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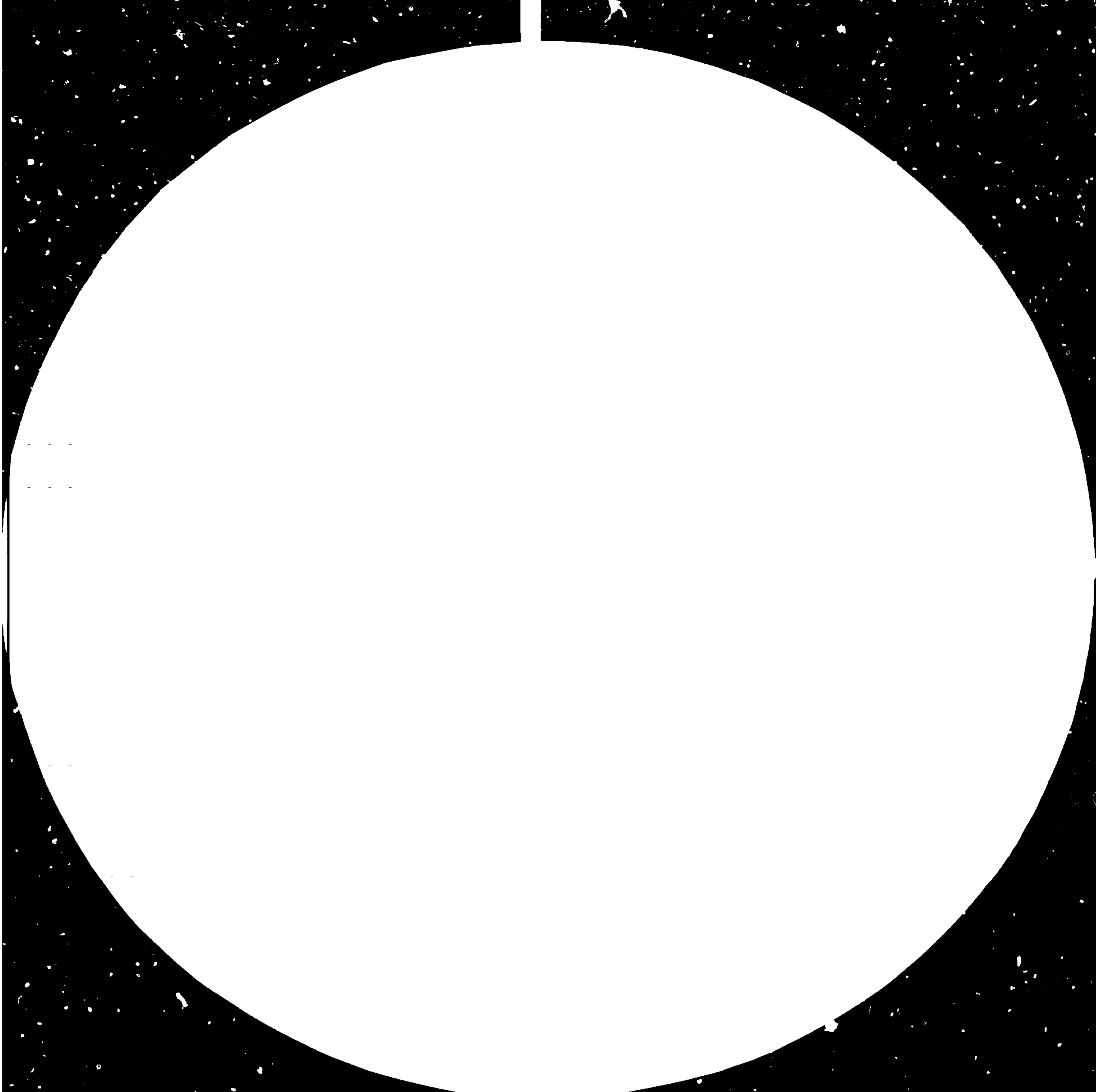

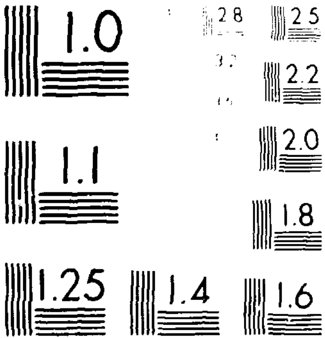
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ENVIRONMENT AND PLANT PROTECTION IN THE OPERATION OF CENTRIFUGAL COMPRESSORS OF A LARGE AMMONIA PLANT *

by

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It is well known that the chemical process designer must set limits to the plant operating conditions: for each equipment and piping item the design conditions, such as temperature, pressure, operating speed, allowable fluid composition etc. must be clearly specified. On this basis the materials of construction are selected and the mechanical design of all the plant components is performed according to internationally accepted standards and codes.

The specification of the design conditions is the first duty of the designer after the definition of the process flow sheet and material and energy balances.

Even when the designer assumes "liberal" safety margins over the expected operating conditions (but today said margins are often only "reasonable") it is possible that, in some instance, one ore more process variables go bayond the control of the operator and/or the instrument loops and reach values which could be dangerous for the plant safety. This situation is an "emergency" which must be handled properly and in due time in order to avoid catastrophic failures and big plant damages.

