8

Safety, fault-finding and maintenance

Safety

Most industrial plant has the capacity to maim or kill. It is therefore the responsibility of all people, both employers and employees, to ensure that no harm comes to any person as a result of activities on an industrial site.

Not surprisingly, this moral duty is also backed up by legislation. It is interesting that most safety legislation is re-active, i.e. responding to incidents which have occurred and trying to prevent them happening again. A prime example of this is the CDM regulations which arose because of the appalling safety record in the construction industry.

Safety legislation differs from country to country, although harmonization is underway in Europe. This section describes safety from a British viewpoint, although the general principles apply throughout the European community and are applicable in principle throughout the world. The descriptions are, of course, a personal view and should only be taken as a guide. The reader is advised to study the original legislation before taking any safety-related decisions.

Most safety legislation has a common theme. Employers and employees are deemed to have a *Duty of Care* to ensure the Health, Safety and Welfare of the employees, visitors and the public. Failure in this duty of care is called *Negligence*. Legislation defines required actions at three levels:

Shall or *Must* are absolute duties which have to be obeyed without regard to cost. If the duty is not feasible the related activity must not take place.

If practicable means the duty must be obeyed if feasible. Cost is not a consideration. If an individual deems the duty not to be feasible, proof of this assertion will be required if an incident occurs.

Reasonably practicable is the trickiest as it requires a balance of risk against cost. In the event of an incident an individual will be required to justify the actions taken.

There is a vast amount of safety legislation with varying degrees of authority. Acts (e.g. the Health and Safety at Work Act (HASWA)), are statutes passed by full parliamentary procedures and are enforced by criminal law. Often acts such as HASWA (called Enabling Acts), are arranged to allow supplementary regulations to be made by the Secretary of State without going through the full parliamentary procedure.

Regulations are introduced under an enabling act. They have the same power and status as acts. Most British safety regulations have been made under the Health and Safety at Work Act 1974.

Approved Codes of Practice (ACOPs) are documents written to define safe working methods and procedures by organizations such as CENELEC and British Standards Institute. They are approved by the Health and Safety Commission. Whilst they are not mandatory (i.e. there can be no prosecution for not following them), failure to follow ACOPs may be viewed as a contributory factor in investigations of an incident.

Codes of Practice are guidance codes provided by trade unions and professional organizations. These do not have the semi-legal status of ACOPs, but contain good advice. Again, though, implementation or otherwise can be given in evidence in court.

In Europe there is a serious attempt to have uniform legislation throughout the EC. At the top level is EC Regulations which override national legislation. Of most relevance are EC Directives which require national laws to implemented.

In Britain the primary legislation is the Health & Safety at Work Act 1974 (HASWA). It is an enabling act, allowing other legislation to be introduced. It is wide ranging and covers everyone involved with work (both employers and employees) or affected by it. In the USA the Occupational Safety and Health Act (OSHA) affords similar protection.

HASWA defines and builds on general duties to avoid all possible hazards, and its main requirement is described in section 2(1) of the act:

> *It shall be the duty of every employer to ensure, so far as is reasonably practicable, the health, safety and welfare at work for his employees*

This duty is extended in later sections to visitors, customers, the general public and (upheld in the courts), even trespassers. The onus of proof of *Reasonably Practicable* lies with the employer in the event of an incident.

Section 2(2) adds more detail by requiring safe plant, safe systems of work, safe use of articles and substances (i.e. handling, storage and transport), safe access and egress routes, safe environment, welfare facilities and adequate information and training.

If an organization has five or more employees it must have a written safety policy defining responsibilities and employees must be aware of its existence and content (section 2(3)) Employers must consult with worker safety representatives

The act is not aimed purely at employers, employees also have duties described in sections 7 and 8 of the act. They are responsible for their own, and other's safety and must co-operate with employers and other people to ensure safety, i.e. they must follow safe working practices. They must not interfere with any safety equipment (e.g. tampering with interlocks on movable guards).

The act defines two authorities and gives them power for the enforcement of the legislation (sections 10–14 and 18–24). The Health and Safety Commission is the more academic of the two, and defines policy, carries out research, develops safety law and disseminates safety information. The Health & Safety Executive (HSE) implements the law by inspection and can enforce the law where failings are found. Breaches of HASWA amount to a indictable offence and the HSE has the power to prosecute the offenders.

The power of HSE inspectors are wide. They can enter premises without invitation and take samples, photographs, documents, etc. Breaches of HASWA amount to a indictable offence and the HSE has the power to prosecute the offenders. People, as well as organisations, may be prosecuted if a safety failing or incident arises because of neglect by a responsible person.

The HSE also has the power to issue notices against an organisation. The first, an Improvement Notice, is given where a fairly minor safety failing is observed. This notice requires the failing to be rectified within a specified period of time. The second, a Prohibition Notice, requires all operations to cease immediately and not restart until the failing is rectified and HSE inspectors withdraw the notice.

It is all but impossible to design a system which is totally and absolutely fail-safe. Modern safety legislation, such as the Six Pack, recognises the need to balance the cost and complexity of the safety system against the likelihood and severity of injury. The procedure, known as *Risk Assessment*, uses common terms with specific definitions:

Hazard	The potential to cause harm.
Risk	A function of the likelihood of the hazard occurring and the severity.
Danger	The risk of injury.

Risk assessment is a legal requirement under most modern legislation, and is covered in detail in, standard prEN1050 '*Principles of Risk Assessment*'.

The first stage is identification of the hazards on the machine or process. This can be done by inspections, audits, study of incidents (near misses) and, for new plant, by investigation at the design stage. Examples of hazards are: impact/crush, snag points leading to entanglement, drawing in, cutting from moving edges, stabbing, shearing (leading to amputation), electrical hazards, temperature hazards (hot and cold), contact with dangerous material and so on. Failure modes should also be considered, using standard methods such as HAZOPS (Hazard & Operability Study, with key words Too much of and Too little of), FMEA (Failure Modes and Effects Analysis) and Fault Tree Analysis.

With the hazards documented the next stage is to assess the risk for each. There is no real definitive method for doing this, as each plant has different levels of operator competence and maintenance standards. A risk assessment, however, needs to be performed and the results and conclusions documented. In the event of an accident, the authorities will ask to see the risk assessment. There are many methods of risk assessment, some quantitative assigning points, and some using broad qualitative judgements.

Whichever method is used there are several factors that need to be considered. The first is the severity of the possible injury. Many sources suggest the following four classifications:

Fatality	One or more deaths.
Major	Non reversible injury, e.g. amputation, loss of sight, disability.
Serious	Reversible but requiring medical attention, e.g. burn, broken joint.
Minor	Small cut, bruise, etc.

The next step is to consider how often people are exposed to the risk. Suggestions here are:

Frequent	Several times per day or shift.
Occasional	Once per day or shift.
Seldom	Less than once per week.

