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Safety When Externally Pressurising Hydraulic Systems

Carrying Out Diagnostic Activities Using External Energy Sources

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In liaison with BFPA
REPRESENTING HYDRAULIC & PNEUMATIC INDUSTRIES

Safety When Externally Pressurising Hydraulic Systems

Additional Information Sources

The following information sources should be understood and complied with by those planning and managing the process:

- Health and Safety at Work Act 1974
- Management of Health and Safety at Work Regulations 1996 (plus 2006 amendment)
- Provision and Use of Work Equipment Regulations 1998
- Health and Safety Executive Guidance Note GS4 - Safety with pressure testing
- Control of Substances Hazardous to Health Regulations 2002
- BFPA – Fluid Injection Injuries Emergency (http://www.hydraulichosesafety.co.uk)

Note*: this list is not exhaustive*

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- British Fluid Power Association
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- This Construction Plant-hire Association-issued document only contains basic safety information and should not be the sole source of information to the operative of this equipment. The document published by the Health and Safety Executive (HSE) – guidance note GS4 – *Safety with pressure testing* should be referred to at all times.
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- The Construction Plant-hire Association continually updates the information contained in this document and reserve the right to withdraw at any time pending review.

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Safety When Externally Pressurising Hydraulic Systems

Introduction

The pressurising of oil-based hydraulic circuits, systems or components using an external hydraulic energy source – usually a hand-operated power pack, is an activity occasionally undertaken by construction plant-based maintenance staff to determine component function or fluid loss.

However, serious incidents have occurred during this activity as the stored energy created by the external energy source has led to system or component failures. These can include:

- rupture of components, ancillary or pressurising equipment;
- disintegration of system components;
- inadvertent disconnection of connectors or adaptors.

Each type of failure can and has caused injury or death to those in the vicinity of the activity through being struck by for example:

- flying fragments of ruptured or disintegrated components;
- hose whip caused by failure of a connector;
- high-pressure fluid release through the rupture of a hose or component.

A common factor has been the pressurisation of systems and components which have exceeded safe values. Causes of these failures can include:

- lack of knowledge of the activity by those carrying out the operation (the 'operative');
- lack of planning and supervision;
- lack of safe procedures;
- faulty or worn equipment, components and ancillary equipment;
- lack of knowledge of the dangers when potential failures occur.

Aim of the Document

This document has been produced by the Construction Plant-hire Association in liaison with the British Fluid Power Association to provide guidance in the prevention of incidents related to the pressurising of construction plant and equipment-based hydraulic systems and components as it is considered a high-risk activity.

This document is divided into 3 sections:

Section 1: 'stay safe' guidance written for those carrying out the task;

Section 2: operational guidance written for those responsible for managing and supervising the operation;

Section 3: supporting underpinning knowledge relating to the technical content and outlines the required knowledge, skills and training for those carrying out the operation.

The document specifically deals – based on past incidents - with system and component pressurisation of systems and components using an external energy source either in-situ i.e. in their normal place on the machine or removed from the machine and pressurised externally.

Although it is not specifically aimed at the pressurising of hydraulic system and components using the machine's own hydraulic pressurising system, many of the same principles will apply.

This document is based on, and reinforces the content of the Health and Safety Executive (HSE) publication; Guidance Note GS4 - *Safety Requirements for Pressure Testing*. Publication GS4 is generic across all sectors and includes the activities of pressurising components for proof-testing during and post manufacturing purposes, as well as for maintenance purposes.

GS4 provides comprehensive information relating to the planning of pressure-testing activities and the CPA and the BFPA advocate that GS4 must be read and complied with in the first instance.

This CPA published document contextualises the content of GS4 specifically for the construction plant maintenance sector in a bid to raise awareness of the specific dangers of pressure testing for diagnostic purpose using an external energy source, and to promote the availability of guidance note GS4.

The use of grease guns by maintenance staff to pressurise components for adjustment purposes has resulted in fatalities where failures have occurred under high pressure due to the stored energy. Much of the content of this guidance relates to the use of grease guns when used under pressure.

Employers should as a first step consider utilising organisations that specialise in pressure testing activities and have the correct equipment and appropriate knowledge to safely conduct this high-risk activity.

Case Study

An experienced fitter was using a portable hydraulic hand-operated pump to test a cylinder for an oil leak. During the activity, the valve block on the cylinder fractured due to excessive pressure. The resulting explosion caused an ejection of metal and other debris at high speed.

The fitter was crouching at close proximity to the cylinder. He was not wearing protective headwear and was not shielded by a protective screen. He was struck by debris, resulting in a serious head injury. He was taken by air ambulance to hospital where he died the same day.

An investigation by the Health and Safety Executive (HSE) found that the company had failed to have adequate supervision in place for this task and they failed to inform the fitter of the safe working pressure for the cylinder he was testing.

The investigation also found that the employer failed to have protective screens in place to prevent projectiles injuring staff. They also did not exclude other people from the test area.

