REFITTING OF HYDRAULIC MACHINERY

BY

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Introduction

Before the special techniques used in refitting hydraulic machinery can be appreciated, it is important to understand why hydraulic machinery is special, and how this machinery differs from others.

The principle on which the theory of the hydraulic transmission of power is based is a law formulated by Blaise Pascal in 1648. This states that pressure at any point in a static liquid is the same in every direction, and pressure exerted on an enclosed liquid is transmitted undiminished in every direction and acts with equal force on equal areas. This led to what might be thought of as a hydraulic lever or force multiplier. It is used in practice in hydraulic jacks and presses where a small force, applied over a small area, is transmitted to a larger piston that will support a proportionately larger weight.

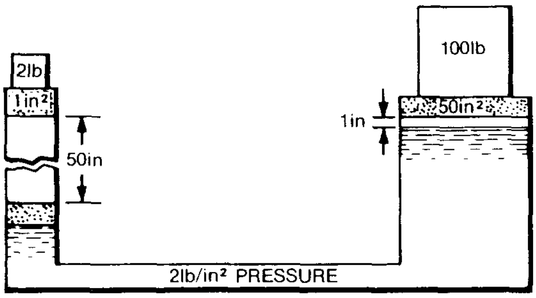

FIG. 1—THE PRINCIPLE OF A HYDRAULIC PRESS

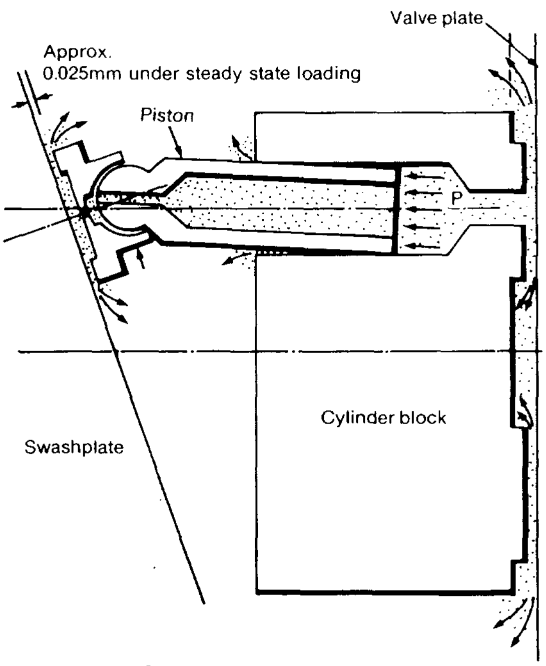

FIG. 2—CRITICAL CLEARANCES IN AN AXIAL PISTON PUMP

It will be noted from FIG. 1 that the pressure is easily transmitted round corners and that the two cylinders can be any reasonable distance apart. However, since the volume of liquid leaving the small cylinder must equal the volume of liquid entering the large cylinder, it can be seen that this force amplification is achieved at a sacrifice of distance and so the small piston is replaced by a pump making many short strokes to achieve the lift required.

Early hydraulic machinery employed water as the working fluid. Water was cheap and plentiful, so leakages from the system were common and acceptable. Water, however, is a poor lubricant and the actuator internals would therefore be likely to seize; thus only relatively low pressures could be used. The areas of the operating cylinders were large in consequence, and this meant that the application of hydraulics was constrained mainly to static machinery.

With the development of independent hydraulic systems (sometimes called constant volume systems), the total volume of fluid required was reduced considerably and so more expensive mineral oil could be used. This enables higher pressures to be employed and consequently the size of the plant could be reduced. This gave rise to the requirement for still higher pressures and thus, to maintain these pressures, better seals, finer finish to mating parts, and smaller clearances between those parts were necessary. This in turn meant tighter tolerances during manufacture and more stringent controls on cleanliness throughout assembly and use of this machinery. (see FIG. 2).

Failure of Hydraulic Components

It will be no surprise therefore that one of the most common causes of failure of hydraulic components is dirt in the system. The significance of the contamination depends upon the size of the particles, and the most damaging are those greater than a critical size specified for the system.

Common sources of contamination are:

(*a*) new oil, usually contaminated during storage or delivery;

(*b*) built-in system contamination from new components and pipes. This is usually in the form of swarf, shop dirt, dust, fibres, sand, moisture, weld splatter, corrosion particles, and paint chippings;

(*c*) environmental contamination entering through breather pipes, equipment access covers, cylinder shaft seals, and replenishment connections. In a marine environment this is usually dirt brought in from the dockside, or salt particles from the atmosphere which in turn produces corrosion particles within the system.

It will be seen therefore that contamination by liquids and air, though of secondary importance, gives rise to corrosion products already mentioned and also generates wear products through causing the lubrication of the moving parts to break down.