The usual mechanical safety devices (relief valves, excess flow valves, rupture disks, etc.) in general requested by codes must be installed, but they do not offer enough protection to the plant. These devices should be considered as the last defence line because their intervention most often causes new problems. A relief valve blowing means an incontrolled release of process fluids to the atmosphere which might cause a new emergency in the environment or in other sections of the plant.
We traced briefly the origin of the safety problem to pinpoint two important factors :

- the compliance with the most modern and sophisticated standards and codes and the best engineering practice are necessary, but are no substitute for a substantial operating know how.

- the elimination of any potential risk, or at least a high safety level can be obtained only trough a detailed and careful "emergency analysis". This analysis in turn is based on a great deal of operating know how, a deep knowledge of the process, of the operating limits of the components and of the functional links between the sections of the plant.

Therefore the emergency analysis is to be considered a key step in the plant design and must be identified, scheduled and implemented within the engineering activity in order to obtain the most effective results.
The analysis may be divided into 3 steps :

i) Emergency identification

A working party is set up, headed by a senior process engineer, comprising all the designers who developed the P & I diagrams and operating people with past experience of startup and operation of similar plants.
The party must try to find out all the emergencies that might occur in the plant and in individual equipment and to define, for each emergency, the sequence of events which will follow on the plant.

This exercise in the case of a large ammonia plant is difficult and cumbersome: we found that it was easier to start from the rear end of the plant and proceed backwards towards the front end including in the analysis increasingly larger sections of the plant. The first question to answer is: "what happens if the ammonia transfer pump to the storage tank stops?".

The result of this first step of the analysis will be a list of the emergencies, each one identified by a first cause and the related final effects.

ii) <u>Emergency classification</u>

The emergencies must be then classified and grouped according tho their level of hazard: a commonly accepted classification is the following :

CLASS	HAZARD	RESULTING IN
1st	Explosion Fire Emission of dangerous materials Excessive noise	Injury to personnel of environment.
2nd	Failures	Plant damage
3rd	Partial or total shutdown	Production losses

iii) <u>Resolution of the emergencies</u>

Considering the problem as stated above, it is readily understood that the consequences of at least some 3rd class emergencies have to be accepted, i.e. some occasional and limited loss of production: to avoid these losses every equipment item should be duplicated and instrumented for automatic startup in case of failure of the operating one. It is apparent that such a provision cannot be economically justified for equipment which is very reliable and at the same time very costly.

Therefore in most of the cases the problem to be solved is the minimization of the damage and the goals are the following :

- all the emergencies potentially belonging to 1st and 2nd class must be reduced to 3rd class.
- the plant must be brought into steady and safe operating conditions as near as possible to full load in order to minimize the time needed to restore the regular operation and consequently the production loss.

In order to reach these objectives effectively in each emergency situation the following actions are needed :

- check the plant instrumentation to be sure that all the alarm devices needed to give the operator an early warning of the ouset of an emergency are provided.
- find out which is the most convenient set of operating conditions where to stabilize the plant; to this purpose material and energy balances of the portion of the plant remaining in operation must be recalculated in order to verify that the selected condition is stable and safe and to evaluate, in our case, the required load of the auxiliary boiler or the demand of import steam.

- define the sequence of actions to be performed in order to reach the desired plant conditions.
- verify that the plant is provided with all the necessary hardware (such as sensors, controllers, valves, etc.) required to perform said actions.
- evaluate the maximum time allowable for the completion of each action with the purpose of deciding if any action and which one may be left to the care of the operator.
- develop conceptual automatic trip diagrams, which will be completed by instrumentation engineers.
- verify the logics of the automatic trip sequencies i.e. their consistency and the constraints imposed to plant startup procedures and load changes.
  During this part of the study it is decided which automatic trip sequencies must be excluded (set "manual") during startup and planned shutdowns.
- collect the results of the work described above in a complete and clear report in which all the actions left to the operator's care are clearly identified. Said actions will be thoroughly described in the operating manual.

We spent some time in describing our safety audit procedure because we applied it during the design stage of our latest ammonia plant (Ferrara, Italy, 1500 MTPD) and the results obtained in terms of plant reliability in 3 years of operations were rewarding.
In the following we will limit ourselves to the specific subject of emergencies caused by and/or affecting the operation of centrifugal compressors.

Syngas compressor

We will begin with this machine which is by far the most critical piece of equipment of the whole plant, because it handles a dangerous gas at high pressure, uses the largest power and rotates at the highest speed. The result of our analysis has been the adoption of 3 different automatic trip sequencies related to the 3 emergengy classes, shown in simplified form in fig. 1, 2, 3.

Fig. 1 illustrates the trip sequence against 1st class emergencies: the objective is to avoid any discharge of syngas to the environment due to loss of seal at the ends of the compressor casings.

The sequency stops the machine, isolates it completely from the process and from the steam mains and relieves the pressure completely in all the casings.

The syngas producing plant upstream is kept in operation venting the gas to the flare stack by means of a pressure controller located upstream the methanator (the hydrogen stream needed for desulphurization is now drawn from methanator outlet).