Linked to this is how long the exposure lasts. Is the person exposed to danger for a few seconds per event or (as can occur with major maintenance work), several hours? There may also be a need to consider the number of people who may be at risk; often a factor in petro-chemical plants.

Where the speed of a machine or process is slow, or there is a lengthy and obvious (e.g. noisy) start-up, the exposed person can easily move out of danger in time. There is obviously less risk here than with a silent high speed machine which can operate before the person can move. From studying the machine operation, the probability of injury in the event of failure of the safety system can be assessed as:

Certain, Probable, Possible, Unlikely

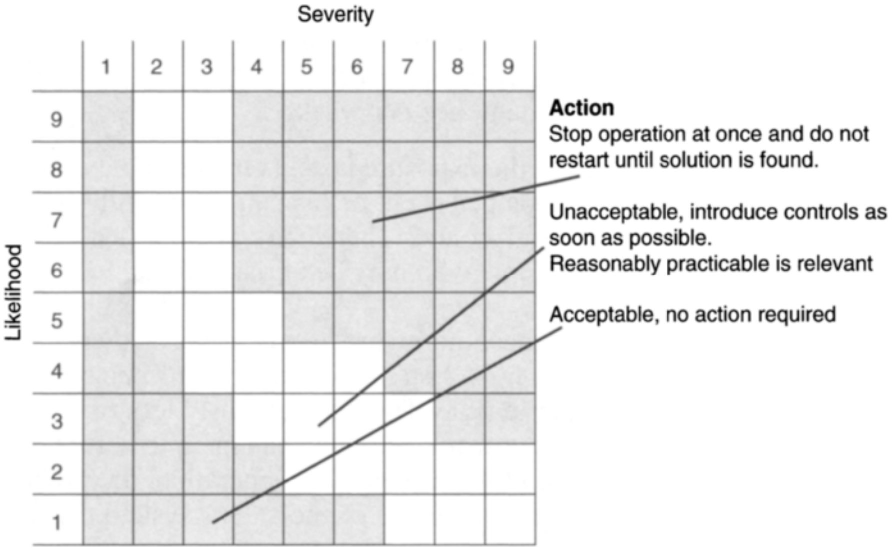
From this study, the risk of each activity is classified. This classification will depend on the application. Some sources suggest applying a points scoring scheme to each of the factors above then using the total score to determine *High*, *Medium* and *Low* risks. Maximum Possible Loss (MPL) for example uses a 50 point scale ranging from 1 for a minor scratch to 50 for a multi-fatality. This is combined with the frequency of the hazardous activity (F) and the probability of injury (again on a 1–50 scale) in the formula:

$$\text{risk rating (RR)} = \text{F} \times (\text{MPL} + \text{P})$$

The course of action is then based on the risk rating.

An alternative and simpler (but less detailed approach) uses a table as Figure 8.1 from which the required action can be quickly read.

Likelihood of incident	**Severity of outcome**
9. Almost certain	9. Fatality
8. Very likely	8. Permanent total incapacity
7. Probable	7. Permanent severe incapacity
6. Better than even chance	6. Permanent slight incapacity
5. Even chance	5. Off work for > 3 weeks but subsequent recovery
4. Less than even chance	4. Off work for 3 days to 3 weeks with full recovery
3. Improbable	3. Off work for less than 3 days with full recovery
2. Very improbable	2. Minor injury, no lost time
1. Almost impossible	1. Trivial injury



Action
Stop operation at once and do not restart until solution is found.

Unacceptable, introduce controls as soon as possible.
Reasonably practicable is relevant

Acceptable, no action required

Figure 8.1 *A typical risk assessment table. Although this is based on a real application, it should not be applied elsewhere without supporting study and documentation. The main point of a risk assessment is identifying and reducing the risks associated with a specific task*

There is, however, no single definitive method, but the procedure used must suit the application and be documented. The study and reduction of risks is the important aim of the activity.

The final stage is to devise methods of reducing the residual risk to an acceptable level. These methods will include removal of risk by good design (e.g. removal of trap points), reduction of the risk at source (e.g. lowest possible speed and pressures, less hazardous material), containment by guarding, reducing exposure times, provision of personal protective equipment and establishing written safe working procedures which must be followed. The latter implies competent employees and training programs.

There is a vast amount of legislation covering health and safety, and a list is given below of those which are commonly encountered in industry. It is by no means complete, and a fuller description of these, and other, legislation is given in the third edition of the author's *Industrial Control Handbook*. An even more detailed study can be found in *Safety at Work* by John Ridley, both books published by Butterworth-Heinemann.

Commonly Encountered Safety Legislation:
Health & Safety at Work Act 1974 (the prime UK legislation)
Management of Health & Safety at Work Regulations 1992
Provision & Use of Work Equipment Regulations 1992 (PUWER)
Manual Handling Regulations 1992
Workplace Health, Safety & Welfare Regulations 1992
Personal Protective Equipment Regulations 1992
Display Screen Equipment Regulations 1992
  (*the previous six regulations are based on EC directives and are known collectively as 'the six pack'*)
Reporting of Injuries, Diseases & Dangerous Occurrences Regulations (RIDDOR) 1995
Construction (Design & Management) Regulations (CDM) 1994
  Electricity at Work Regulations (1990)
Control of Substances Hazardous to Health (COSHH) 1989
Noise at Work Regulations 1989
Ionising Radiation Regulations 1985
Safety Signs & Signals Regulations 1996
Highly Flammable Liquids & Liquefied Petroleum Gas Regulations 1972
Fire Precautions Act 1971
Safety Representative & Safety Committee Regulations 1977
Health & Safety Consultation with Employees Regulations 1996
Health & Safety (First Aid) Regulations 1981
Pressure Systems & Transportable Gas Containers Regulations 1989

As hydraulic systems are nowadays invariably linked to Programmable Controllers (PLCs), the reader should also consult the occasional paper OP2 'Microprocessors in Industry' published by the HSE in 1981 and the two later booklets 'Programmable

Electronics Systems in Safety Related Applications', Book 1, an Introductory Guide and Book 2, General Technical Guidelines both published in 1987.

Electrical systems are generally recognised as being potentially lethal, and all organisations must, by law, have procedures for isolation of equipment, permits to work, safety notices and defined safe-working practices. Hydraulic and pneumatic systems are no less dangerous; but tend to be approached in a far more carefree manner. High pressure air or oil released suddenly can reach an explosive velocity and can easily maim, blind or kill. Unexpected movement of components such as cylinders can trap and crush limbs. Spilt hydraulic oil is very slippery, possibly leading to falls and injury. It follows that hydraulic and pneumatic systems should be treated with respect and maintained or repaired under well defined procedures and safe-working practices as rigorous as those applied to electrical equipment.