Definitions for this guidance

pump

An external energy source, usually hand-operated for the context of this guidance and used to create hydraulic energy and increase system pressure in a closed system

system

Series of interconnected components and equipment utilised to raise the pressure and includes the pump, lines, connectors, adaptors and component being investigated, and includes internal oilways of the component

safe system of work

A procedure resulting from a systematic examination of a work process that identifies the hazards and specifies work methods that eliminate the hazards or controls and minimises the relevant risks

operative

The person who predominately carries out the pressurising activity

Part 1 – For operatives, how to stay safe

Pre-activity checks

Stay safe by…

- seeking other methods for fault-finding activities that do not require the pressurisation of systems or components
- carrying out diagnostic activities with the component in its normal place and using the machine's own system to supply pressurised oil where inbuilt safeguards such as pressure relief valves prevent over-pressurising
- getting trained and/or be formally assessed so that you have demonstrated you can safely and competently carry out pressurising activities with an external energy source
- understanding the procedures to be followed and that emergency procedures are in place detailed within a provided safe system of work
- ensuring that shielding and screening, adequate to contain flying fragments, are in accordance with the safe system of work and are in the correct position to be effective
- establishing a sufficient exclusion zone and ensuring that all non-essential personnel/other workers are outside of the exclusion zone during pressurising activities
- pressurising only the components or system identified within the safe system of work
- being familiarised on the pressurising process for the specific equipment, components and test equipment
- wearing the generic and specific personal protective equipment PPE suitable for hydraulic pressurising purposes
- ensuring that the pump to be used is compatible for pressurising activities
- incorporating a pressure gauge on or between the pump and the component so that overall system pressure is easily and accurately identifiable
- having a means of safely and efficiently exhausting overall system pressure between the pump and the relevant components
- checking the integrity and condition of the pump
- identifying the maximum pressure rating of the component or system being checked
- identifying the maximum pressure rating of the pump, hoses, connectors, adaptors and all ancillary equipment used for the pressurising activity
- ensuring that units of pressure are the same or have been correctly converted, including any pressure gauge readings
- checking the compatibility, condition and integrity of hoses, connectors and adaptors, threads and securing equipment including pressure ratings and thread types
- determining internal oilways of a component by referral to a hydraulic diagram
- not carrying out the pressurising activity where the safe system of work is unable to be followed, or where clarification of the safe system of work is required.

Carrying out the activity

Stay safe by…

- thoroughly cleaning all hose, connector and adaptor threads, ports etc. before connecting
- tightening connectors and adaptors to the specified torque setting
- using correct sealing items – O rings etc. of the right type and size
- minimising the number of connections and adaptors between the pump and the component (or entry point to a system)
- connecting whip-check cables between hoses and connectors
- checking the pressure gauge for clarity, function and accuracy
- slowly increasing pressure within the system whilst maintaining observation for potential failure of the system or components
- maintaining a constant check of the pressure within the system
- increasing the pressure in the system in stages and allowing a rest period between each stage
- checking for leaks at each stage and halt any further pressure increase if a leak is detected
- not exceeding the pressure rating of any component within the system which has the lowest pressure rating
- carrying out fault finding observations by keeping the maximum distance needed to maintain observation
- being prepared to release system pressure in the event of a potential failure of equipment
- using the minimal amount of system pressure to carry out the fault-finding activity
- keeping limbs clear of potential failure areas – hose connectors, screwed/bolted sub-components etc.

Completion of the activity

Stay safe by…

- exhausting pressure within the complete system that has been pressurised (note: some components may retain 'trapped' pressure even though the system - lines, pump etc. may have been depressurised)
- cleaning displaced hydraulic oil and, along with cleaning residues and materials, dispose in accordance with environmental procedures
- thoroughly cleaning all components used for the pressuring activity
- checking components used for the activity for wear and damage created during the pressurising activity, and marking and placing out of service if defects are noted
- fitting protection devices such as end-caps onto test hoses, connectors etc. to prevent ingress of material/debris during storage
- storing all components using their storage receptacles/cases etc. and/or in their correct location that protects and prevents damage during storage
- reflecting on the activity against the conditions and procedure laid down within the safe system of work and advising planners of the process where improvements can be made.

Part 2 – Planning and supervising

Introduction

Correct selection, planning and supervision is essential for the safe use of pressuring hydraulic systems, however incorrect operation often occurs and is responsible for many accidents and incidents, causing serious injuries and death.

Hydraulic systems or components for fault-finding purposes should not be subject to pressurisation where more effective or methods can be used.

Pressurisation activities can be hazardous without proper planning, and managers and supervisors need to understand safe methods of work and the potential issues that can exist. Managers and supervisors have personal and legal responsibility to ensure safe systems of work are devised and relayed to those undertaking the work.

Where any doubt exists on complying with the listed safety requirements and control measures needed to safely conduct pressuring activities, it is essential that serious consideration is given to employing specialist organisations to carry out the work

Before starting work, managers and supervisors should ensure that the operative carrying out the task

- knows that if it is not safe to carry out the activity - they must inform you;
- knows that if it is not safe to continue with the activity - they must stop and inform you;
- undertakes the activity according to the safe system of work.

Managers and supervisors need to plan and implement action so that the pressurising of components will not expose personnel to unnecessary risks.

Those undertaking the pressurising activity should have knowledge of, and the authority to, stop the work should concerns of safety becomes apparent.

Managers and supervisors further need to ensure that those working around and near to hydraulic maintenance and fault-finding activities are aware of the potential risks and the consequences of any failure.

These notes for managers and supervisors are in addition to the information within sections 1 and 3 and they should be conversant with the content of these other sections.