On the steam network the by pass valves of the HP turbine open automatically discharging on the MP main header; these valves are provided with installed spares and are operated in split range by the pressure controllers of both HP and MP networks; during regular operation one of these valves is always slightly open, letting down some 20 TPH of steam on a total of about 370 TPH. In our plant the auxiliary boiler is feeding the HOP network and for this reason we felt that a safe, steady and foolproof feed of the MP main was of the utmost importance for the safety of the reformer furnace.

Downstream in the synthesis loop the refrigeration compressor is automatically tripped by minimum suction pressure on 2nd stage, which draws gaseous ammonia from the final chiller of the HP synthesis loop. By this means negative gage pressures on 1st stage suction are avoided.

The following actions are left to the operator's care :

- reduction of the load of the auxiliary boiler down to the level required to close the valve venting steam to the atmosphere from the HP main
- shifting all the BFW flow to the shift conversion water heater to avoid premature boiling (in regular operation, BFW is heated in parallel in said exchanger and in an economizer at the ammonia converter outlet)
- closure of the synthesis loop purge gas valve
- shutdown of the ammonia product pump, which otherwise would run completely bypassed under level control
- trimming the quench water sent to the HP steam superheater located on the reformer flue gas
- any other action relevant to the shutdown of the machine as per manufacturer instruction.

The 2nd class emergencies are handled by the trip sequency illustrated in fig. 2. This sequency is automatically started by abnormal mechanical operation of the machine (e.q. high thrust, high vibrations): as such, it is the machine self protection. Also process variables which give an early warning of a probable shortage of steam on the MP network operate the same sequence : in such way the process changes needed to insure enough MP steam for the protection of the reformer are anticipated.

The sequency stops the machine, isolates it from the synthesis loop whilst the suction valve is kept open.

The effects on the balance of the plant as well as the actions left to the operator's responsibility are the same as described above.

Fig. 3 illustrates the sequence provided to cope with 3rd class emergencies.

This sequency is automatically started by upstream emergencies such as air compressor trip, CO_2 removal plant or methanator trip, or downstream, such as refrigeration compressor trip, high level in HP ammonia separator. The same sequence may be manually activated by the operator in order to shut down the synthesis loop.

This sequence does not stop the machine but keeps it running completely by passed and isolated on the discharge side, under manual remote control.

After the automatic or manual start of the sequence the operator must reduce the speed to the value suggested by the manufacturer for this unloaded condition and them perform the other duties mentioned above.

In our Ferrara plant the auxiliary boiler provides steam also for a 1500 TPD urea plant (both driving and process).

The ammonia feed is drawn from a large atmospheric storage tank connected in series: therefore it is possible to produce urea during short shutdowns of the syngas compressor and synthesis loop as long as CO_2 is available.

The firing of the auxiliary boiler in these cases is automatically adjusted to the HP steam demand of the CO_2 compressor driving turbine.

Natural gas compressor

The emergency analysis relevant to this machine is simular to the one of the syngas compressor.

In this case, however, we adopted only one automatic trip sequence which simply stops the machine.

In fact in our Ferrara plant this compressor is usually in stand by because the pressure of the natural gas pipeline is, for most of the time, high enough to feed directly the plant; should an emergency occur in the rare occasions in which the machine is running, the isolation and venting of the machine is the duty of the operators.

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We remind that the size of the valves to be operated is much lower than in the syngas machine. Accordingly there is not an automatic sequence for the 1st class emergencies, whose handling is left to the operator's responsability.
The consequencies of a plant feed loss are obviously very large on the whole plant: accordingly there is no advantage in unloading the machine instead of stopping it.
On the basis of the above considerations we adopted a single sequence to handle 2nd and 3rd class emergencies. As shown by fig. 4, the objective of the sequency is the protection of the machine from mechanical damage; moreover, it is automatically started in case of primary reformer trip because in this case the steam available is not enough to keep the compressor running. The immediate effect is the closure of the steam throttle valve and the machine stops; this cause the intervention of the primary reformer trip sequence due to minimum feed flow and the consequential shutdown of the whole plant.

Process air compressor

This machine cannot conceivably cause 1st class emergencies. Even in this case there is no difference between the effects of 2nd and 3rd class emergencies and accordingly a single automatic trip sequence has been provided for the protection of the machine (see fig. 5); the sequency is also started in case of primary reformer trip. The immediate consequence is the machine stop, which operates the process air trip sequence, which in turn causes the isolation of the CO_2 removal section and the unloading of the syngas compressor.
In this emergency the CO_2 compressor of the urea plant and by consequence the whole plant are automatically stopped due to lack of steam.

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Refrigerating compressor

This machine is directly connected to the synthesis loop chillers and to vessels containing liquid ammonia by large diameter pipes; it is impossible, to vent the compressor in case of loss of seal. Accordingly the 1st class emergencies cannot be handled by a "stop and vent" trip sequence, but only by insuring in any case, including electric power "blackout", the circulation of sealing oil.

An unloading sequence has not been provided for this compressor for two reasons :

- avoid any risk of vacuum on the 1st stage suction
- save steam during synthesis loop trips which can be more conveniently used to drive the CO_2 compressor keeping in operation the urea plant.

Accordingly for this machine a single automatic trip sequence has been provided which stops the machine keeping it under gaseous ammonia pressure without isolating it from the plant: this is feasible because all the piping involved and the casings of the machine were designed for a pressure of 20 kg/cm^2 g.