Some particular points of note are:

- before doing *anything,* think of the implications of what you are about to do, and make sure anyone who could be affected knows of your intentions. Do not rush in, instead, *think*;
- anything that can move with changes in pressure as a result of your actions should be mechanically secured or guarded. Particular care should be taken with suspended loads. Remember that fail open valves will turn *on* when the system is de-pressurised;
- never disconnect pressurised lines or components. Isolate and lock-off relevant legs or de-pressurise the whole system (depending on the application). Apply safety notices to inhibit operation by other people. Ideally the pump or compressor should be isolated and locked off at its MCC. Ensure accumulators in a hydraulic system are fully blown down. Even then, make the first disconnection circumspectly;
- in hydraulic systems, make prior arrangements to catch oil spillage (from a pipe-replacement, say). Have containers, rags and so on, ready and, as far as is possible, keep spillage off the floor. Clean up any spilt oil before leaving;
- where there is any electrical interface to a pneumatic or hydraulic system (eg, solenoids, pressure switches, limit switches) the control circuits should be isolated, not only to remove the risk of

electric shock, but also to reduce the possibility of fire or accidental initiation of some electrical control sequence. Again, *think* how things interact;

- after the work is completed, leave the area tidy and clean. Ensure people know that things are about to move again. Check there is no one in dangerous areas and sign-off all applied electrical, pneumatic or hydraulic isolation permits to work. Check for leaks and correct operation;
- many components contain springs under pressure. If released in an uncontrolled manner these can fly out at high speed, causing severe injury. Springs should be released with care. In many cases manufacturers supply special tools to contain the spring and allow gradual and safe decompression.

Cleanliness

Most hydraulic or pneumatic faults are caused by dirt. Very small particles nick seals, abrade surfaces, block orifices and cause valve spools to jam. In hydraulic and pneumatic systems cleanliness is next to Godliness. Dismantling a valve in an area covered in swarf or wiping the spool on an old rag kept in an overall pocket does more harm than good.

Ideally components should not be dismantled in the usual dirty conditions found on site, but returned to a clean workshop equipped with metal-topped benches. Too often one bench is used also for general mechanical work: it needs little imagination to envisage the harm metal filings can do inside a pneumatic or hydraulic system.

Components and hoses come from manufacturers with all orifices sealed with plastic plugs to prevent dirt ingress during transit. These should be left in during storage and only removed at the last possible moment.

Filters exist to remove dirt particles, but only work until they are clogged. A dirty filter bypasses air or fluid, and can even make matters worse by holding dirt particles then releasing them as one large collection. Filters should be regularly checked and cleaned or changed (depending on the design) when required.

Oil condition in a hydraulic system is also crucial in maintaining reliability. Oil which is dirty, oxidised or contaminated with water forms a sticky gummy sludge, which blocks small orifices and causes pilot spools to jam. Oil condition should be regularly checked and suspect oil changed before problems develop.

Fault-finding instruments

Electrical fault-finding is generally based on measurements of voltage, current or (less often) resistance at critical points in the circuit. Of these, voltage is easier to measure than current unless ammeters or shunts have been built into the circuit, and resistance measurement usually requires the circuit to be powered-down and the device under test disconnected to avoid sneak paths. An electronic circuit is given in Figure 8.2. This converts a voltage input V_i to a current signal I, where $I = V_i/R$. Such a circuit is commonly used to transmit an instrumentation signal through a noisy environment. A typical checking procedure could be:

Voltage checks;	A	(input signal)
	B and C	(amplifier ± 15 V supply)
	D	(return voltage should equal A)
	E	(across load, 15 V indicates open circuit load, 0 V indicates short-circuit load).

Followed by:

Current checks;	X, Y	(X should equal Y and both equal A/R)
Resistance checks;	F, G	(for open- or short-circuit load or resistance).

In pneumatic or hydraulic systems, pressure measurement is equivalent to electrical voltage measurement, while flow measurement is equivalent to current measurement. There is no direct simple measurement equivalent to electrical resistance. Pressure tests and (to a lesser extent) flow tests thus form the bases of fault-finding in pneumatic or hydraulic systems.

There is however, a major difference in the ease of access. Electrical systems abound with potential test points; a voltage probe can be placed on practically any terminal or any component, and (with a little more trouble) a circuit can be broken to allow current measurements to be made.

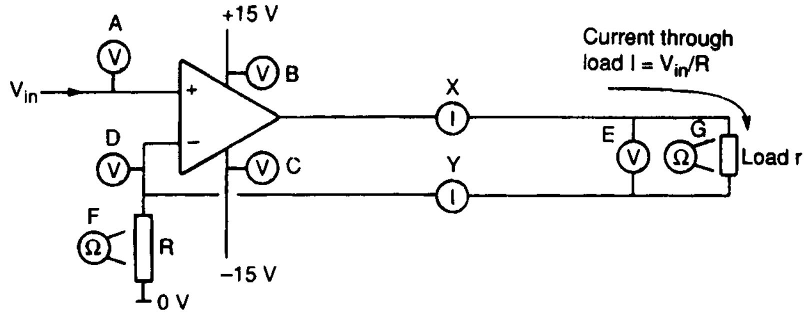


Figure 8.2 *Test measurement points on an electronic circuit*

In fluid systems, oil or gas is contained in pipes or hoses, and measurements can only be made at test points which have been built-in as part of the original design. Test points can be plumbed in on an ad hoc basis but this carries the dangers of introducing dirt from cutting or welding, and in hydraulic systems any air introduced will need to be bled out. The designer should, therefore, carefully consider how faults in the system can be located, and provide the necessary test points as part of the initial design.

By far the most common technique is a built-in rotary pressure select switch, as shown in Figure 8.3, which allows pressure from various strategic locations to be read centrally. An alternative technique uses quick-release connections, allowing a portable pressure meter to be carried around the system and plugged in where required.

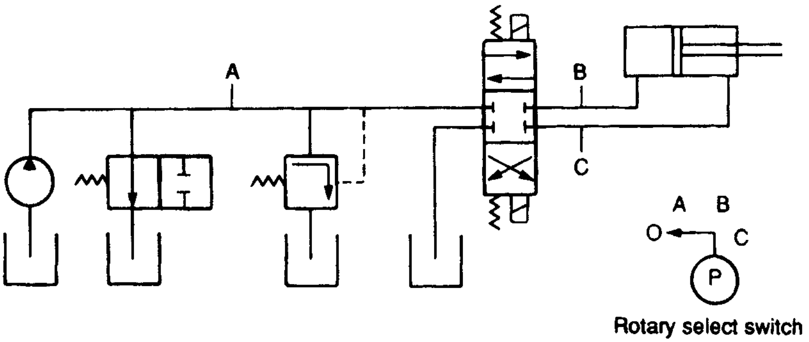


Figure 8.3 *The commonest hydraulic and pneumatic test system, a rotary select switch*

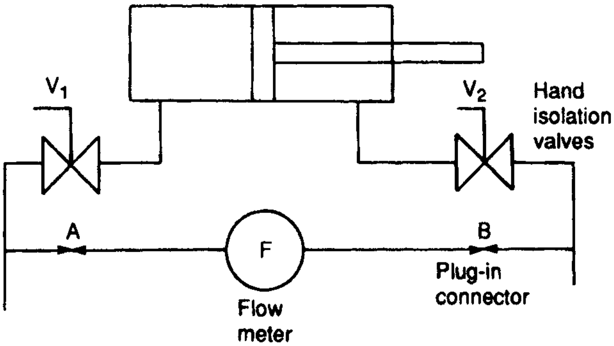


Figure 8.4 *Checking flow available at an actuator*

Flow measurement is more difficult, as the basic flow transducer needs to be built-in. Portable flow meters can be used, as shown in Figure 8.4, where the flow available for a cylinder is checked by closing hand valves V_1 and V_2 while connecting a flow meter between quick-release connections A and B.

