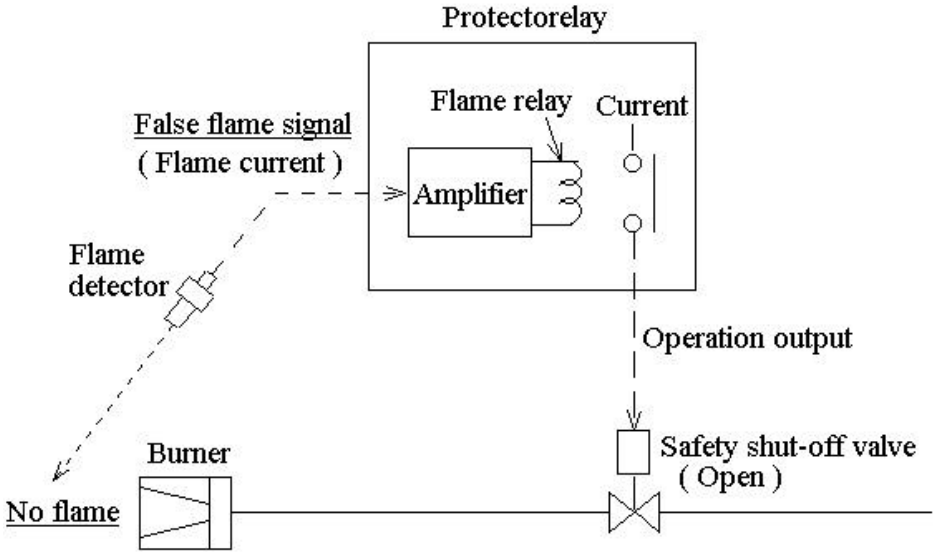


Figure: False flame signal

Because of such an occurrence, the Protectorelay for a batch operation (at least one starting / stopping operation every day) conducts a self-checking for flame detector and flame detecting circuit prior to the actual operation start.

Note:

A Protectorelay for the continuous operation equipment (no operation stoppage for a month or one year after the operation start) makes a self-checking for flame detector and flame detecting circuit while supervising combustion, and stops the operation by sending a stop signal in case of having the abnormality.

? Abnormality of safety switch heater -----disconnected wire or burn-out

The safety switch has very important functions of shutting off the safety shut-off valve at no burner firing and flame outage during normal operation, and to perform the lockout, namely, to conduct no restarting unless a resetting is made after the actuation of safety switch.

The structure of safety switch is shown in the diagram below. When the current flows continuously into the heater, the bimetal deforms due to its generated heat, and the switch is tripped so as to make the load relay off and to close the safety shut-off valve. This is the reason that the Protectorelay makes a self-checking prior to startup to see if the safety switch heater has no wire disconnection or burnout.