Fig. 6 illustrates the automatic trip sequence provided for this compressor; it is started by the usual machine protection devices and by a minimum 2nd stage suction pressure switch, i.e. by any stop in the gas circulation in the synthesis loop. Furthermore, the operator starts this sequence by pushbutton when the ammonia product pump stops and the automatic start sequence of the spare pump fails (a warning to the operator being given by an alarm of very high level in the atmospheric ammonia let down tank.

The trip of the refrigerating compressor causes the unloading of the syngas compressor because in our plant it is impossible to operate the synthesis loop even at reduced load without refrigeration.

The actions left to the operator's care are the same as in the case of syngas compressor shutdown.

Loss of utilities

We fin. convenient to complete this survey of the safety procedures related to the compressors operation in a large ammonia plant with a discussion of emergencies arising from shortage or complete loss of utilities.
Describing the automatic trip sequencies of the single machines we already covered the case of steam shortage. During regular operation the pressure on each steam network is controlled as follows :

- LP steam network: a pressure controller operates a valve which draws steam from the MP main and desuperheats it; a second controller vents steam to the atmosphere in case of high pressure;

- MP steam network: a flow controller keeps constant the flow of steam extracted from the syngas compressor driving turbine; a pressure controller operates in split range a set of valves which draw and desuperheat steam from HP main; a second controller vents steam to the atmosphere in case of high pressure;

- HP steam network: a pressure controller acts on the firing of the auxiliary boiler; a second pressure controller operates the let down valves discharging into MP main mentioned in the point above to relieve the excess of HP steam, eventually a third pressure controller vents steam to the atmosphere in case of high pressure.
  With this flexible arrangement we obtained a satisfactory control of the steam system. Furthermore in order to increase the plant safety, four pressure switches on the MP steam network with decreasing set points trip in case of low pressure the big machines starting from the refrigerating compressor and ending with the natural gas compressor. This is done in order to insure maximum availability of steam for the reformer in any situation.

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The loss of cooling water causes the loss of vacuum in the steam condenser, which in turn starts the trip sequencies of all the compressors.

A more detailed analysis is in point for the case of loss of electric power, or "blackout".

During regular operation the main oil pumps are operated by steam turbines: the electrically operated stand by pumps are connected to a preferential electrical network and are automatically started by the failure of the corresponding steam driven machine.

We must take into account that the machines need some electric power even in case of blackout because the rotors must be rotated slowly during the cooling to avoid permanent deformations and lube oil must circulate trough the bearings until they are cool enough; furthermore for the refrigerating compressor, is explained above, the oil seals must be mantained. Therefore, in order to insure a sage shutdown in case of complete loss of external power we have provided a small Diesel motor-generator set connected to the following services :

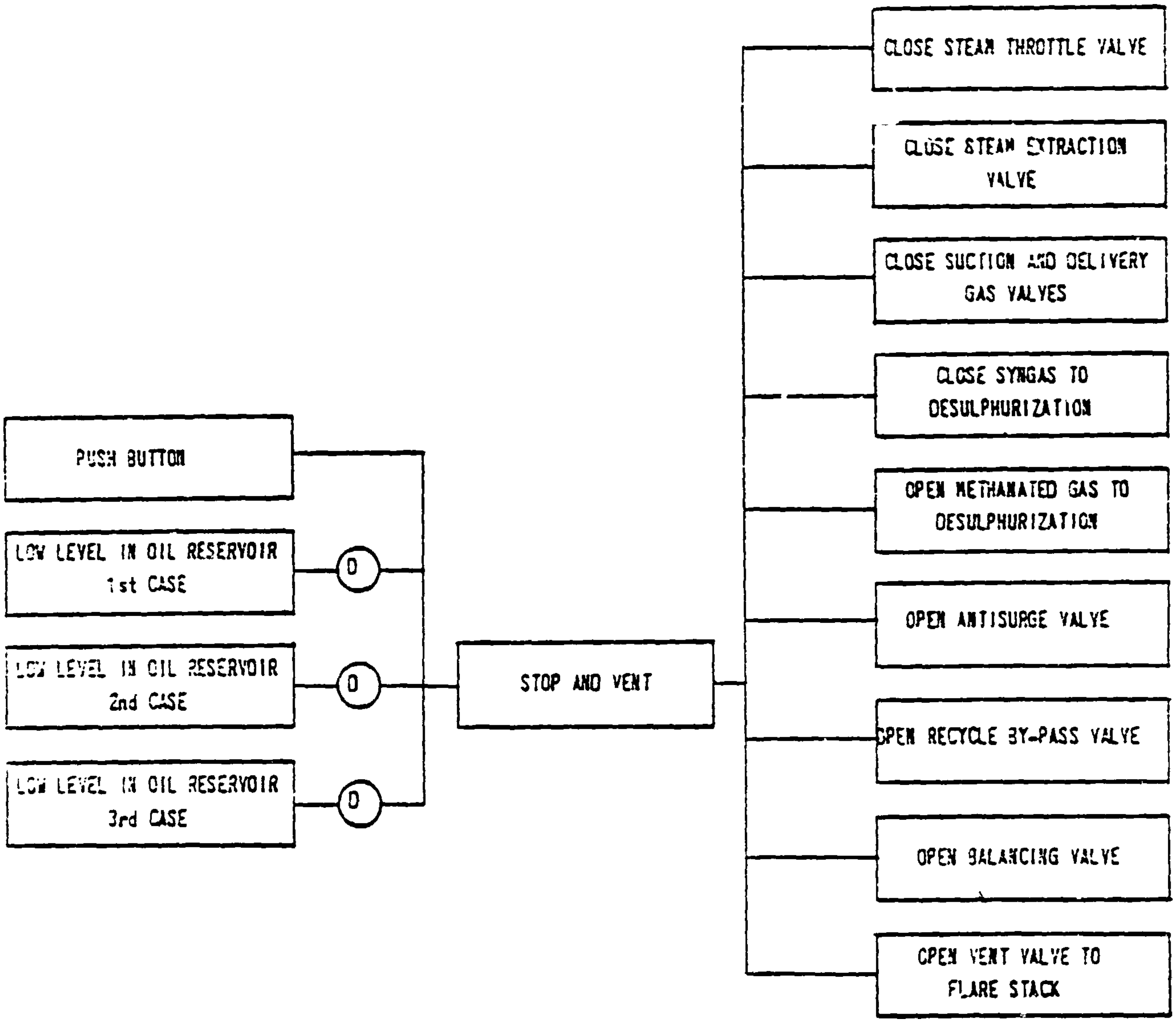
- virators of main turbocompressors
- oil pumps of refrigerating compressor
- small emergency oil pumps on each machine, sucking from the oil sump and feeding the main lubrification header.