The UCC System 22 is an invaluable three in one 'plumbed-in' test instrument which provides measurement of pressure, flow and temperature at the installed point with a plug in test meter. The inclusion of such a device should be provided immediately after every pump (but before the first relief valve) to allow pump delivery to be checked and at crucial points such as the pressure lines to a critical cylinder or motor. Remember, with hydraulics and pneumatics the test points have to be designed in.

An indicator in the plug of a solenoid valve will show voltage is arriving at the solenoid (see Figure 8.9) but this is not a fool proof indication that the solenoid itself is operating. The coil may, for example, be open circuit or there is a loose connection inside the plug. RS components sell a very cheap and useful solenoid tester (part number 214–338), which illuminates when held in a strong magnetic field. About the size of a fountain pen it can be touched onto the body of a solenoid to see if the solenoid really is being energized.

Fault-finding

Fault-finding is often performed in a random and haphazard manner, leading to items being changed for no systematic reason beyond 'Fred got it working this way last time'. Such an approach may work eventually (when every component has been changed!) but it is hardly the quickest, or cheapest, way of getting a faulty system back into production. In many cases more harm than good results, both with introduction of dirt into the system, and from ill advised 'here's a control adjustment; let's twiddle it and see if that makes any difference' approach. There must be a better way.

There are three maintenance levels. First line maintenance is concerned with getting faulty plant running again. When the cause of a fault is found, first line staff have the choice of effecting a first line, on site, repair (by replacing a failed seal, say) or changing the complete faulty unit for a spare. This decision is based on cost, time, availability of spares, technical ability of staff, the environment on site and company policy.

Second line maintenance is concerned with repair to complete units changed by first line maintenance staff. It should be performed in clean and well-equipped workshops. Work is usually well-defined and is often a case of following manufacturers' manuals.

The final level is simply the return of equipment for repair by manufacturer. The level at which this is needed is determined by the complexity of equipment, ability of one's staff, cost and the turnround time offered by the manufacturer.

Of these three levels; first line maintenance is hardest as work is ill-defined, pressures from production staff are great and the responsibility high. Unfortunately, it is too often seen as a necessary evil.

Fault-finding is, somewhat simplistically, represented by Figure 8.5. All the evidence on the fault gathered so far is evaluated, and possible causes considered. The simplest test to reduce the number of possibilities is then performed and the cycle repeated until the fault is found.

The final steps in Figure 8.5 are concerned with fault recording and fault analysis. Any shift crew (which performs almost all the first line repairs) only sees one quarter of all faults. The fault recording and analysis process shows if there is any recurring pattern in faults, indicating a design or application problem. Used diplomatically, the records may also indicate shortcomings in crews' knowledge and a need for training.

Modern plants tend to be both complex and reliable. This means that a maintenance crew often sees a plant in detail for the first time when the first fault occurs. (Ideally, of course, crews should be involved at installation and commissioning stages – but that is another story!). It is impossible to retain the layout of all bar the

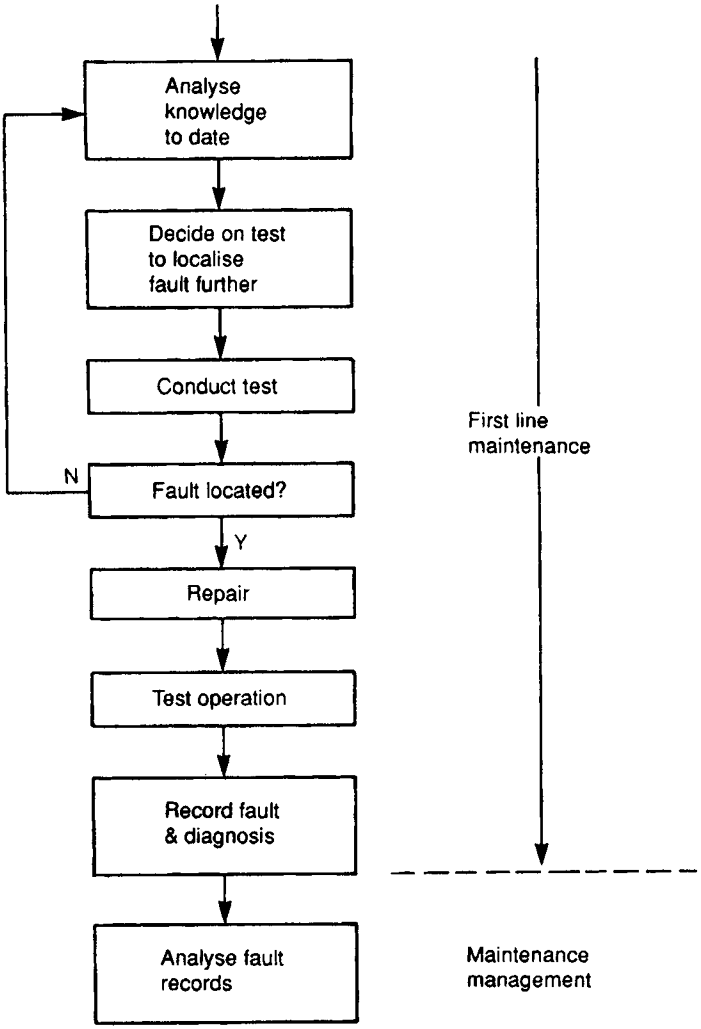


Figure 8.5 *Fault-finding process*

simplest of systems in the mind, so it is essential to have schematic diagrams readily available.

Equally important, readings at each test point should be documented when the system is working correctly. It is not much use to know pressure at TP_3 is 15 bar, the motor draws 75 A or flow to rotary actuator C is 1500 $l\ min^{-1}$ under fault conditions, without knowing what the normal readings are.

It can often be difficult to decide what a fault really is; usually the only information is simply 'the Firkling Machine is not working'. The first diagnostic step is, therefore, to establish what is *really* wrong – whether there is one fault or several from a common cause. A quick visual and manual check should be made for any obvious aberrations; noise, vibration, heat, leaks, unusual motor current.