Managers and supervisors should:

Planning the activity
• Consider safer methods of diagnostic fault finding that mitigate risks to those undertaking the event and those nearby, such as the machine's own oil pressure supply where inbuilt safeguards such as pressure relief valves prevent over-pressurisation • Check using machine and component manufacturer's data that faults with the component or system is capable of being diagnosed through the use of an external pump • Ensure that a full risk assessment is undertaken by a competent person • Construct a safe system of work based on a risk assessment and method statement that is written in a logical sequence which states clearly each step of the operation and the safety procedures to be followed • Disseminate the information to the operative undertaking the activity as well as any supervisory staff • Specify physical barriers, signs and other equipment that prevent others from entering the activity area

Planning the activity (cont'd)

- Consider the forces involved such as those identified with guidance note GS4
- Determine and specify shielding and impact protection equipment that, based on the potential forces involved, can contain and adequately shield the operative in case of high-pressure fluid ejection and flying debris
- Specify minimum exclusion zones so that those not involved in the event are safely clear in case of malfunction such as high-pressure fluid ejection, flying debris and large volumes of oil loss
- Specify the required personnel protective equipment that is adequately suitable for the activity
- Ensure that the operative undertaking the activity has suitable knowledge, skills and experience of using the relevant type of external pressure sources
- Verify that all equipment being used is of the correct type, pressure rating and is fit for purpose
- Verify that the maximum pressure of the least-rated component within the system, including the test equipment has been identified
- Make clear to the operative, using a method where easy reference can be made, the pressure which must not be exceeded
- Ensure that adequate lighting and, where required, ventilation is available throughout the activity
- Ensure that first aid provision and emergency procedures in cases of medical emergencies are in place
- Specify and ensure that emergency equipment such as oil spill kits are supplied
- Evaluate and provide necessary platforms and methods of fall prevention or protection where working at height is involved
- Ensure that a quick and easy method of pressure dissipation is provided allowing overall system pressure to be readily and safely exhausted.

Supervision requirements

- Specify the level, extent and frequency of supervision required for the activity
- Ensure that the supervisor or supervisors are fully briefed on the activity being undertaken including emergency procedures
- Ensure that non-essential staff are outside of the exclusion zone.

During the activity

- Regularly review the procedure for the activity and record changes or amendments
- Immediately suspend the activity if unencountered or unexpected problems occur.

After the activity

- Ensure that following completion of the activity, that all equipment used is checked for integrity and damage before being stored.

Part 3 – Supporting Information

Fundamentals and Principles

Oil flow and pressure are used in construction plant to operate services using linear or rotary motion to produce or assist with an output of work. This flow of oil is provided by a pump or pumps driven by an on-board power unit – internal combustion or electric-motor – and produces a controllable flow of oil to a selectable service. When maintenance and fault-finding activities are carried out, an external pump may be used to replicate and provide oil flow to a particular component or part of a system.

An oil pump provides a forced flow of oil. It is resistance to that forced flow which raises the pressure with a system or component. The resistance to that flow can come from either the oil being forced through one of more restrictions or meets an obstruction where oil cannot escape - a closed system. As the pumping action continues, the pressure will increase and resistance will build up in the pump from which:

a) an in-built safety measure such as a pressure relief valve is activated which exhausts and limits the rising pressure; or
b) there is insufficient energy to drive the pump and stalls the powering unit; or
c) a failure or rupture will occur due to the pressure exceeding the safe maximum for the component, part etc.

Pressure Acting upon a Surface

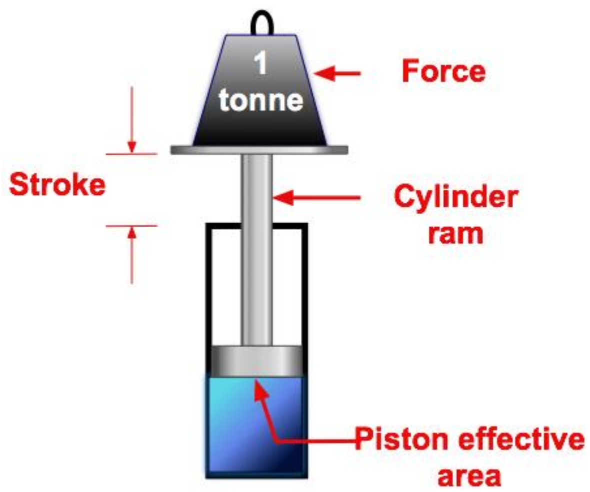


Figure 1: relationship between force, pressure and area

Figure 1 shows a closed cylinder having a force acting on the ram and piston. Below the piston is trapped hydraulic oil. The force applied by the weight raises the pressure below the piston which is constant and transmitted equally in that part of the cylinder. Increasing the force proportionally increases the pressure and increasing the pressure applies a greater force. The relationship is expressed by the formula:

Force = area x pressure (F = A x *P*) or Force = pressure/area (F = *P*/A)

When pressure is applied to two pistons of the same effective surface area, an equal force is applied to both pistons. If the pistons differ in surface area, the one with the larger diameter would be able to apply or contain a greater force.

Hydraulics are an efficient way of converting pressure into a force which can be multiplied by the increasing the effective surface area that the pressure is acting upon. Where the system is closed, it is liable to a great pressure rise due to forced flow of oil until pressure is advertently or inadvertently exhausted.

As an example, a hand pump can raise great pressures within a closed system and – providing the system can bear the pressure – is only limited by the operative's ability to apply an effort to the pumping handle. This is because hand pumps contain a piston with a small surface area which although is limited in the amount of oil moved per stroke, can apply great pressures with a system. Without this understanding, operatives can easily exceed safe system pressures by continual pumping of the handle and /or applying physical exertion on the handle where resistance to pumping is felt.

