PROCESS CONTROL PRACTICES

On-Line Trip Testing

An oil and gas fire that resulted when emergency stop valves failed to close was one of the factors that led ICI to regularly test the reliability of its trip systems.

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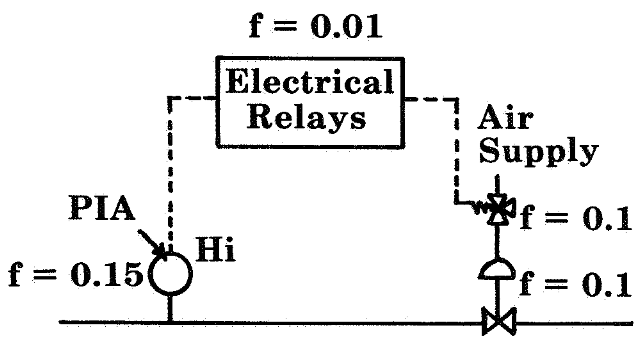
In the last two years there has been a strong move towards on-line testing of important trip systems on the ammonia plants at Imperial Chemical Industries, Billingham, England. Beginning with a concern for the protection of vessels, this effort was given further momentum when a major failure of the synthesis gas compressor occurred because of malfunction of its trip system.

Much work has gone into deciding frequency and methods of trip testing using simple reliability calculations as a guide. Minor modifications have been necessary to allow trip systems to be tested in a practical situation.

On-line trip testing is now carried out on both instrument and machine trip systems. On a number of occasions a trip system has been found not to work when tested. In such cases, the faults have been corrected and the trip system recommissioned in working order.



Failure rate of pressure switch = 0.15
Failure rate of electrical relays = 0.01
Failure rate of solenoid valve = 0.1
Failure rate of trip valve = 0.1
Assume entire system is tested one a month; i.e., $T = 1/12$

Then:

$$fdt = 1/2ft$$
$$= 1/2(0.15 + 0.01 + 0.1 + 0.1) \times 1/12$$
$$= 1/2 \times 0.36 \times 1/12$$
$$= 0.015$$

Figure 1. Calculation of fractional dead time for simple trip system.

There are two reasons why we have taken pains to develop on-line trip testing. The first concerns recent changes in internal ICI regulations that relate to the security of pressure vessels and furnaces. For many years ICI has had a code of practice for the inspection of pressure vessels at regular intervals. When this code was revised in 1972, provisions were added to require that any protective devices for the vessels be sufficiently reliable and adequately tested. At about the same time another code of practice was drafted, which dealt with the instrumentation designed to protect fired heaters from conditions that could cause serious damage to plant or injury to personnel. The result of these two documents has been to promote a detailed look at the design and testing of the instrument trip systems involved.

The second reason for developing on-line trip testing is concerned with problems with the oil system for the three main machines. These problems are described by J. G. Livingstone of ICI Billingham in a July, 1975, report, "Compressor Oil System Problems on Ammonia Plants."

In effect, these problems resulted in deposits in the oil, which eventually caused hydraulic trip actuators to stick and, therefore, not to operate when required to do so. As a consequence, a major incident occurred on one plant in January, 1974. During an upset caused by instrument problems on the front end of the plant, the synthesis gas compressor was tripped by push button from the control room. The trip valves on the delivery and recycle lines operated correctly, but because of oil deposits in the trip actuators, neither the high nor the low pressure emergency stop valve closed. As a result, the machine continued to run against closed delivery and recycle valves, and quickly suffered severe mechanical failure, followed by an intense gas and oil fire. Because of this incident, a detailed study of the reliability of the machine trip systems was carried out, leading to a number of modifications and a move towards regular trip testing.

Fractional dead time

The trip systems that are tested regularly are:

1. Those which directly protect vessels; but only where they are the last line of defense (i.e., a high pressure trip is not included if it is backed up by a relief valve).
2. Those which protect fired heaters from serious damage to equipment or personnel.
3. Those which protect the main machines.

The standard which has been set is to make these trip systems as reliable as existing relief valves, and the method of measuring reliability that has been used is the concept of fractional dead time (*fdt*).