From maintenance records it should be possible to see if any recent work has been done or if this is a recurring fault. Recent work is always suspect – particularly if the unit has not been used since the work was done. Some points to check if work has recently been performed are:

- whether the correct units were fitted. Stores departments are not infallible and lookalike units may have been fitted in error. Non-return valves can sometimes be fitted the wrong way round;
- whether all handvalves are correctly open or shut. Many systems are built with standby pumps or compressors with manual change over. These are (in the author's experience) a constant source of trouble after a changeover (one invariable characteristic seems to be one less valve handle than there are valves!). Valves can also creep open. Figure 8.6 shows a common fault situation with two hydraulic units, one in use and one standby. If any of the hand isolation valves V_1 to V_4 are set incorrectly open on the main or standby units, flow from the duty unit returns direct to tank via the centre position of the standby directional valve and the actuator will not move;
- after electrical work, check the direction of rotation of the pump or compressor. Most only operate in one direction, usually defined with an arrow on the casing, and may even be damaged by prolonged reverse running;
- have any adjustments been 'twiddled' or not set correctly after an item has been changed? On many directional valves, for example, the speeds of operation from pilot to main spool can be set by Allen key adjustments. If these are maladjusted, the main spool may not move at all.

If no recent work has been done, and these quick checks do not locate a fault, it is time to start the fault-finding routine of Figure 8.5. One advantage of pneumatic systems is their natural break into distinct portions: (1) a supply portion up to and including the receiver and (2) one or more application portions after the receiver.

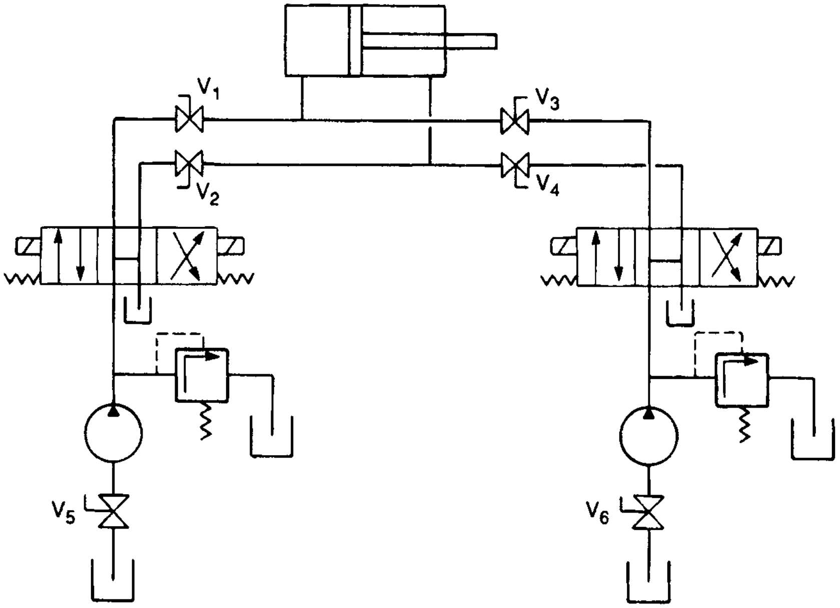


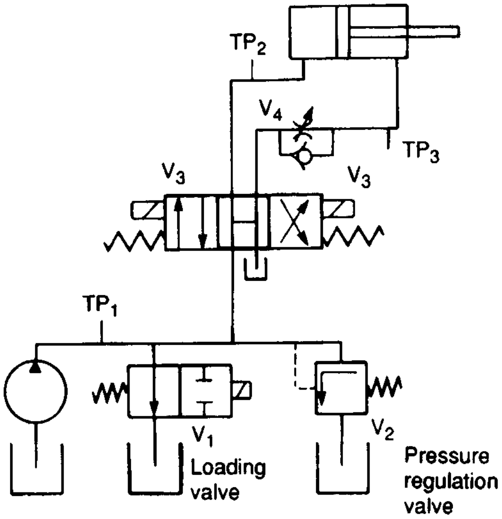
Figure 8.6 *A common source of trouble; a main/standby system with hand isolation valves. Wrong setting of valves leads to many obscure faults*

The pressure gauge on the receiver allows a natural fault-finding split.

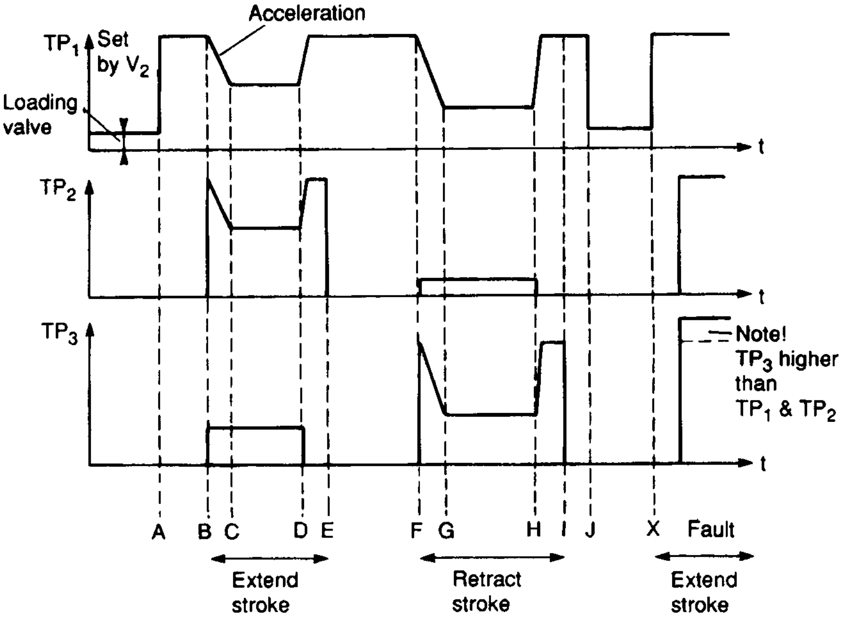
Problems generally fall into three types; a lack of force, low speed (or no speed), or erratic operation. Lack of force or no movement is generally a pressure-related fault. Low speed arises from a flow fault. Erratic operation can arise from sticking valves or from air in a hydraulic system.

Usually pressure monitoring is much easier than flow monitoring but is often misunderstood. A typical example of fault-finding using pressure test points is given in Figure 8.7. Up to time A the system unloads via the solenoid-operated unloading valve V_1. When valve V_1 energises, pressure rises to the setting of the relief valve V_2. At time C, directional valve V_3 calls for the cylinder to extend. Pressure *falls* as the cylinder accelerates, until the cylinder is moving at constant speed when P=F/A. At time D, the cylinder reaches the end of travel, and the pressure rises back to the setting of the relief valve. Directional valve V_3 de-energises at E. Note the low pressures in return line test points.

A similar retract stroke takes place during time F to I. The pressure between G and H is lower than between C and D, because fric-



(a) Circuit diagram



(b) Pressure readings

Figure 8.7 *Fault-finding with pressure test points* tion alone opposes the movement. The loading valve comes off at time J.