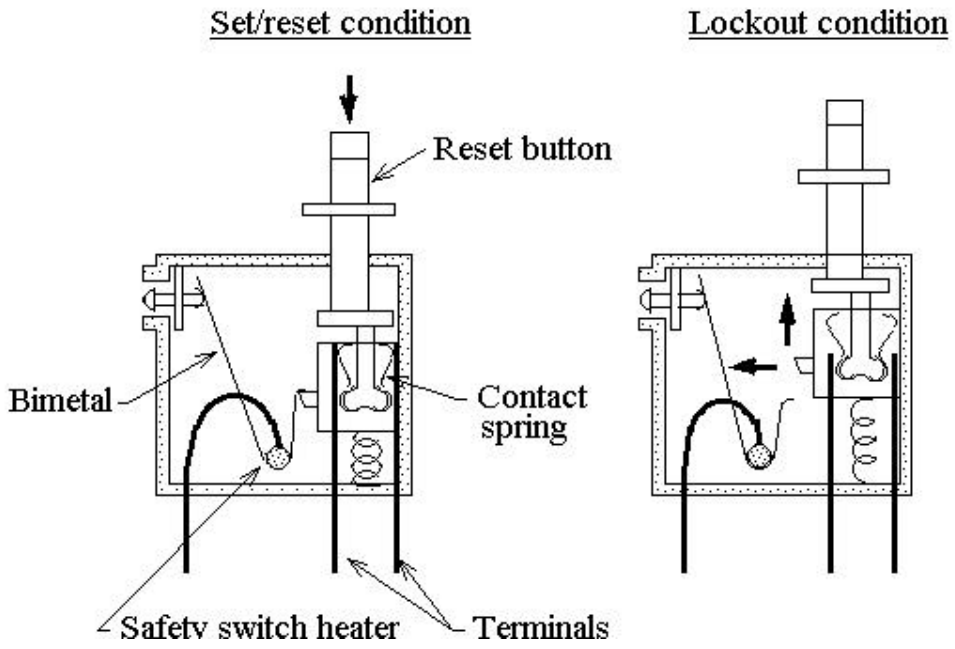


Figure: Operation of safety switch

d. Shutdown at no ignition

When the burner firing does not occur despite of the ignition trial, the ignition transformer continues to operate with sparking, and the consequent situation becomes very dangerous under unburned gas filling in the combustion chamber unless something must be done.

In order to prevent this possibility, the Protectorelay will make the lockout by stopping the operation of ignition transformer, closing the safety shut-off valve and operating the safety switch when the burner firing can not be started by the burner ignition action of the Protectorelay within a specified timing that is originally fixed.

e. Fail-safe design

The term "Fail-safe" means that the combustion system is automatically switched to the safe operation function when combustion equipment, control system or operation becomes a state of failure or abnormality.

A Protectorelay has a fail-safe design embedded in it so as not to start the relevant equipment when electronic components in the important circuits such as flame detecting, load control and lockout circuits become defective.

? Precautions in Use ?

? Wiring of Protectorelay and Loads (The Japan Gas Association)

The connection of the loads such as safety shut-off valve, pilot shut-off valve, ignition transformer, etc. must be wired to the terminals of the Protectorelay.

In case of controlling safety shut-off valve through the contacts of an auxiliary relay which may make the malfunction or contact welding, there is a possibility of explosion at the moment of ignition due to the explosive fuel mixture with air blown in by pre-purging when the safety shut-off valve opens simultaneously at the electric power on regardless of the Protectorelay operation, thus pushing out a large amount of unburned fuel from the burner.

Such an explosion accident can be avoided if the Protectorelay is directly connected with loads to the control terminals, and the load control is performed by signals of the Protectorelay.

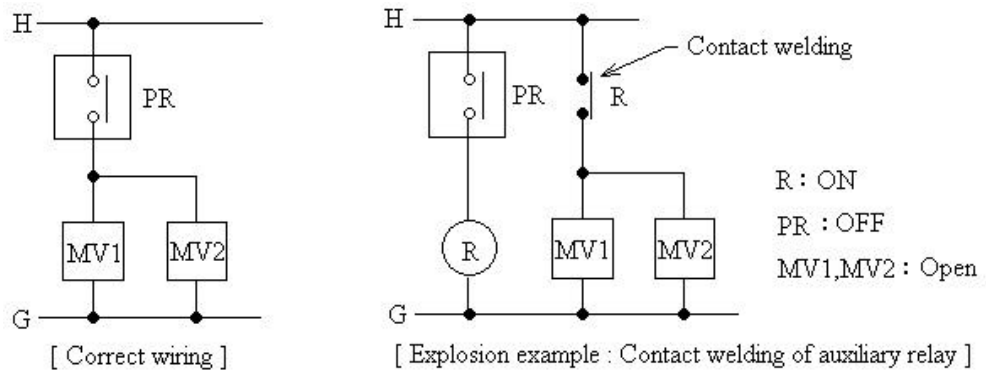


Figure : Wiring of Protectorelay and loads

? Correct wiring of auxiliary relay (The Japan Gas Association)

In case an auxiliary relay must be necessary due to the capacity shortage of Protectorelay contacts, the following measures should be taken for the malfunction and the contact welding of auxiliary relay in order to secure the fail-safe function.

- An auxiliary relay must be installed for each safety shut-off valve.(Two auxiliary relays are required for wiring to make the duplicated shutdown.)
- Starting inter-lock is required by the switch to confirm the closing of safety shut-off valve at startup and ignition in case of using an auxiliary relay.