The fractional dead time of a system or a piece of equipment is the fraction of the year it is out of commission. In the context of this article that means in the fail to danger condition. For example, if a system has a failure rate (to danger) of f times per year, and the length of time between testing is T years, then on average it will be in the fail danger state for $\frac{1}{2}T$ on f occasions/yr. In other words, it will have a $fdt = \frac{1}{2}fT$ yr./yr. Figure 1 shows the calculation of *fdt* for a simple trip system.

Data from one particular source within ICI shows that relief valves, which are tested every two years, fail at a rate of $f = 0.015$/yr. Hence, the *fdt* for these devices $= \frac{1}{2} =$ 0.015.

The intention then is to design trip systems to have a suitable failure rate f, and to test them at a suitable frequency T, such that they have an $fdt = 0.015$. In practice of course, this is a simplified and idealistic approach, particularly on existing plants, where the design of trip systems is largely fixed, and trip testing at frequent intervals produces serious practical problems. However, it has been possible with a certain amount of modification, and a careful look at testing methods, to produce a system which comes very close to the required standard.

On each of the ICI ammonia plants there are 55 trip initiators covered by the philosophy discussed above and thus requiring regular testing. Of these, 44 are instrument initiators and 11 are hydraulic initiators attached to the machines. Table 1 lists the trip systems concerned.

The practice of trip testing is a compromise between the ideal philosophy and the practical problems of testing. It has been arrived at by trial and error, and in general, it operates as follows:

All instrument trip systems are being modified by inserting an electrical defeat after each initiator that allows the system to be tested in two halves. Figure 2 shows a typical trip system. Each instrument initiator is tested up to the defeat at a frequency of once per month, using the most realistic method of simulating a trip condition that can be achieved.

The second half of the trip system, from the defeat (electrical switch which breaks the trip circuitry allowing the initiator to be tested without activating the final element) up to the trip valve, can be tested by inserting a chock that allows the valve to make a small movement, and then initiating a trip by pushbutton. We have departed from this method, however, because of the number of chocks involved and because many of the trip valves are also control valves. Instead, calculations have shown that some minor modifications to the trip system (usually an extra solenoid valve and some repiping) can achieve the required reliability by checking valves fully only at shutdowns, provided the valve can be tested for movement once a month. This is relatively easy to do. Trip valves can be