These simple provisions allow us to face a blackout emergency without too much fear, taking into account another trivial but important provision: we store in an old ammonia converter, which was available at the site, high pressure nitrogen which is automatically fed to the instrument air network in case of loss of air.

This gives us the possibility of operating the control valves for a few hours in the worst conditions, thus avoiding all the risks connected with a "blind" shutdown.

SYNGAS COMPRESSOR

1st CLASS EMERGENCIES

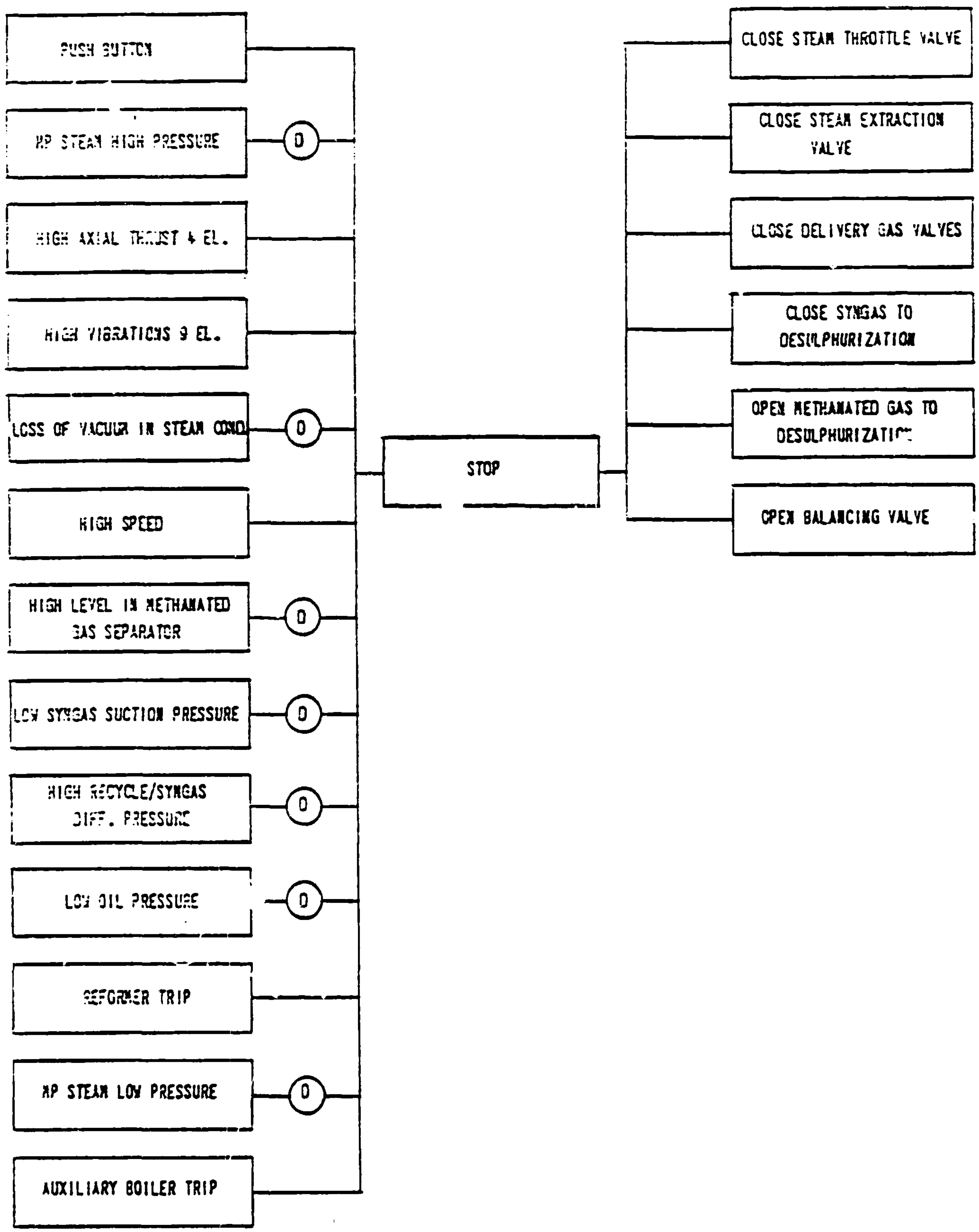


D = Delayed signal

- Fig. 1 -

SYNGAS COMPRESSOR

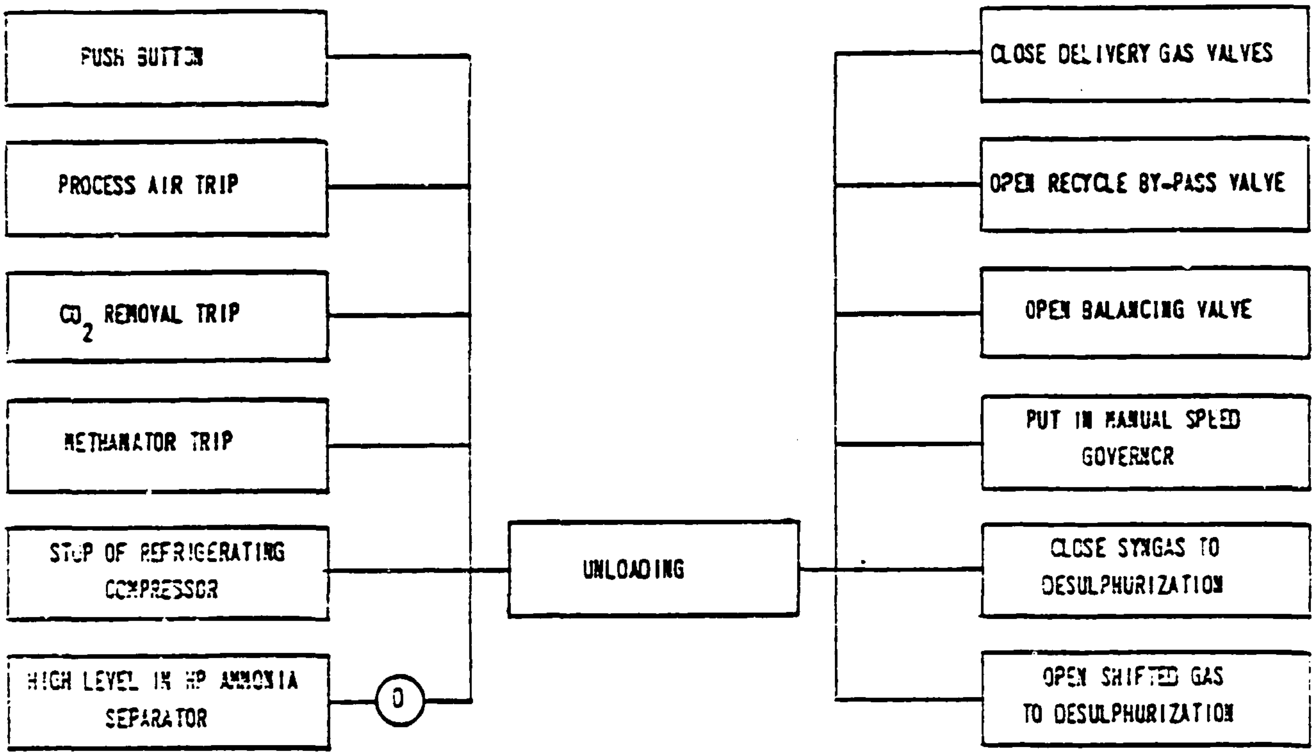
2nd CLASS EMERGENCIES



- FIG. 2 -

SYNGAS COMPRESSOR

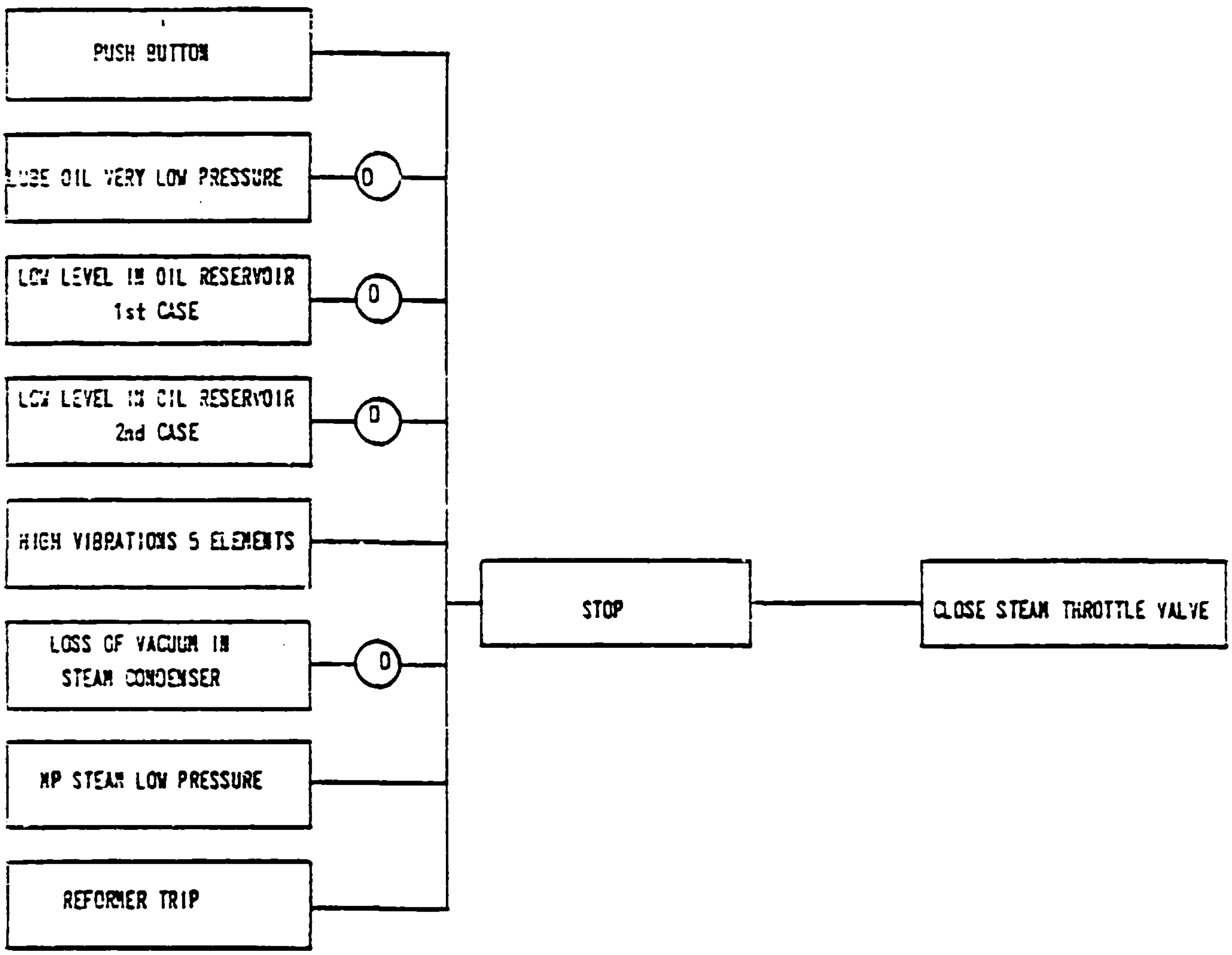
3rd CLASS EMERGENCIES



- Fig. 3 -

NATURAL GAS COMPRESSOR