Pressure Units and formulas

The official SI unit for pressure is the pascal (*Pa*) which is equal to one newton per square metre - (*N/m^2 or kg/ms^2*). Pressure can also be expressed in units such as pound per square inch (*psi)* or bar. A letter can sometimes be appended to the psi unit to indicate the measurement's zero reference, for example 'psia' for absolute pressure and 'psig' for gauge pressure.

A pascal is a small unit for pressurised hydraulic systems used in construction plant for which bar is more frequently used, or a multiple of the unit e.g. 1000 pascals (*Pa),* which can be indicated as 1 kilopascal (kPa). Figure 2 provides a conversion factor between commonly-used units of pressure.

The maximum pressure rating of both the component or components being diagnosed and the gauge being used to show system pressure may be indicated by different units. The operative and those managing the operation need to be able to both identify and convert the various units so that maximum system and applied pressures are clearly understood during the activity.

No specific unit is mandated providing one unit is converted and used consistently throughout the operation, and that the operative is able to easily read and identify the unit involved. For easier referencing by the operative, the unit that should be used is the one indicated by the pressure gauge that is reading overall or maximum system pressure.

Fundamental Unit	Pounds per square inch	Bar	Pascal	Newton/Square metre
Practical Unit	**psi *(lbf/in^2)***	**bar**	**kPa**	**kN/m^2**
psi	1	0.0689	6.89	6.89
bar	14.5	1	100	100
kPa	0.145	0.01	1	1
kN/m^2	0.145	0.01	1	1

Fig 2: Pressure Conversion Factors

Examples: 1000 pascals (*p*) = 1 kilopascal (kPa*)* = 0.001 MPa

3000 psi = 206 bar = 21,000 kPa = 20 MPa

For higher pressures used within plant hydraulic systems, the values for kPa and kN/m are too great and may be converted to MPa (mega-pascal) or MN/m^2.

psi (lbf/in^2)	bar	MPa	MN/m^2
100	6.9	0.69	0.69
500	34	3.4	3.4
1000	69	6.9	6.9
1500	103	10.3	10.3
2000	138	13.81	13.81
2500	172	17.2	17.2
3000	207	20.7	20.7
3500	241	24.1	24.1
4000	276	27.6	27.6
4500	310	31.0	31.0
5000	345	34.5	34.5
5500	379	37.9	37.9
6000	414	41.4	41.4
6500	448	44.8	44.8
7000	483	48.3	48.3
7500	517	51.7	51.7
8000	551	55.1	55.1
8500	586	58.6	58.6
9000	621	62.1	62.1
9500	655	65.5	65.5
10000	689	68.9	68.9

Figure 3: Conversion chart indicating example values at different ranges

Pressure Readings and Gauges

The raising of any pressure within a closed system should not take place unless a device that reads live pressure within the system is employed. These are commonly a dial-type gauge or those utilising a digital readout. Dial type gauges have a graduated scale with pressure indicated by a rotating needle against the scale. Gauges may be marked with a single scale of unit or more commonly equipped with two or more units.

Where there is a choice, gauges with single units corresponding to the unit specified within the safe system of work should be used to negate the operative having to convert units during the activity. Where gauges with several units are being used, the operative needs to ensure that the correct unit is being read. To accurately read a dial-type gauge, the operative should view the face of the gauge at a right angle.

Figure 4: Analogue Dial-type pressure gauge with two scaled units

Digital readout gauges normally have a selectable mode where different units can be shown, for which the right unit that corresponds to the unit specified in the safe system of work should be selected, minimising the potential for any miss-reading. Digital readout units can have the limitation of not being readable at certain angles and strong sunlight or reflections can render a gauge unreadable.

Gauges used to read system pressure should have a higher rating than the maximum pressure of the system so that any over-pressurisation can be easily noted. Subjecting a gauge to a higher pressure than it's rated maximum can damage the gauge possibly affecting its accuracy and risking failure.

Hoses, Connectors, Adaptors and Fittings

Hoses come in a variety of types for which their ability to withstand pressures is a result of their construction and material type. Hoses used for hydraulic purposes generally have double wire braiding, with quadruple braiding where higher pressures are employed. The form of the braid can further reflect the hose's ability to contain pressure.

Hoses are pressure rated and indicated by the manufacturer stating the maximum pressure rating by one or more of the following methods:

- Written text on the hose;
- Labelled tag;
- Colour coded hose (for which a conversion chart is required);
- Trade name and colour coding.

For most operatives, the only sure way of determining the pressure rating of a hose is through the manufacturer's identification marking.

Hoses with no marking or formal rating identification should not be used.

Figure 5: Hydraulic hose indicating the maximum working pressure

Connectors are generally joined to a hydraulic hose through a crimping method or via a screwed compression fitting. Continual movement of a hose around the connector can cause a weakening which is not always evident through a visual examination. Where stresses have been suspected around this area means that the hose should not be used for pressurisation purposes.

Figure 6: hose with a crimped connector and double male adaptor

In the majority of cases, using an external oil supply means that the pump will need to be mated through one or a series of hose fittings. These will be threaded meaning a variety of thread sizes and pitches may be involved from which compatibility issues may occur. Common thread types for the majority of fittings include:

- BSP
- BSPT
- Metric
- SAE
- JIC

To connect a pump to a component using lines or hoses may involve the use of adaptors for which the thread compatibility between pump, hoses and components needs to be ensured. As thread sizes and types may vary, adaptors having different thread sizes and types on each end may need to be used.

For example, an adaptor may have a metric thread one end and a BSP on the other but of a different diameter. Connectors and adaptors may further have either a male or female thread or a mixture of both e.g. male one end and female the other end. Allied to the various thread types means that great care needs to be taken to ensure that correct types are identified and specified by a competent person.