The failures produced by contamination fall broadly into three types:

(*a*) *Catastrophic failure*—when a large particle causes a pump or valve moving parts to jam or a control orifice to be blocked.

(*b*) *Intermittent failure*—when contaminant on the seat of a poppet valve prevents it seating correctly, but is washed away when the valve reopens.

(*c*) *Degradation failure*—due to wear, corrosion, and erosion. This causes increased internal leakage in hydraulic components or sloppy control due to the erosion of the control edges of spool valve pistons.

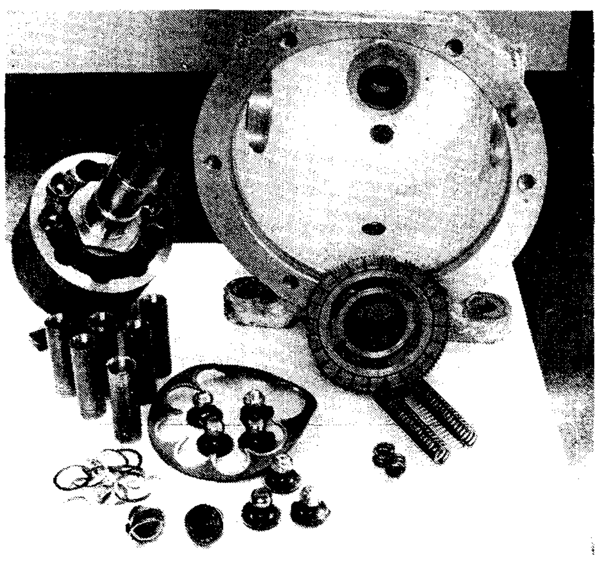

FIG. 3—CATASTROPHIC FAILURE OF AXIAL PISTON PUMP SHOWING DAMAGE RESULTING FROM PISTON SEIZURE

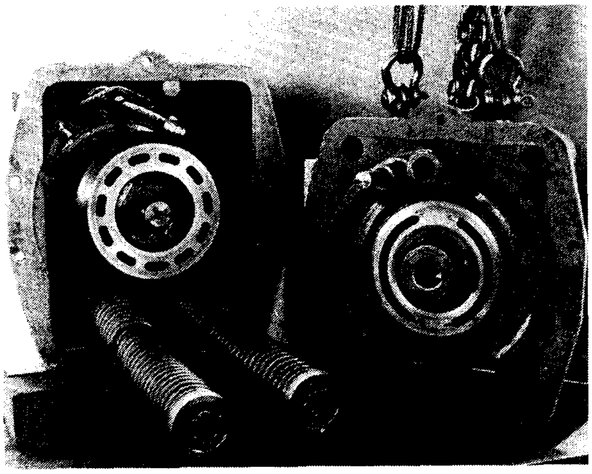

FIG. 4—DEGRADATION FAILURE OF AXIAL PISTON PUMP SHOWING WEAR CAUSED BY DIRT TO PUMP BARREL AND VALVE PLATE FACES

Refitting Hydraulic Systems and Components

It has already been shown that dirt is Public Enemy No. 1 to hydraulic systems and components. From the outset, therefore, care must be taken to ensure that no further contamination can enter a system when a defective component is removed for repair.

To prevent any contamination from entering the system when any pipes or threaded connections are detached, the exterior surrounding area must be cleaned well, and subsequently all openings should be sealed with plugs or caps.

Before any hydraulic system is disturbed, there is one aspect of personnel safety that must be observed. Hydraulic systems under pressure are reservoirs of a large quantity of energy. It is vital therefore to ensure that the system is depressurized before any pipe work is disconnected, as any escaping jet or spray of oil is a potential fire or explosion hazard and it can also cause severe damage to the eyes or exposed skin.

On receipt of the defective component for repair, it is cleaned externally, stripped down, and its constituent parts cleaned and degreased. All parts are examined visually for signs of damage, and then critical dimensions are measured accurately in a clean and temperature-controlled room; these dimensions are compared with those on the relevant dimensional inspection chart. If the component size is within its permitted limits, and it shows no signs of scoring or pitting, it is passed on to the fitting benches for preparation for re-assembly. At this stage it is sometimes necessary to replace worn parts with new spares or, if these are not available, reclaim worn components or manufacture new ones.

Common forms of wear are deep scores on actuator or accumulator cylinder bores, and grooving of pump shafts in way of the shaft seals. In both cases, reclamation is effected by grinding back the bore or journal to remove the score marks and then building up the surface by hard chrome plating. Up to 0·030 inches can be reclaimed in this way. For air-loaded accumulators most score marks can be removed by honing and fitting oversize piston rings. If this is not possible, the cylinders are sent to have the bores 'fescolized' before grinding to the original size.