It is important to monitor return line pressure. A fault exists from time X onwards; the return line from the cylinder is blocked, possibly because the spool in the meter-out flow control valve has jammed, allowing no fluid to return. At time Y the directional valve operates causing a rise in pressure on test point TP_2 to the setting of the relief valve. Because of the blockage in the return line, point TP_3 also rises to a *higher* pressure because of the lower annulus area on the return side of the piston ($P_1A=P_2a$, remember!).

Pressure is therefore a good indication of what is going on in a system, the pressure being the *lowest* demanded by the loading/ unloading valves, the relief valve(s) or the load itself.

A hydraulic pump is a positive displacement device (see Chapter 2). This has useful implications when fault-finding. If a pump is working its flow *must* be getting back to tank via some route. If it does not the pressure will rise and the oil will eventually go everywhere! Tracking the oil flow route by as simple a method as following warm pipes by hand can sometimes indicate what is wrong.

Remember these basic facts for fault finding:

- Knowing if the pump is delivering fluid is vital. If there is not a UCC system 22 or similar flow sensor immediately after the pump but before the first relief valve consider installing one as soon as possible
- Hydraulic pumps are invariably positive displacement pumps. If a pump is delivering fluid it must be going somewhere.
- Acceleration is determined by pressure
- Force is determined by pressure
- Velocity (speed) is determined by flow
- The pressure at any point is determined by the *lowest* pressure the system can provide under the current conditions.

The interface with the electrical control can cause confusion. The control sequence should be clearly understood. Figure 8.8 shows a typical electrical/hydraulic scheme used to build a tight pack of objects. An object is placed onto the skid, and its presence noted by a proximity detector connected as an input to a programmable controller (PLC).

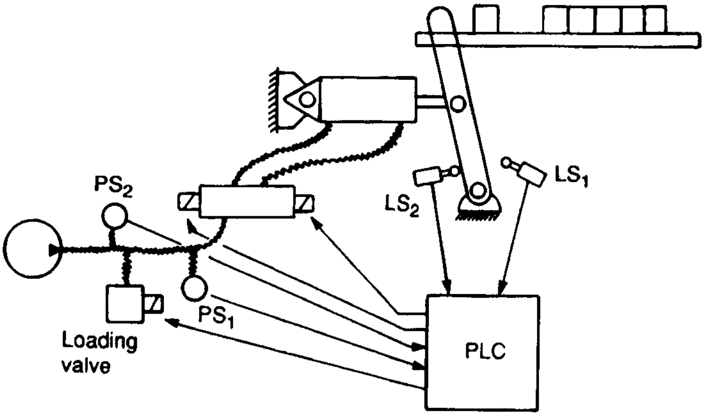


Figure 8.8 *A typical sequencing application*

When the PLC sees an object, it energises the loading valve, and causes the cylinder to extend. The cylinder extends until the front limit switch LS_1 makes (for the first few objects) *or* the pressure switch PS_2 makes (indicating a full stalled pack) *or* timeout (indicating some form of fault). The cylinder then returns to the back limit LS_2 *or* a timeout (again indicating a fault) when the loading valve is de-energised. The PLC also monitors pump action via pressure switch PS_1, which is made whenever the loading valve is energised.

A knowledge of the complete system, both electrical and hydraulic, is required to fault-find on this application. Fault-finding involves checking the sequence by monitoring the state of electrical outputs to solenoids and inputs from limit switches.

All solenoid valves should have an indicator in the plug tops to allow electrical signals to be observed local to the valves. Indicator blocks which fit between plug and valve are available for retro fitting onto systems without this useful feature. It should be remembered, though, that indications purely show electrical voltage is present – it does not, for example, identify an open circuit solenoid coil.

Solenoids can operate on AC (usually 110 V AC) or DC (usually 24 V DC). DC solenoids have totally different operating characteristics. An AC solenoid has a very high inrush current producing a high initial force on the pilot spool. As the spool moves in, the inductance of the coil rises and current falls to a low holding current (and a low force on the pilot spool). If the pilot spool jams the current remains high, causing the protection fuse or breaker to open or the solenoid coil to burn out if the protection is inadequate. Operation of a 110 volt solenoid system with cold oil is best undertaken with a pocketful of fuses.

The current in a DC solenoid is determined by the coil resistance and does not change with pilot spool position. The solenoid does not, therefore, give the same 'punch' to a stiff spool but will not burn out if the spool jams. Current in a DC solenoid also tends to be higher requiring larger size cables, particularly if a common return line is used from a block of solenoids.

A useful monitoring device is the through-connector with an integral current indicator shown in Figure 8.9. This *does* give indication of an open circuit coil and combined with the indicator on the plug top can help find most electrical faults.

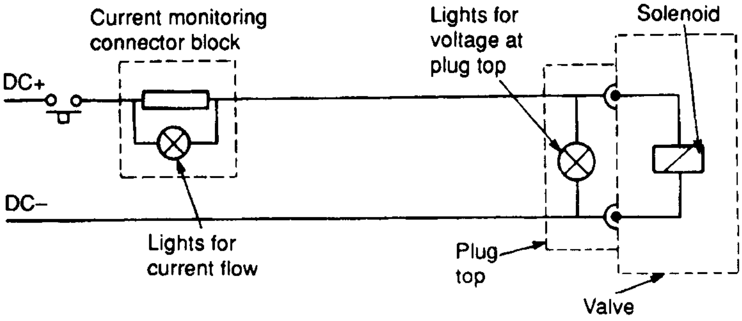


Figure 8.9 *Monitoring a DC solenoid*

On most electrically-operated valves the pilot spool can be operated manually by pushing the spool directly with a rod (welding rod is ideal!). Electrical signals should, however, be disabled when operating valves manually, as pushing in the opposite direction to the solenoid can cause the coil to burn out.

Designers of a system can simplify maintenance by building in a fault-finding methodology from the start. This often takes the form of a flowchart. Figure 8.10 shows a typical system, which can be diagnosed by following the flowchart of Figure 8.11. Such charts cannot solve every problem, but can assist with the majority of common faults. If transducers can be fitted to allow the system to be monitored by a computer or programmable controller, Figure 8.11 could form the basis of a computer-based expert system.