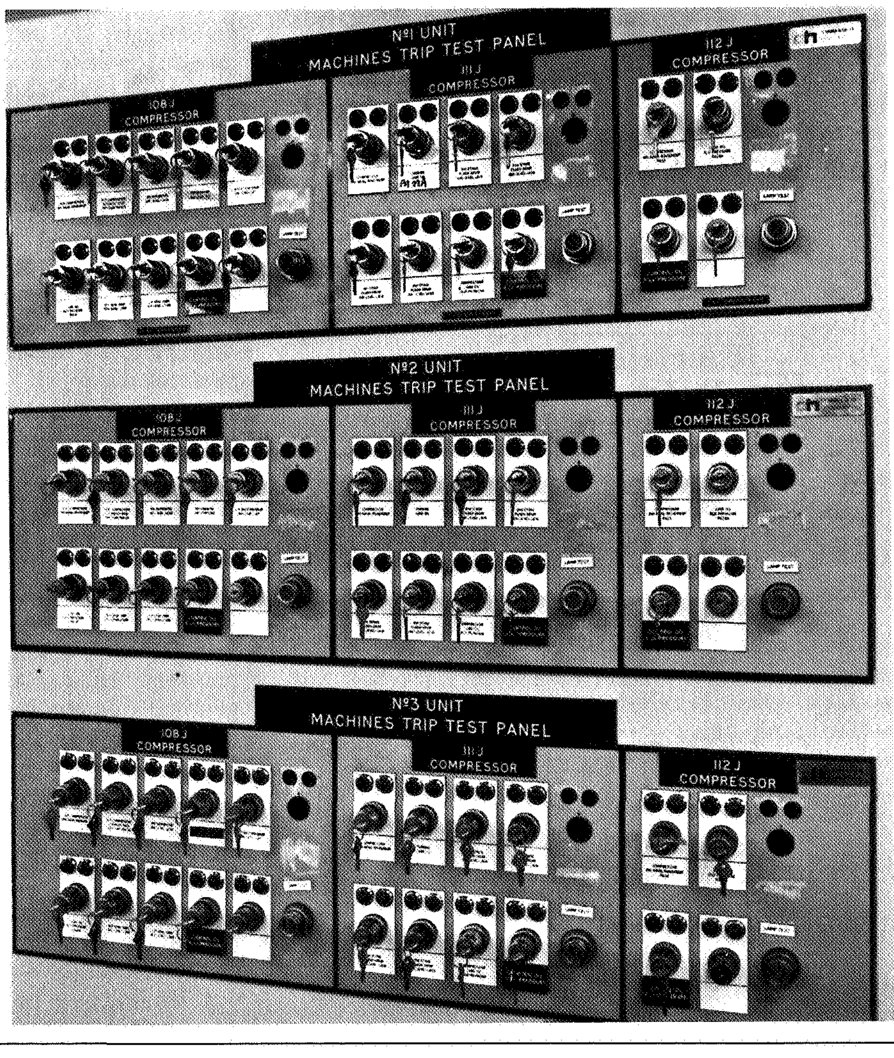


Figure 2. Instrument trip test panel for three ammonia plants.

Table 1. Trip systems that require regular testing.

1. Vessel Protection Trips
   - High level in steam drum blowdown vessel
   - High level in product flash drums
   - High air flow to CO_2 absorber
   - Low gas flow exit CO_2 absorber
   - High temperature exit, secondary reformer
   - Nitrogen blanket on CO_2 stripper
   - Methanator catalyst high temperature

2. Machine Protection Trips

Air Compressor

Trip	Initiators
Compressor axial movement	Instrument Initiators
Low lube oil pressure	
Low control oil pressure	
Turbine overspeed	Hydraulic Initiators
Turbine axial movement	
Low lube oil to turbine	

Refrigeration Compressor

Trip	Initiators
High level in first through fourth stage flash drums	Instrument Initiators
Turbine low lube oil pressure	
Compressor low lube and seal oil pressure	
Low control oil pressure	Hydraulic Initiators
Turbine overspeed	
Turbine low lube oil pressure	

Synthesis Gas Compressor

Trip	Initiators
Low level in high pressure seal oil tank	
Low level in low pressure seal oil tank	
High level in low pressure case suction drum	Instrument Initiators
High level in primary separator	
Low control oil pressure	
Low lube oil pressure	
High thrust bearing temperature, high pressure compressor	
High compressor axial movement	
High pressure turbine overspeed	
Low pressure turbine overspeed	Hydraulic Initiators
High pressure turbine axial movement	
Low pressure turbine axial movement	
Low lube oil pressure	

3. Furnace protection trips
   - Primary reformer high furnace pressure
   - Low combustion air pressure
   - Low pressure natural gas fuel to preheater
   - Low pressure tail gas fuel to preheater
   - Low pressure natural gas to superheater
   - Low pressure tail gas fuel to superheater
   - Low pressure natural gas fuel to startup heater
   - Low pressure fuel to primary reformer
   - Low pressure fuel to primary reformer rows 1 through 8
   - Low flow feed to preheater
   - Low flow air to preheater
   - Low flow syn gas to startup heater

moved slightly by altering the air supply pressure, and those that are also control valves can usually be assumed to be moving if control is being maintained.

This approach leaves a small part of the electric circuit in the middle of the system untested, but this is sufficiently reliable provided it is tested at shutdowns it adds very little to the fractional dead time.

A typical reliability calculation for the above approach, outlined in Figure 3, demonstrates the reliability achieved with the alternative assumptions that shutdowns occur every six or 12 months.

Hydraulic trip systems. The failure rate statistics available for hydraulic mechanisms show a very high reliability, and based on these data testing every third month is sufficient to achieve the required *fdt*.