Figure 7: Examples of adaptors of male-to-male and female-male types

Some hose and connector suppliers specify the use of a Teflon/PTFE based tape or other form of thread sealant to be placed onto tapered male threads which provides further sealing action without using excessive tightening forces. Non-tapered threads should be fitted with 'O' rings or Dowty-type washers.

Where the correct fitting with the right thread types and ends have not been readily accessible, operatives or others have created 'home-made' versions by cutting and welding or brazing different connector ends together. As these are potential weak points and not tested to withstand system pressures, they should not be used.

Where connecting hoses or lines to a component where different thread types or sizes exist and the correct type of adaptor is not available, operatives have joined up a chain of numerous adaptors in sequence. This arrangement can be a weak point meaning that the correct connectors or adaptors need to be sourced at all times.

Continual re-use of connectors and adaptors can start to fatigue and wear the threads and subsequently become a weak point. As threads start to wear, weeping of oil under pressure can occur for which the tendency of an operative is to overtighten the connector. This action can further deform the thread leading to a greater risk of failure under pressure.

A further cause of thread damage is the where operatives have attempted to couple male and female components of similar diameters but different pitches and have forced or wound them together.

Figure 8: Example of a quick-release coupler

Quick-release connectors may be used to connect regularly used components together and are less likely to encounter wear and damage. They are however still prone to damage, particularly where unprotected when not being used. Couplers should be cleaned before disconnection or reconnecting as dirt can enter and contaminate the system and small particles of dirt can prevent a good seal between mating components. Couplings should be examined and where signs of wear are evident or where component parts such as the locking balls are missing, both parts of the coupler should be replaced in tandem.

Quick release connectors can be disconnected under pressure retaining trapped oil pressure in each of the lines. When releasing quick release couplings, operatives and others must not stand in line in case there is an inadvertent release of high-pressure oil, or where the couplers fly apart.

As some types cannot be reconnected under pressure, a tendency is to release pressure by loosening the hose fitting or by applying pressure to the nipple, ball or face; each being an unsafe activity. Unless the coupling can be reconnected under pressure, the line should be exhausted before disconnecting the coupler. Once connected, a visual inspection should be made to ensure that the carrier sleeve has returned to its correct position. On screw-type couplings, the mating threads should be fully engaged.

External power sources - Pumps

The pump should be of a type that allows full oil flow from the unit and subsequent pressure rise to be fully controllable. It should further allow pressure to be safely and adequately exhausted back to the pump once the activity is complete unless another form of pressure exhaustion has been applied. The pump should be fitted with a with a pressure relief valve (PRV) set at or below the maximum permitted pressure of the lowest rated component within the system. Where not fitted, a PRV should be contained within the system.

If a pressure gauge is fitted to the pump, as with all gauges it should be fully functional, accurate, the pressure ratings clearly marked and visible to the operative at all times during the activity. Where not always visible, a secondary gauge within the system should be fitted with a pressure rating comparable with the pump’s gauge or able to be easily converted.

Figure 9: Example of a hand-operated external power pump (without built-in pressure gauge)

The pump should be stable and where necessary, secured so that unnecessary movement cannot occur during the pumping process.

Hazards, risks and potential failures

For the testing of leaks, there is minimal need to subject the component to its maximum rated pressure. The pressure should be raised slowly and once the leak is observed, there should be no further requirement to raise the pressure.

The release of system pressure should be undertaken through a valve able to be operated from outside of any enclosure and capable of extinguishing pressure within the overall system quickly whilst safely containing released oil.

When raising the pressure in a closed system, this should be done in stepped stages before increasing the pressure to the next stage. This allows:

a) the pressure within the system to acclimatise;
b) for any pressure drop to be observed;
c) a visual inspection to be carried out for leak, potential failures etc.

Systems containing an accumulator should not be pressure tested using a hand-type pump, particularly off the machine. Accumulators are pressure vessels, designed to store energy and maintain pressure and require specialist knowledge for removal, dismantling and testing purposes. Reference should be made to the machine manufacturer's maintenance manual of procedures for the diagnosing of potential faults in accumulators.

Where hoses are used, whip check cables should be utilised so that in the event of a hose departing from a coupler, connector or adaptor, the movement of a hose has been limited. Where uncontrollable hose whip occurs, it has the capacity to strike those nearby with a great force, and spray out over a great distance hydraulic oil which may further be hot - able to cause third-degree burns. Whip check cables should be secured to both the hose and retained to a nearby component that can withstand the force of a failed hose.

Figure 10: Example of hose whip cables and securing method

If aiming to identify external leaks from welded areas, low pressures such as 3 - 5 Bar are generally considered more than adequate to locate external leaks. Where higher pressures are used, this can deform the component, possibly causing a contraction of a weld, preventing the ejection of oil and masking the source of a leak.

Note: some specialists have suggested that when pressurising construction plant systems or components for diagnostic purposes (except for checking system pressure relief valve settings), most diagnostic activities would unlikely to need pressures exceeding 200 Bar.

If a hydraulic component such as a connector, adaptor etc. is ejected in any way, the component should not be re-used, since it is likely to have sustained damage during the event. Where a threaded component has detached, all male and female parts involved should be scrapped and not reused. Partially stripped threads may not appear visibly damaged but will be unable to sustain their design pressure.

The integrity of the union between any replacement components and the assembly should be verified by a competent person. If there is any doubt, employers should seek advice and guidance from the original equipment manufacturer or supplier. All scrapped components should be destroyed to prevent future use.