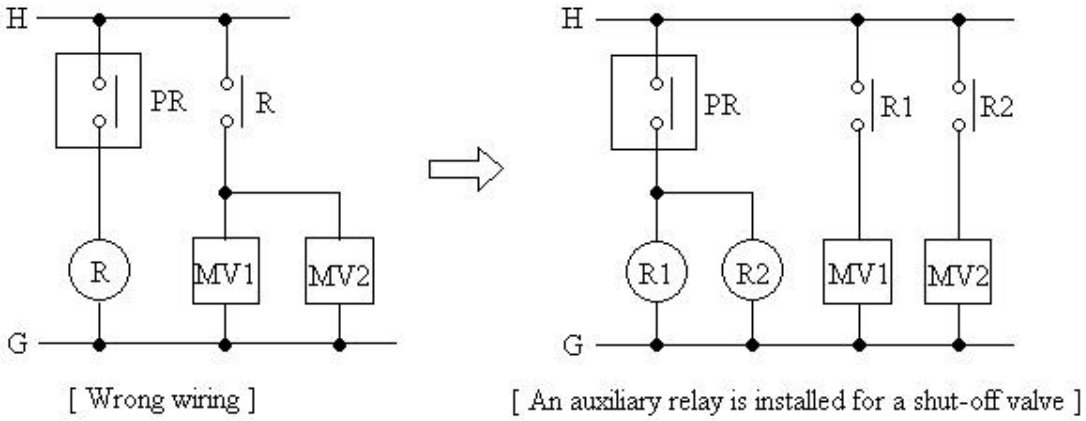


Figure: Correct wiring of auxiliary relays

? Power supply (hot, ground) to Protectorelay

a. About power supply

The power source of 100/200 Vac is supplied from a transformer mounted on a street electric power pole with this voltage that is stepped down from 6,600V transmission lines. In order to secure the safety, the secondary side (100/200Vac) of the transformer has one wire for grounding (GROUND) as low electric potential and the other wire for high electric potential side (HOT).

b. Accident example by wrongly handled power source connecting method (The Japan Gas Association)

The following example was the actual happening of an explosion accident by combustion equipment.

The diagram hereunder shows a wrong connection of the controller side of power supply with an inverse connection of the high potential side (H) and the ground side (G). When the insulation failure occurred by accident between the Protectorelay and the safety shut-off valve and the grounding (connection to earth) was made, the earth current flew into the safety shut-off valve at the same time the electric power was turned on and made the safety shut-off valve open to push a large amount of unburned fuel from the burner. Under this condition the pre-purging necessitated air flowing into the combustion chamber to create the explosive mixture which eventually caused explosion at the moment of ignition start.

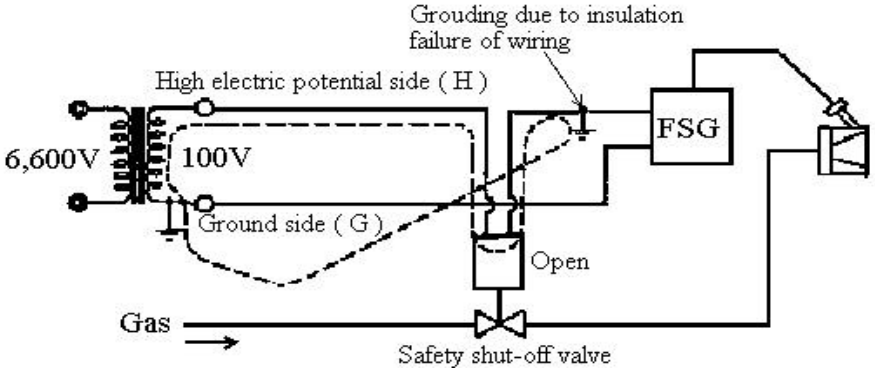


Figure: Wrongly handled power source connection method

c. Correctly handled power supply connection method (The Japan Gas Association)

If the correct connection is made between the high electric potential side (H) of the control side power source and the ground side (G), the earth current can not flow into the safety shut-off valve so as to cause the valve opening even though the insulation failure occurs. Consequently, the valve closing prevents the fuel flowing into the combustion chamber and maintains the safety.