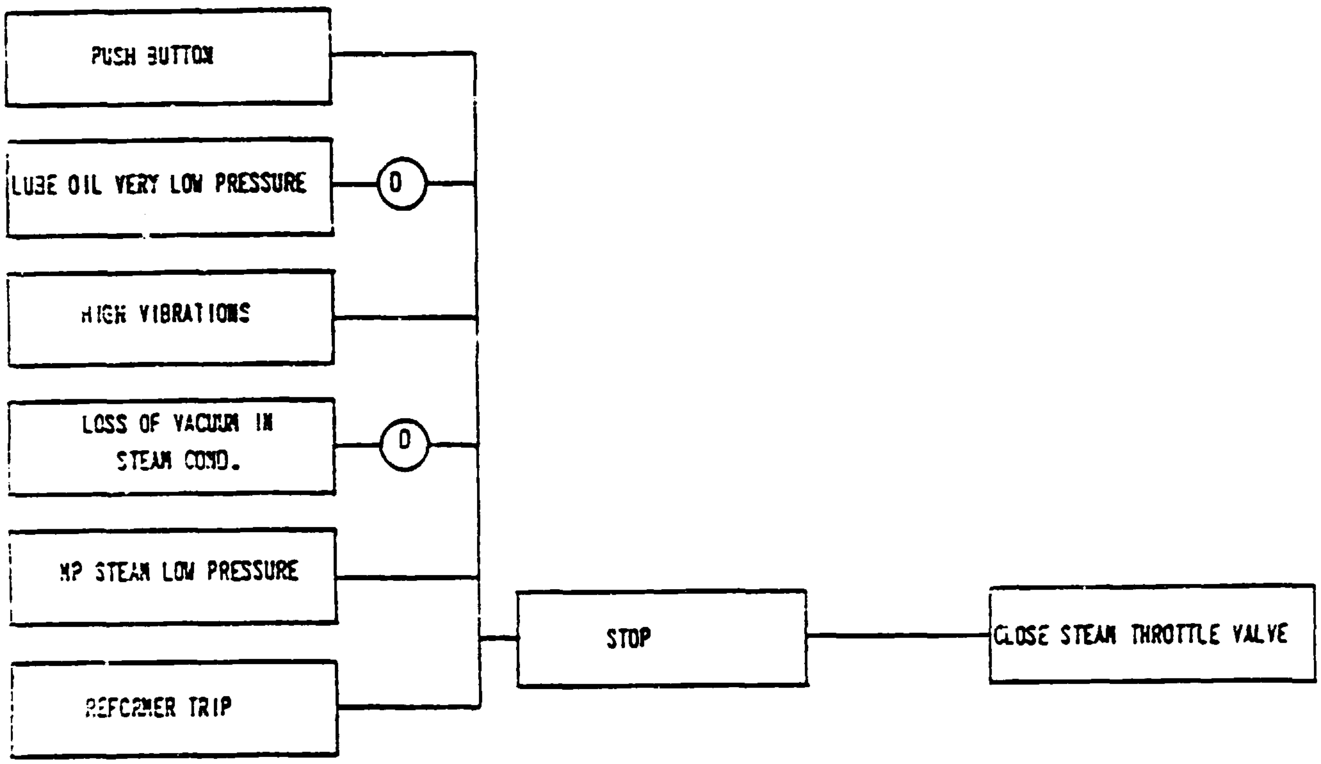
2nd AND 3rd CLASS SEQUENCIES



- Fig. 4 -

PROCESS AIR COMPRESSOR

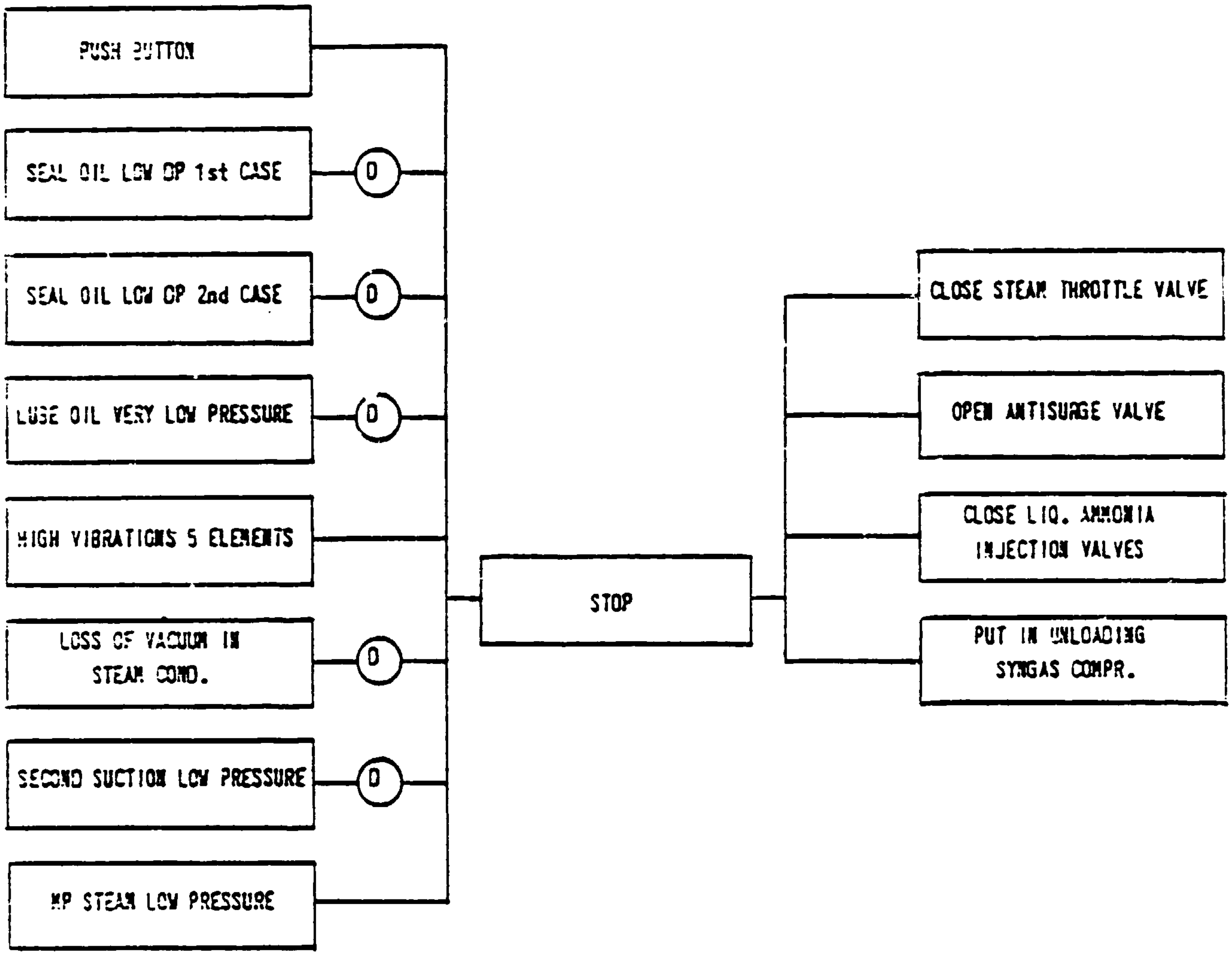
2nd AND 3rd CLASS EMERGENCIES



- Fig. 5 -

REFRIGERATING COMPRESSOR

2nd AND 3rd CLASS EMERGENCIES



- Fig. 6 -