Factors for burst containment

Pressurising hydraulic components is a high-risk activity as there is a potential for failures or ruptures to occur at medium to high pressures. This could cause the fragmentation or detachment of components, or any accessories used for the pressurising activity, which can create fragmented missiles ejected at high speed.

Containment methods such as enclosures of sufficient strength should be utilised to contain ruptures, fragments and high-pressure oil. The HSE's Guidance Note GS4 *Safety requirements for pressure testing* indicates that as a guide, mild steel plating should be used which has a minimum thickness of 3 mm. Further information on calculating enclosure strengths can be sourced from the HSE research report CRR168/1998 – *Pressure test safety.*

The area within the enclosure should be considered a no-entry zone to operatives when the system is at pressure. This area shall only be entered after a rest period. All other non-essential personnel should not enter the enclosure during the pressurising activity with barriers, screens etc. should be utilised to keep them well clear of the activity area.

Sufficient hose or line length should be used between the pump and the component being pressurised, with sufficient distance between them so that the component is shielded from the pumping area. The point where system pressure is being exhausted should additionally be remote from the component being pressurised.

Effects of oil on the body

Hydraulic oil is generally a mineral-based product that can cause skin conditions and is classed as a carcinogen – which has the ability to cause cancerous cells, particularly on sensitive areas of skin. The biggest risk to those involved when dealing with pressurised systems is the ejection of oil from a pressurised system which has the potential to enter the body involuntary.

Where oil ejected at high velocities enters the skin, this can enter the blood stream which has the high potential to cause life-changing injuries. Hydraulic injection injury can occur at pressures as low as 7 Bar. The use of grease guns under high pressures has further caused the injection of grease which has entered the skin, causing death to maintenance staff.

Hydraulic Circuits and Symbols

A hydraulic circuit is the system that connects the pumping element of the machine to the component which is activated by oil flow, and includes the internal oilways within a component e.g. actuating cylinder. The routing of internal oilways are not evident externally, for which refence needs to be made to a system or circuit diagram which indicates internal galleries and elements. Operatives need to be competent in deciphering hydraulic symbols in order to determine the layout of a system and the function of the components. Annex A shows a simple system using a hand pump and indicated using hydraulic symbols.

Diagnostic Procedures

Preparation:

Equipment and components being used for the pressurising activity should be cleaned internally and externally and if necessary, flushed out to remove foreign objects that may cause damage or hamper the pressurising activity.

Checks on condition of threads, 'O' rings and seals should be made for damage along with ensuring that all components, accessories etc. are clean and free of dirt and debris, Threads should be in good condition and where used, sealing devices such as 'O' rings and 'Dowty'-type washers be undamaged.

Visual checks need to be made on hoses and their ends and if they are unclean, damaged (cuts/exposed braiding etc.) rusty, chafed etc. they should not be used. If the pressure rating of the hose is not known, it should not be used.

Oil used for diagnostic purposes should be compatible with the machine's hydraulic system. The use of an incorrect type of oil may contaminate and affect the seals, which can lead to premature seal failure.

Temporary blanking plugs should be removed and stored safely in readiness for re-fitting at the end of the activity.

The pressure gauge should be accurate and calibrated with a clearly visible scale and needle (or readout) and the unit or units of the scale clearly marked.

The gauge needs to indicate overall system pressure and where this is not possible due to for example flow restrictors in the circuit, a secondary gauge should be employed in the different parts of the within system.

The rating of the pressure gauge or gauges should exceed that of maximum system pressure. However, gauges having a high rating or have minimal markings on the scale may not be able to be read accurately enough to indicate when maximum system pressure has been reached.

When connecting hydraulic components to the external energy source, minimal adaptors should be used when thread types and sizes differ as they are a potential weak point.

Where air needs to be expelled from the system, this should be from the proper bleed points positioned at the highest point. The loosening of a connector or adaptor to expel air can cause the pipe or hose to depart from the connector.

Carrying out the activity

Where fluid leaks are being detected, high-pressure oil ejection can occur and may not be visibly noticeable to the naked eye. Other methods to indicate weeping or leaking oil, such as the use of a coloured card placed near to the suspected area should be used, with the operative wearing suitable PPE that prevents oil from contacting skin. Note: generic PPE will not prevent the injection of high-pressure oil through the skin.

If checking the movement of a component e.g. the stroke of a ram, the extension or movement of the component beyond its intended or design maximum should be taken into account. The area of any potential overreach should be aimed and shielded away from the operative and others within the area.

If a component being checked contains an internal pressure relief valve (PRV), its nominal maximum pressure needs to be determined and the valve adjusted where necessary so that the component's maximum system pressure is not exceeded. Checks and provision needs to be made so that in the event of the activation of a PRV, exhausted oil is safely diverted and contained accordingly.

The internal make-up of a component or system should be known – usually by reference to a hydraulic diagram - so that the location, type and number of PRVs, one-way valves, internal oil ways and oil flow directions etc. are understood. Oil supply from the external source should only be applied to the component's normal flow direction in case for example, one-way valves are fitted.

Where blanking plugs are used to seal an oilway, it should be ensured that this does not prevent pressure reduction from for example, a PRV.

Pressurisation of a system should be raised in a controlled manner and pressure applied gradually. The raising of the pressure should be done in small stages with rest period in between each stage. The pressure should not be increased further if a defect or leak if found. If several defects or leaks are suspected, the first discovered issue needs to be remedied before increasing system pressure.