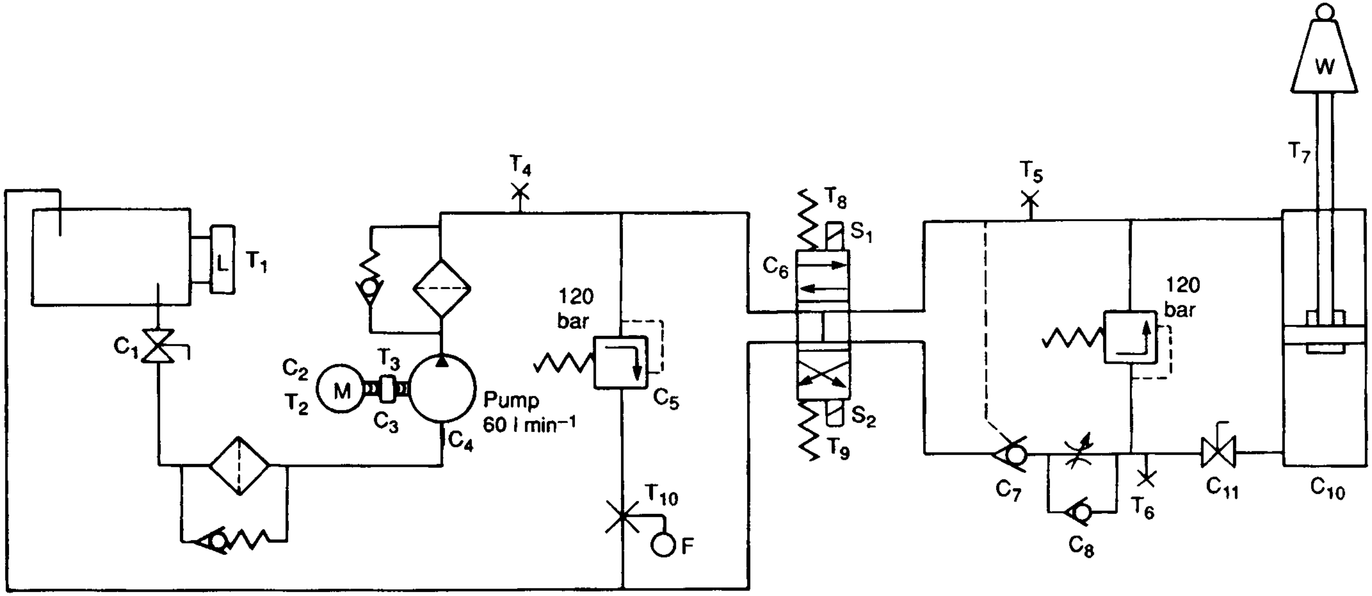
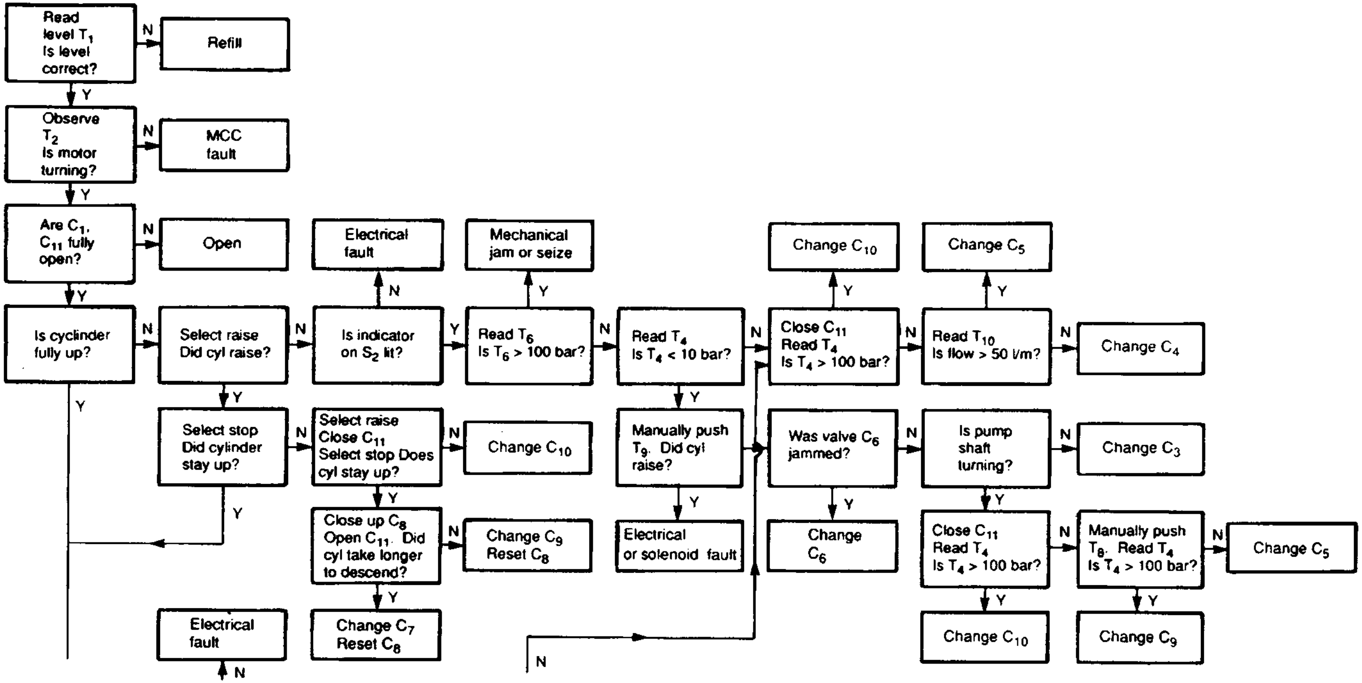


Figure 8.10 *Hydraulic circuit for diagnostic chart*


Read level T_1 Is level correct?
N
Refill
Y
Observe T_2 Is motor turning?
N
MCC fault
Y
Are C_1, C_{11} fully open?
N
Open
Y
Is cyclinder fully up?
N
Select raise Did cyl raise?
N
Is indicator on S_2 lit?
N
Electrical fault
Y
Read T_6 Is T_6 > 100 bar?
Y
Mechanical jam or seize
N
Read T_4 Is T_4 < 10 bar?
N
Close C_{11} Read T_4 Is T_4 > 100 bar?
Y
Change C_{10}
N
Read T_{10} Is flow > 50 l/m?
Y
Change C_5
N
Change C_4
Y
Select stop Did cylinder stay up?
N
Select raise Close C_{11} Select stop Does cyl stay up?
N
Change C_{10}
Y
Close up C_8 Open C_{11}. Did cyl take longer to descend?
N
Change C_9 Reset C_8
Y
Change C_7 Reset C_8
Y
Manually push T_9. Did cyl raise?
Y
Electrical or solenoid fault
Was valve C_6 jammed?
Y
Change C_6
N
Is pump shaft turning?
N
Change C_3
Y
Close C_{11} Read T_4 Is T_4 > 100 bar?
Y
Change C_{10}
N
Manually push T_8. Read T_4 Is T_4 > 100 bar?
N
Change C_5
Y
Change C_9
Y
Y
Electrical fault
N
N