However, these figures apply to systems operating on clean oil and cannot be simply translated to a system where the oil is dirty. For this reason, we have set up a system to test hydraulic systems at least once every three months, but at the plant manager's discretion, this is done more often when the oil is known to be contaminated.

Emergency stop valves. There have been a number of occasions when the hydraulic system has worked correctly, but one of the emergency stop valves failed to operate. Unless these valves are duplicated, complete testing is impossible except at shutdowns. However, it is possible to demonstrate that the valves are not seized by moving them slightly with the hand wheel. In this case, there are no reliability figures to indicate a frequency of testing.

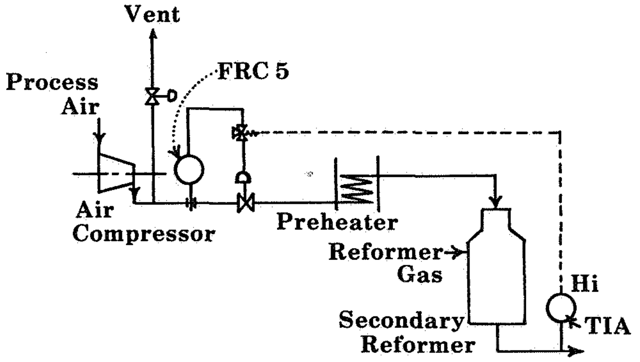
Trip test procedures. To minimize the chance of mistakes being made while carrying out trip testing, both instrument and hydraulic trip tests are carried out using written step-by-step procedures with tick boxes at the side of each step. An important part of each test is the *emergency procedure*, that is, the action that should be taken if a real trip condition arises while the trip system is out of action. This is printed at the top of each test procedure.

The implementation of on-line testing has been spasmodic because the development of the procedure has been a learning process, and because of the need to wait for the modifications that facilitated trip testing. Initially, an attempt was made to do regular on-line testing of the systems associated with pressure vessels by chocking the final trip valves and then simulating trip conditions at the initiators.

Some modifications were needed

To conduct on-line trip testing, modifications have been made that allow the trip bar in the stop valves to be removed. The final hydraulic piston can then operate without tripping the machine. These modifications are:

For instrument trips: 1) insert electrical defeats for each initiator, 2) in some cases duplicate the final solenoid



1. Assuming a shutdown occurs every six months

The instrument system is modified to include two solenoid valves in the air signal to FRC5 control valve so that if either operates, the control valve will be tripped.

The temperature transmitter and its associated electrical relay are tested each month to a defeat.

f for transmitter = 0.25
f for relay = 0.002
Therefore, *fdt* for transmitter and relay = $1/2 \times 1/12 \times 0.252 = 0.0105$

The trip valve is tested for movement monthly by inspection (since it is also a control valve)

f for valve = 0.1
Therefore, *fdt* for valve = $1/2 \times 1/12 \times 0.1 = 0.004$

The two solenoid valves are tested at six-month intervals at shutdowns.

f for solenoid = 0.1
Therefore, *fdt* for one solenoid $1/2 \times 1/12 \times 0.1 = 0.025$ and *fdt* for either one of two solenoids $4/3 \times 0.025^2 = 0.0008$

The final trip relay is tested also at six month shutdowns.

f for relay = 0.002
Therefore *fdt* for relay = $1/2 \times 1 \times 0.002 = 0.005$
Therefore total *fdt* for system = $0.0105 + 0.004 + 0.0008 + 0.0005 = 0.0158$

2. Assuming a shutdown every 12 months

The only changes to the above calculations are for the solenoid valves and the final trip relays.

The *fdt* for one solenoid becomes = $1/2 \times 1 \times 0.1 = 0.05$ and *fdt* for either one of two solenoids = $4/3 \times 0.05^2 = 0.003$
The *fdt* for final relay = $1/2 \times 1 \times 0.002 = 0.001$
Therefore total *fdt* for system = $0.0105 + 0.0040 + 0.0033 + 0.0010 = 0.0188$

Figure 3. Simplified flow sheet for a high temperature trip on the air feed to a reformer.

valve, and 3) where necessary, separate trip initiators from control initiators.