If it is necessary to raise the pressure within the system beyond the safe maximum, the potential for failure can dramatically increase. Professional expertise should be utilised to check the need to raise system pressure and determine a safe maximum that must not be exceeded. For most diagnostic situations, there would be little need to exceed the rated system of component pressure.

If over-pressurisation of a component has inadvertently occurred, there could be subsequent damage or the characteristics of the component could change. Appropriate expertise, for example from the machine or component manufacturer, should be sought before re-use of the component.

The adjustment, loosening and tightening of any component or equipment used for the activity should not be undertaken whilst the system is under pressure. Adjustments should only be made after system pressure had been exhausted.

Post activity procedures

All pressure must be exhausted before disconnecting and dismantling the hoses, connectors, adaptors etc. Pressure within a system should only be exhausted via a suitable proportional control valve that directs oil back into the pump or into a suitable container. System pressure must not be exhausted by loosening an adaptor.

Checks should be made to ensure that pressure has been exhausted in the complete system. The use of one-way check valves within a system may prevent total system exhaustion. Examination of the system's or the component's hydraulic diagram should be referenced to the pressurising activity to identify potential areas where trapped pressure may occur.

Quick release connectors can be disconnected with the line under pressure and can trap oil pressure. They should not be disconnected until pressure in the line has been exhausted. There have been attempts to apply a force on the nipple, ball or face of the male connector in a bid to release trapped pressure which has ejected high pressure oil at the operative and caused damage to the coupler, rendering it ineffective.

Residual oil within any components that are to be refitted to the machine needs to be flushed and thoroughly cleaned to prevent contamination of the machine's hydraulic system and all equipment used for the pressurising activity should be thoroughly cleaned, blanking plugs refitted and correctly stored to prevent damage or contamination.

Diagnostic Activities on Site

Where diagnostic activities are occurring on site at or near to the machine, the ability to maintain cleanliness can be challenging because of the type of environment where construction-type equipment is used, meaning that the potential for the ingress of dirt, foreign objects etc. is higher. Care should be taken to shield exposed hydraulic components and diagnostic equipment from the surrounding environment.

The area of the machine being accessed for diagnostic purposes, or where a component is being removed, needs to be clean around that area prior to connecting pressurising equipment or removing the component. This is to prevent contamination and/or ingress of dirt etc.

Where external oil loss will occur during or post the pressurising activity, containment equipment such as drips trays should be used with waste oil collected, containerised and disposed of following the organisation's waste-disposal method that are in compliance with relevant regulations.

Training requirements

Those undertaking fault-finding activities on hydraulic system and components need to have the knowledge, understanding, skills and experience of hydraulic (oil-based) systems including the fundamentals and principle of hydraulics. The following list is the minimum educational levels recommended by the British Fluid Power Association (BFPA) for those dealing with hydraulic systems on a fault-finding and diagnostic basis and should know and understand the following topics:

Basic Principles

1. Basic layout of a typical hydraulic circuit

2. Function and operation of the parts that are used to construct a typical circuit

3. Fundamental principles that underpin the operation of all hydraulic systems in relationship to:
   a) Pressure and Force
   b) Flow, Displacement and Speed
   c) Pressure, Displacement and Torque
   d) Power in with reference to the prime mover
   e) Power out with reference to actuator operations
   f) Pressure drops/Power losses/Heat generation.

This should involve simple calculations, associated units and terminology.

Hydraulic Symbols

4. Recognition of hydraulic symbols in current use relating to ISO-1219-2012 and apply these to the various component parts within a hydraulic circuit with reference to a typical:
   a) Open circuit
   b) Closed circuit.

Hydraulic Pumps

5. Types of pump in common use (gear, vane and piston) with reference to:
   a) Construction and principle of operation
   b) Fixed and variable displacement
   c) Methods used to control displacement (pressure compensation)
   d) Relationship between flow and pressure (pump performance).

Hydraulic Fluid Oil Reservoirs

6. Basic layout and function of typical hydraulic fluid oil reservoirs and their features and characteristics.

Pressure Control

7. Devices used to control and limit pressure within a working circuit with reference to:
   a) Relief valves, pressure reducing valves and sequence valves
   b) Following safe setting up procedures
   c) Effects upon performance if adjustments are made.

Flow Control

8. Differences in construction between a simple throttle valve and pressure compensated flow control valve with reference to:
   a) Performance and energy losses
   b) Pressure intensification through the use of flow control valves.

Direction Control

9. Construction, function and principle of operation of:
   a) Simple inline check valve
   b) Pilot operated check valve
   c) Spool direction control.

Hydraulic Actuators

10. Construction and operation of the types of actuators in common use.

Contamination Control

11. Importance of cleanliness management associated with hydraulic system performance with reference to:
   a) Locations where contamination can enter a system and recommended preventative measures/procedures that should be followed
   b) Effects upon performance due ingression of contamination
   c) Filter performance and location
   d) Regular monitoring of systems to assure target cleanliness levels are maintained.

Hydraulic Fluid

12. Use of hydraulic fluid including:
   a) Function of the fluid within a system
   b) Meaning of the term 'viscosity' and how it affects overall performance
   c) Factors that affect the life of the hydraulic fluid in service
   d) Importance of good storage and transfer processes.