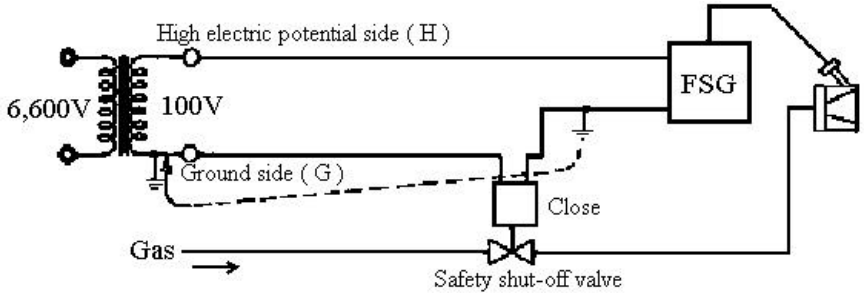


Figure: Correctly handled power source connection method

5)Safety Shut-off Valve

The safety shut-off valve in flame safeguard system has the very important role of fuel supply and quick stoppage of the fuel flow by a signal sent from the Protectorelay, and is incorporated with the following functions:

a. Instantaneous shutdown

When the burner firing stops during the operation of combustion equipment, the safety shut-off valve must quickly shut down the fuel flow. The valve closing time of the safety shut-off valve under the liquid flow gas valve classification is specified as less than one second.

b. Sufficient closing power

Normally, a valve which is installed in a half way of piping has the functions to pass the fluid , shut it off and adjust flow volume. Although the safety shut-off valve is designed to emphasize the shut-off function among these functions, it must be installed with careful consideration on the supply pressure of the combustion equipment as well as the sufficient closing power in its actual usage.

c. Stru cture requiring no power source (air pressure) to close or stop the flow

A safety shut-off valve must automatically shut off the fuel passage with the self-power of spring housed in the valve when its electric power, air pressure or other source is cut off.

d. Structure not to be locked at an open position

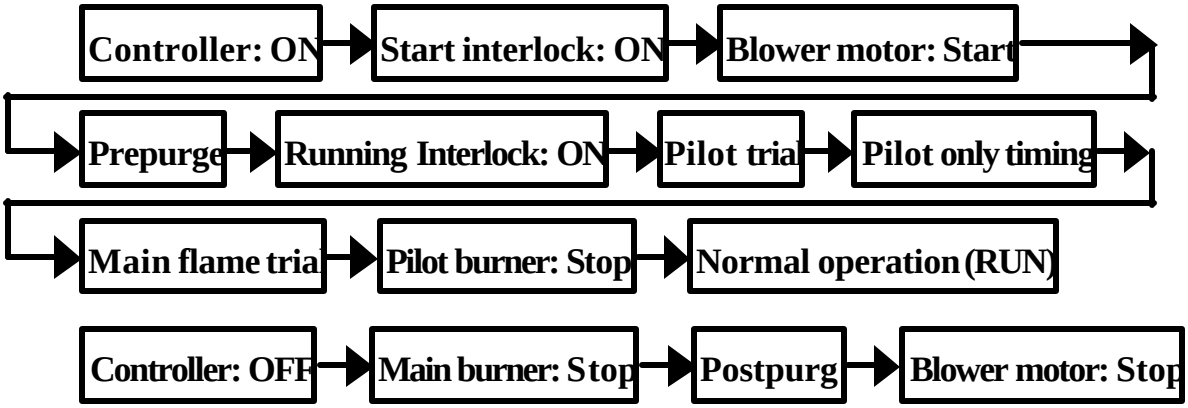
Some valves have such a structure not to close automatically due to its locking at an open position with the mechanism of manual opening / closing. This kind of locking structure can not be accepted for use as a safety shut-off valve.