For hydraulic trips: 1) make trip bars on QOVl and emergency stop valves removable, 2) construct a chock for the reverse check valve, and 3) modify axial trip relays to accept a defeat pin.

The method of trip testing is first to isolate the control oil supply to the pressure reducer for the axial displacement trip, check that the hydraulic trip systems operate correctly, and then to isolate the lube oil supply to the overspeed/low lube oil trip relay, and again check that the hydraulic systems operate correctly. This method checks the entire hydraulic system except operation of the overspeed bolt mechanism, which can only be checked at shutdowns.

Modifications have now been made to all the vessel protection trips and all the machine trips, which allow them to be tested as described above, but work has not yet begun on the furnace trips. The vessel protection trip tests are implemented and carried out regularly, the machine trip tests are currently being implemented.

Corrosion caused some early problems

In the early round of trip tests, when they were largely being done off-line, a significant number of failures were discovered that were due to corrosion and subsequent sticking of the mild steel linkages on manual reset solenoid valves. These have been replaced in stainless steel, and no further problems have been found. Since then, very few faults have been found when doing instrument trip tests.

The work load envisaged when trip testing is fully implemented will occupy one instrument technician for one-third of his time on a single ammonia plant.

Because of the oil problem and the serious nature of its consequences, there was a very strong push for trip testing of the hydraulic systems. Such testing has been going on now for over a year.

Testing frequency has been variable because of the problems of implementation, and it has been left to the discretion of the plant manager. Thus far, on-line tests have been used mainly during periods when any oil system has shown signs of contamination. Since June, 1974, 13 on-line trip tests have been carried out on one or another of the machines. In four of these tests the trip system failed to operate correctly. During the same period, all three machines have been trip tested while shutdown on a number of occasions. There have been 12 instances (covering three plants) when a machine had a faulty trip system when tested.

During genuine trip incidents or shutdown testing, there have been two occasions when a stop valve has not operated even though the hydraulic system worked correctly. This has led to the decision to test these valves for movement every three months.

This discussion would not be complete without some indication of the action taken when something is found wrong with a hydraulic trip system while the plant is on-line. Any hydraulic servomotors or relays not operating correctly are removed, stripped, cleaned, and reassembled, and a final trip test carried out.

Also, if the oil supply pressure to the axial position indicators starts to vary and causes false readings of axial position, a defeat pin is inserted in the trip relay, and the pressure reducer supplying the nozzle is stripped, cleaned, and reassembled. #

J. Hullah, who has worked with ICI Agricultural Div. for 10 years, first as an instrument engineer and then as a plant manager on a Kellogg Ammonia plant, earned a B.S. degree in electrical engineering at University College, London Univ.

DISCUSSION

Q. On your defeat system, do you have a control board display with the status of the defeat switches so it's readily known which ones are in service? Two, is there a local indication on a defeat switch—say for example, a red light, indicating light? And, do you have a key lock access to that switch?

HULLAH: The defeat systems which have been there since the plant was installed, have key operated defeat switches. They don't have a light which indicates when they are in defeat. You just go on the fact that the key is there and the key is turned. You can't take the key out while the system is in defeat.

On the recent modifications around the main machine, we have installed special panels which do have a light indication when the system is in defeat.

Q. This is at each machine then, as opposed to the main control board.

HULLAH: Each machine has its own trip panel in the control room, and each trip system on that machine has its own lights associated with its particular defeat switch.

Q. Don't get me wrong, I think this is a very valuable program but I'm just curious—have you had any occasions where your testing has actually initiated a trip?

HULLAH: Yes there was in the early days, one occasion when we went out to do a trip test on the air machine, and we forgot to put in one of the essential defeats, and subsequently we got a trip down to minimum governor of the air machine. So we put the machine back on line and repeated the trip test. In fact we accept that inevitably, from time to time, we are going to get some spurious trips. So far our experience is very good. When we first tried to put the systems in, the plant operators themselves were very, very nervous and were very reluctant to cooperate.

Now that they have experience of the trip tests, they are far more confident about them and carry them out quite happily.