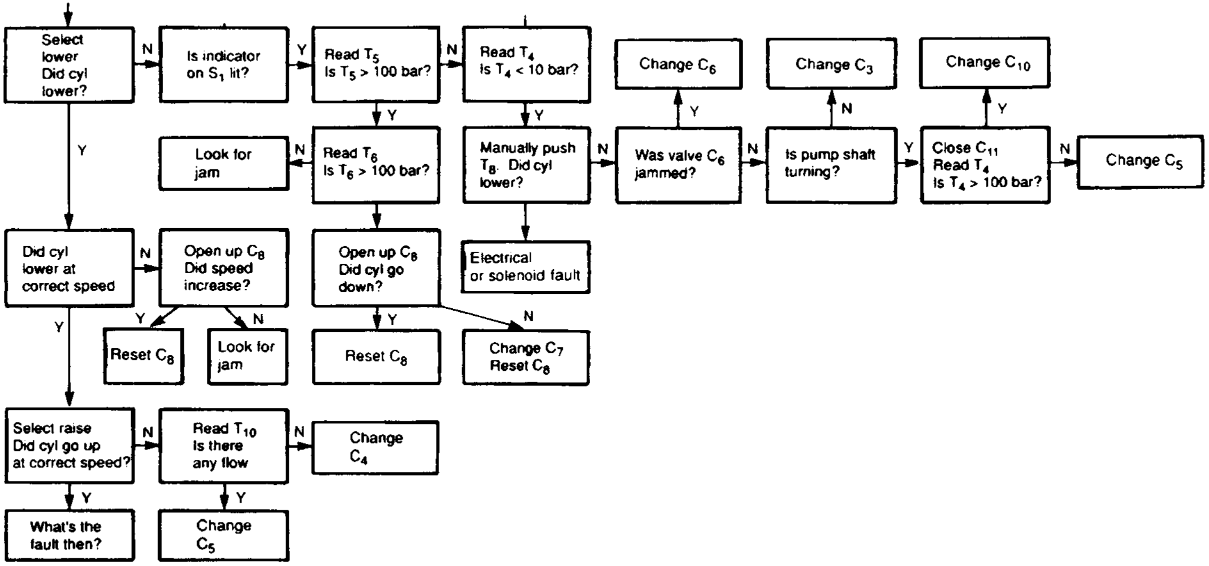


Figure 8.11 *Fault-finding flowchart for circuit of Figure 8.10*

Preventive maintenance

Many production people think a maintenance department exists purely to repair faults as they occur (the common image being a team sitting in the workshop waiting for the 'phone to ring). The most important part of a maintenance department's responsibility, however, is performing routine planned maintenance. This provides regular servicing of equipment, checks for correct operation and identifies potential faults – which can be corrected before they interrupt production. A personal analogy is the 6,000 mile service for motor cars. As an often overlooked side benefit. planned maintenance trains the maintenance craftsmen in the operation and layout of the plant for which they are responsible.

A planned maintenance schedule can be based on a calendar basis (work done daily, weekly, monthly and so on) or on an operation based schedule (work done after so many hours operation, or so many cycles) with time run or number of cycles recorded by control equipment. Different parts of the system may have differing maintenance schedules. Identifying what work needs to be done, and the basis of the schedule for each item is the art of planned maintenance. It depends heavily on the nature of the plant; air filters in a dust filled steel works say, require checking more often than in a clean food factory.

With the advent of the desk-top personal computer many excellent computer-based maintenance planning programs are available. These produce fully detailed work schedules on a shift-by-shift basis, and flag urgent work. The user still, however, has to specify the work to be done and the basis of schedules.

In hydraulic systems it is generally thought that oil problems (level in the tank, contamination by dirt, air or water) are responsible for around three-quarters of faults. Regular checks on oil condition and level are therefore of utmost importance. Any sudden change in level should be investigated.

Oil temperature should also be checked regularly. High temperatures arise from heat produced by flow discharging with a high pressure drop. Apart from the obvious possible fault with a heat exchanger (no water flow for example) other possible causes are incorrect operation of relief or unloading valves (ie, the pump on load continuously) internal leakage or too high a fluid viscosity.

System pressure should be recorded and checked against design values. Deviations can indicate maladjustment or potential faults. Too high a pressure setting wastes energy and shortens operational life. Too low a pressure setting may cause relief valves to operate at pressures below that needed by actuators, leading to no movement. Pressure deviation can also indicate developing faults outside the system. The fouling of a component moved by an actuator, for example, may cause a rise of pressure which can be observed before a failure occurs.

Motor currents drawn by pumps and compressors should also be checked both in working and unloading states (ideally, indication of motor currents should be available on a panel local to the motor). Changes in current can indicate a motor is working harder (or less) than normal.

Filters are of prime importance in both hydraulic and pneumatic systems. The state of most hydraulic filters is shown by a differential pressure indicator connected across the filter element. Obviously filters should be changed before they become blocked. Inlet air filters on pneumatic systems also need regular cleaning (but *not* with flammable fluids such as petrol or paraffin). A record should be kept of filter changes.

Many checks are simple and require no special tools or instruments. Visual checks should be made for leaks in hydraulic systems (air leaks in pneumatic systems generally can be detected from the noise they make!). Pipe runs and hosing should be visually checked for impact damage and to ensure all supports are intact and secure. Connections subject to vibration should be examined for tightness and strain. It is not unknown for devices such as pumps and compressors to 'walk' across the floor dragging their piping with them.

Where the device examined follows a sequence, the operation should be checked to ensure all ancillary devices, such as limit switches, are operating. The time to perform sequences may be worth recording as a lengthening of sequence times may indicate a possible developing fault due to, say leakage in a cylinder.

Actuators have their own maintenance requirements given in manufacturers' manuals. Seals and bushing in cylinders, for example, require regular checking and replacement if damaged. Cylinder rods should be examined for score marks which can indicate dust ingress. Actuators which move infrequently under normal duty can be operated to check they still work (and also to help lubricate the seals).

Treat leaks from around the rods of cylinders with urgency. If oil is leaking out round the neck seal on the extend stroke, dirt is being drawn into the system on the return stroke and a minor leak can soon turn into a major system failure.

Pneumatic preventive maintenance is very similar to hydraulic maintenance (although obviously there is no hydraulic oil to check). Other points such as piping, filters, fittings, sequences and so on need checking in the same way.

Compressors have their own maintenance requirements Many are belt driven, and require belt condition and tension to be checked at regular intervals. Crankcase oil level and the air breather should also be checked.

The compressor is normally sized for the original capacity plus some reserve for future additions. A compressor will thus start life on a low duty cycle, which increases as further loads are added. When compressor capacity is reached, the compressor will be on 100% duty cycle. Any additional load results in a fall of system pressure in the receiver. Leaks also cause a rise in compressor duty cycle, as will any loss of compressor efficiency. Duty cycle of the compressor thus gives a good indication of the health and reserve capabilities of the systems.

Compressor efficiency is determined largely by the condition of valves, piston rings and similar components subject to friction wear. These should be examined at intervals given in manufacturers' instruction manuals.

Other common pneumatic maintenance checks are validation of safety valve operation on the receiver, replenishment of oil in the air lubrication and drainage of water from air dryers.

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