e. Structure to be locked at a closed position

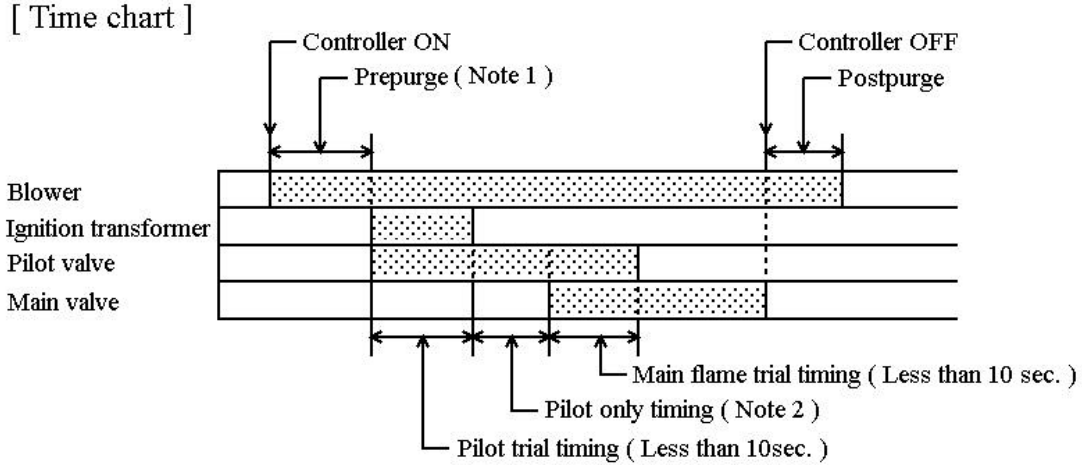
Some valves with the structure to be mechanically locked can not open in just receiving the electric power at the closed position. When the electric power is turned on, it can open again by having its reset lever reset with the manipulating lever. This idea is resulted from a concept of making the manual resetting after drafting countermeasure to cope with causes of abnormal explosions.

3. Operating sequence of combustion equipment (The Japan Gas Association)

The following sequence is a typical one on how a sequence is operated in combustion equipment depending on flame safeguard systems : (The sequencing and each timing differ depending on the models of Protectorelays.)



[Time chart]



Note1: Prepurge timing

- Timing to circulate air as much as more than 4 times the air volume of the combustion chamber.(Depending on the structure, the gas flue volume is added.)
- Pre-purge must have more than 50% air flow of the air volume required in the maximum combustion condition.
- Open fully the exhaust air damper during pre-purging.

Note 2: Pilot only timing

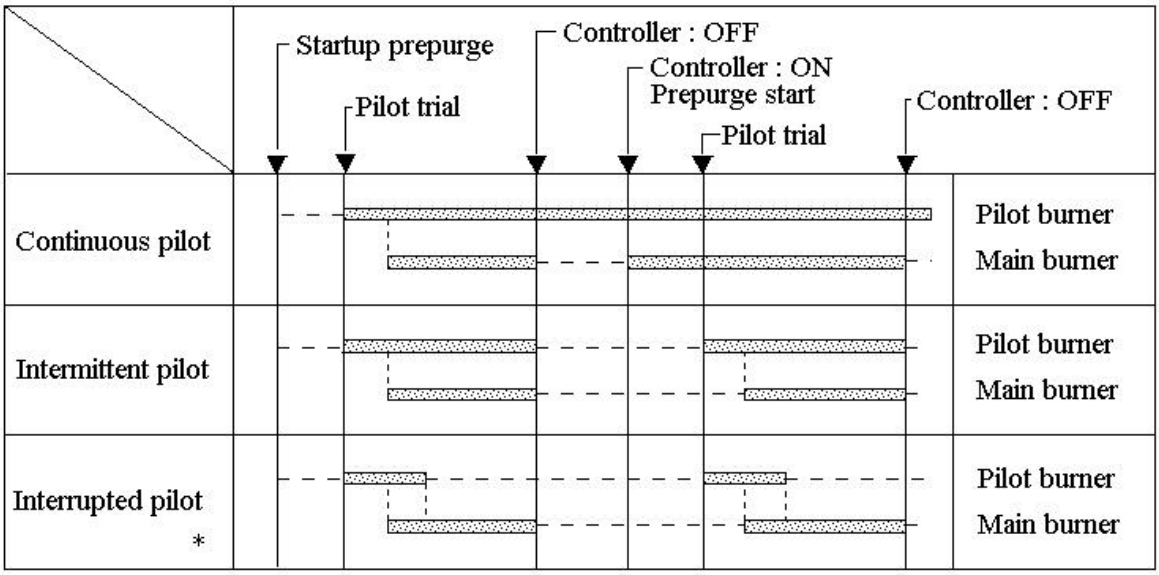
- Flame response + 1 second
- Flame response is the time required from the moment the firing stops(burner flameout) to the start of safety shut-off valve closing.
- Each country concerned specifies the flame response time as follows:

  The Japan Gas Association (Safety Engineering Directives of Industrial Gas Combustion Equipment) --- Less than 3 seconds

  FM, UL (U.S.A) ---------- Less than 4 seconds

DIN (Germany)---------- Less than 1 second

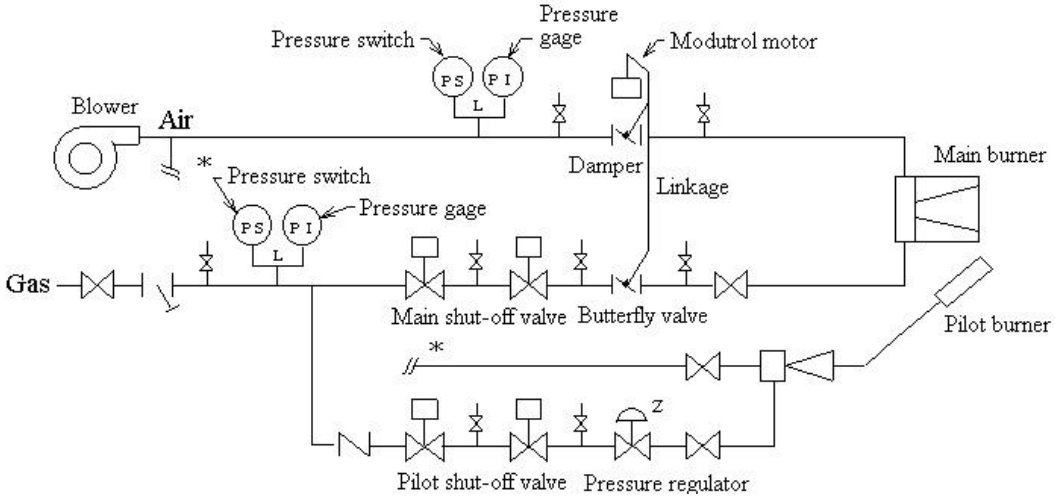
The following three(3) types are available for pilot burner and are categorized for application depending on the equipment. (The Japan Gas Association)



* The adoption of an interrupted pilot is preferable in case of more than maximum combustion rate of 350 k watts