Q. I'm not quite sure I understood you properly about the vessel protection trip. Are you saying that this trip is the primary, or last resort vessel protection device, or is it a pre devise to prevent the relief valve from lifting?

HULLAH: It's a last resort device. If it was a pre-device, we would not consider it in the context of this paper. We would say the relief valve was the final protection. But if it's a device like the high temperature methanator trip, then we would consider that a primary vessel protection trip, and test that.

Q. Bob Osman, Exxon Chemical Co. As a supplement to the on-line testing of the trip systems, have you also done work in the field of going to two out of three voting trip systems to both increase the reliability of the trip itself and also to reduce the number of nuisance trips?

HULLAH: In the Agricultural Division, we don't consider that we have many situations which would require that kind of reliability. However, on two of the most recent plants, one which is built and in operation and one which is currently being built, we have selective systems going for two out of three operations, to give us the increased reliability. Two out of three—I think I'm right in saying that one out of two will give us the increased reliability in terms of the trip being available; two out of three being necessary so that we don't at the same time increase spurious trips.

Q. That's right, you improve your probability in both directions. You get more reliability and you also get less likelihood of spurious trips.

HULLAH: We've gone for two out of three and not for one out of two.

Q. In design of ammonia plants I have always had a difficulty in trying to optimalize in spending money improving the trip system, or spending money in making it possible to test the trip system. Now trying to put that in words, if you were going to build a new plant, would you try to make the oil system, the steam turbine of the sqn gas machine completely separate, and then forget the trip testing? Or would you still decide for trip testing?

HULLAH: I don't think you can really separate one from the other quite like that. Certainly we were involved with an existing plant with an existing oil system, and we have talked about the possibility of separating oil systems out. Perhaps I can refer that question to Dr. Livingston, but I've just added that, even if we went to a separate oil system, and even having improved our trip systems as much as we could under the current technology, we would still end up with some form of regular trip testing.

It may affect the frequency but it won't affect the decision whether or not to do it, I shouldn't think.

LIVINGSTONE, ICI, Billingham: Yes, I think I agree with John's philosophy. I think the point he's making is that if we were starting from scratch with a new plant, as we are in fact in Billingham now, we would have a separate control circuit away from steam turbine and other possible sources of contamination.

But even if not, we would insist at this stage in our knowledge, that we continue with on-line trip testing because, as John is pointing out here, we are not only looking at this from the point of view of contaminants affecting reliability of protective devices, but we are also looking at the atmospheric conditions, on the mechanical side of the business; on indeed also the electrical reliability of solenoids and other items of equipment in this region.

MAX APPL, BASF, Germany: We did partly two from three and in some points even somewhat more elaborate things. For the electronics involved, we had a two channel system, in order to check one channel while the other was working. But even in this case we are still doubting whether the money spending, was necessary or not.

LIVINGSTONE: Well I think again it comes back to the point John made earlier. When you are talking about whether or not you should spend the money, all that happens, or the one thing that happens to hasten the process of spending the money is some major incident involving the failure of those protective devices; and then practical and bitter experience of what that sort of incident can cause you.

And I think if you are always looking at this from the point of view of the fractional dead time, and that concept in isolation, in many many cases you will not spend the money. But if you are looking at it from the point of view of yours and other operators' experiences with failure of these devices it becomes a little easier to spend some of the money.

APPL, What I wanted to point out in my remark was the question: What is better, to risk a trip while testing, or to avoid such a potential trip by having, a two fold electronic system, so you can switch from one to the other while testing the first one. That's what I thought.

LIVINGSTONE: I'm sorry—I understood the point yes. Still, it comes back again to the reliability that you have built-in, in duplicate in whatever system you have. If you like in the extreme, there is no pump that is absolutely 100% safe, you know, it's almost a contradiction in terms. But our experience, and that's all we are trying to portray here, is that even with triple voting systems, two our of three, that you have an item of plant mechanical equipment in there that has a certain failure rate, and sometime, some way, it's going to happen.

And there's a question of whether or not you want it to happen to you—you decide whether or not you spend the money.