Hydraulic Hose Technology

13. Hose types and function including:
   a) General construction of hydraulic hose assembly and the concept of "fit for purpose"
   b) the acronym; 'STAMPED' in relation to hoses *(Size, Temperature, Application, Medium, Pressure, End-couplings & Delivery of Fluids)*
   c) Inspection factors before installing a particular hose
   d) Recommended procedures to effectively installing a hose
   e) Causes of reduced hose life/failure
   f) Safe procedures when carrying out hose inspection and the signs of deterioration and actions to be taken.

Maintenance Procedures

14. Issues and factors when working on hydraulic systems including:
   a) Main causes of failure in hydraulic systems
   b) Importance of being able to identify normal key system performance indicators
   c) Symptoms associated with a change in performance
   d) Importance of a pro-active maintenance scheme and associated record keeping
   e) Importance of following safe working procedures at all times when carrying out such activities as:
      - installation
      - commissioning
      - servicing/testing
      - inspections
      - checking performance
      - other activities that fall within the job role specification.

Test and Measurement in Hydraulic Systems

15. Test and measurement equipment in common use.

Health and Safety Factors

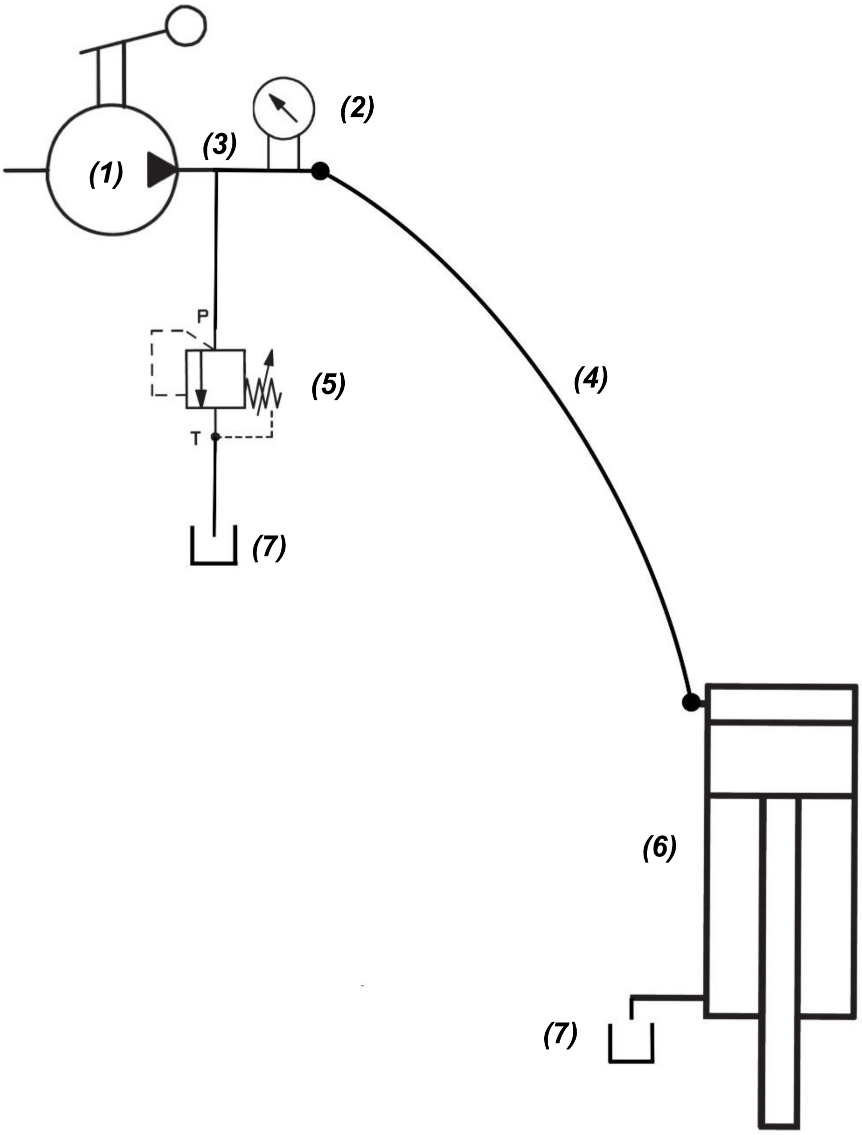
16. Due to pressures, temperatures and transmission of power that is involved; knowledge and understanding of the hazards, risks and control measures are required to deal safely with hydraulic systems and includes:

a) Importance of personal protection associated with the working environment
b) Importance of safe isolation practices and understanding the operation of any machinery on which they are planning to work
c) Dangers of trapped and stored energy and how to deal with it (such as accumulators)
d) Dangers associated with hydraulic oil leakage and how to deal with it
e) Effects of oil injection injuries and the immediate actions to be taken
f) Procedures to follow before starting work on any hydraulic system
g) Importance of training and working within their trained capability
h) Importance of following all safe working procedures and rules laid down by the employer.

The BFPA offer a range of hydraulic and pneumatic system-based training courses for industry at their Training Academy along with a training passport scheme. Further details can be found at www.bfpa.co.uk/training/courses and www.bfpatrainingacademy.co.uk respectively.

Annex A

The diagram below shows a typical construction plant type activity where the function of a hydraulic ram is being checked for operational purposes. The layout is a simple one and the system is shown using hydraulic symbols according to ISO 1219-1. The pressure gauge and pressure relief valve may be incorporated in some pumps



(1) – Hydraulic pump – hand operated
(2) – Pressure gauge
(3) – Rigid line/pipe
(4) – Flexible line/hose
(5) - Pressure relief valve (adjustable)
(6) – Double acting cylinder – single rod
(7) – Reservoir/tank (open)