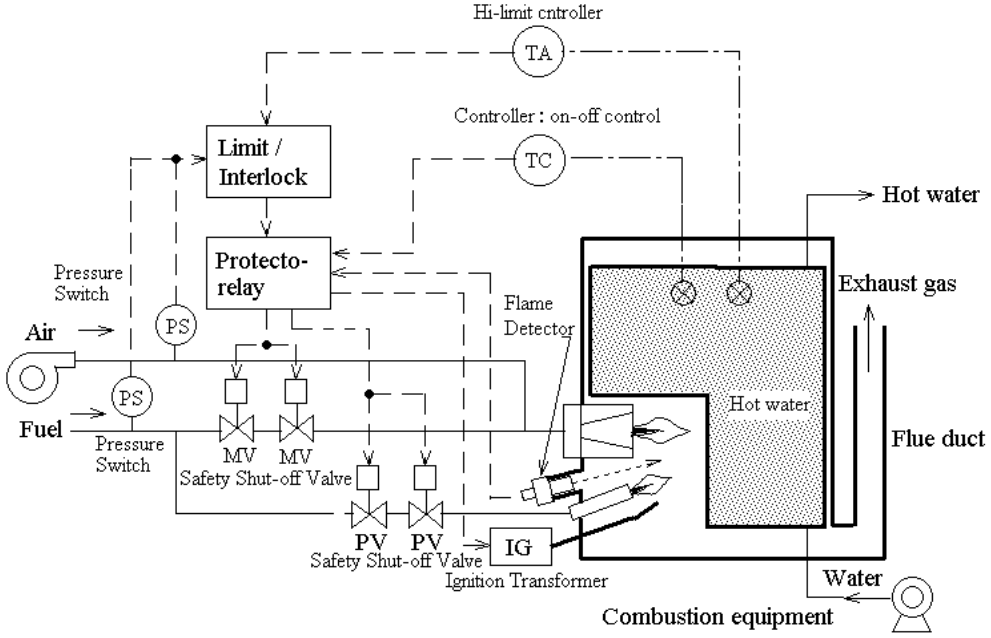
Actual Case of Combustion System

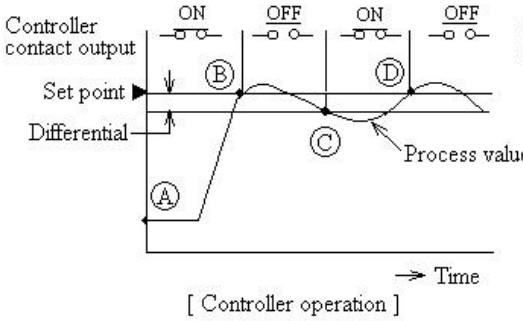
In case of automatic ignition by low pressure gas supply (The Japan Gas Association)



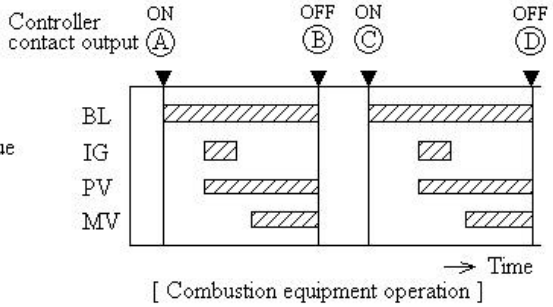
Examples of combustion equipment having employed the on-off control controller

- **Small hot water boiler : Temperature control**
- **Small steam boiler : Pressure control**

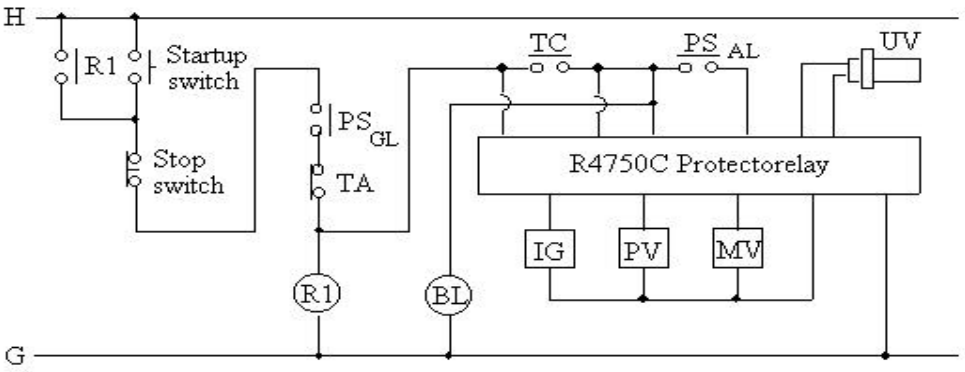




[Controller operation]



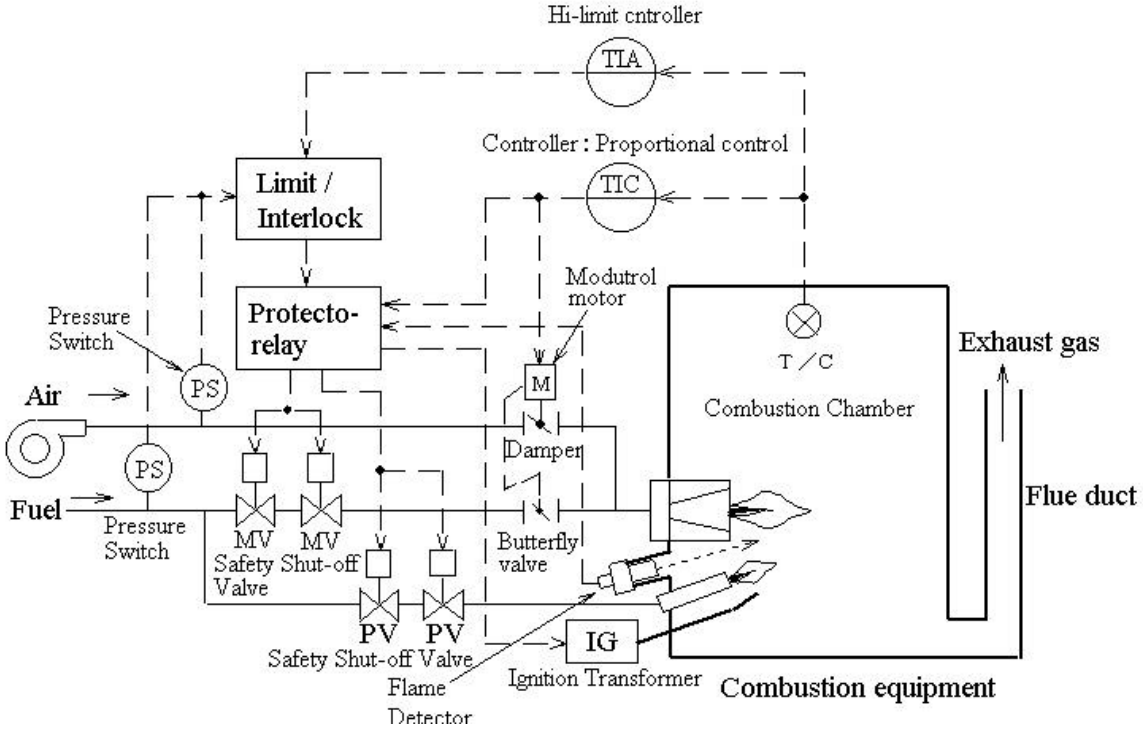
[Combustion equipment operation]

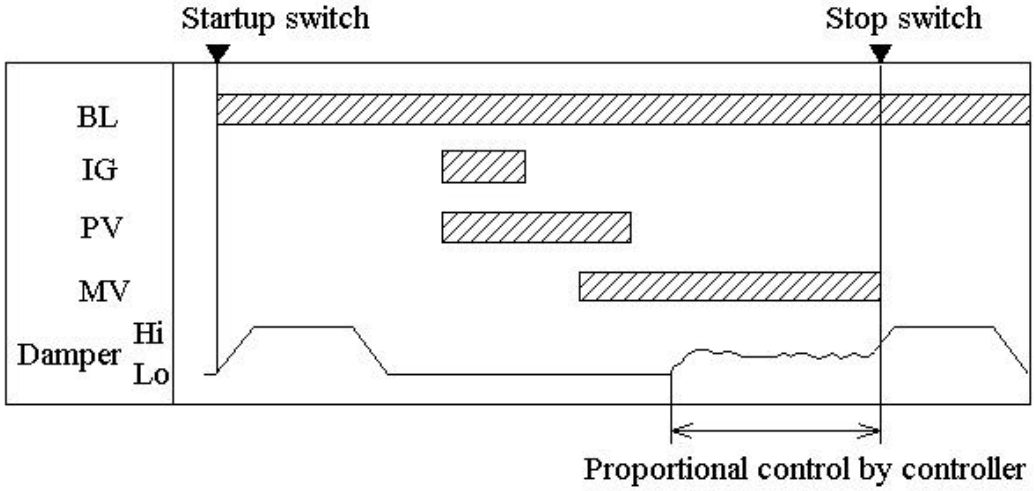


[Application example of R4750C Protectorelay]

Examples of combustion equipment having employed the proportional control controller

(Large combustion furnace, Oven)





[Operation of Combution devices]