Sometimes the cylinder barrels of piston pumps are worn oval. If this ovality is within prescribed limits, the barrels can be ground and lapped and a standard oversize piston fitted. Similarly, control valves can be resleeved, or the bores ground oversize and a standard replacement spool fitted. Valve plates of axial piston pumps can be lapped to remove wear between the ports and, provided the case-hardening is intact, these can be re-used.

In a particular case, where the bore in a control valve was integral with the body (i.e. there was no separate spool valve sleeve), the scored bore was reclaimed by boring the block oversize and shrink-fitting a replacement sleeve. Both mating surfaces have to be lapped to a high standard of finish and the replacement sleeve chilled in a flask of liquid nitrogen. As the valve ports had to be drilled in the replacement sleeve, it was necessary to leave the sleeve fairly thick to prevent the drill distorting the sleeve away from the body. Then, after fitting the sleeve, the ports were drilled in stages with a small pilot hole drilled first. Finally the sleeve inner diameter was bored, ground, and lapped to finish size.

When all dirt-making operations have been completed, the components are once again cleaned and degreased before passing into a clean room for assembly and testing.

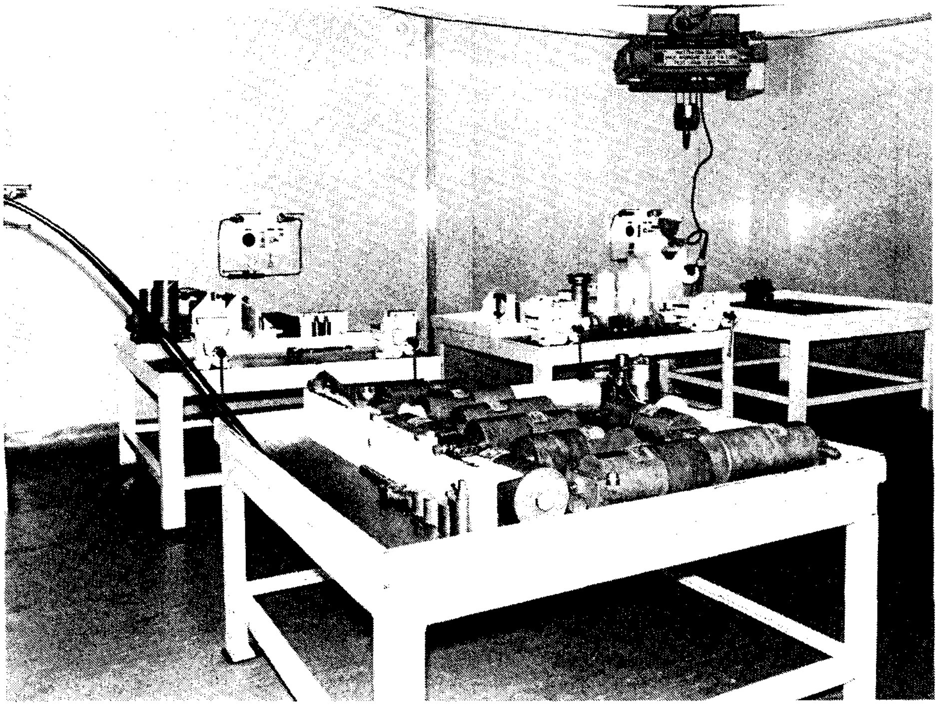

FIG. 5—A HYDRAULIC CLEAN ROOM

Testing Hydraulic Valves and Machinery

The test procedure for refitted hydraulic components is usually carried out in two parts. The first operation is a pressure test using the hydraulic fluid specified for the system (of which the component is a part), the test being carried out at the specified temperature to ensure a standard viscosity. This proves the adequacy of the envelope of the components and the efficiency of the seals. Secondly, flow measurements are taken, if required, to set up the restrictors in the control blocks or to prove the volumetric efficiency of the actuators.

Pumps are tested in a loading rig, where the rig pressure is controlled by the setting on the relief valve. The rig prime mover is a variable speed electric motor. The pump is first run up light and then loaded to the required pressure. Pressure and flow readings are measured periodically and the pump casing leak-off is collected and measured. Throughout the test the temperature of the hydraulic fluid is monitored and the pump discharge oil is passed through a cooler to maintain the temperature in the circuit within the prescribed limits. Some trials require heat runs to be carried out for four or eight hours to prove that there is no untoward build-up of temperature in the pump. For weapon equipments, a maximum temperature of 140°F anywhere in the circuit is specified. This is to ensure that, even at local hot spots, the oil never reaches that temperature at which carbonization occurs which would cause solid contamination of the hydraulic circuit.

The casing leak-off quantity is a good guide to the condition of the pump. At low pressures, if the leak-off is excessive, it can mean that there is inadequate sealing between the valve plate and the cylinder of the pump. At high

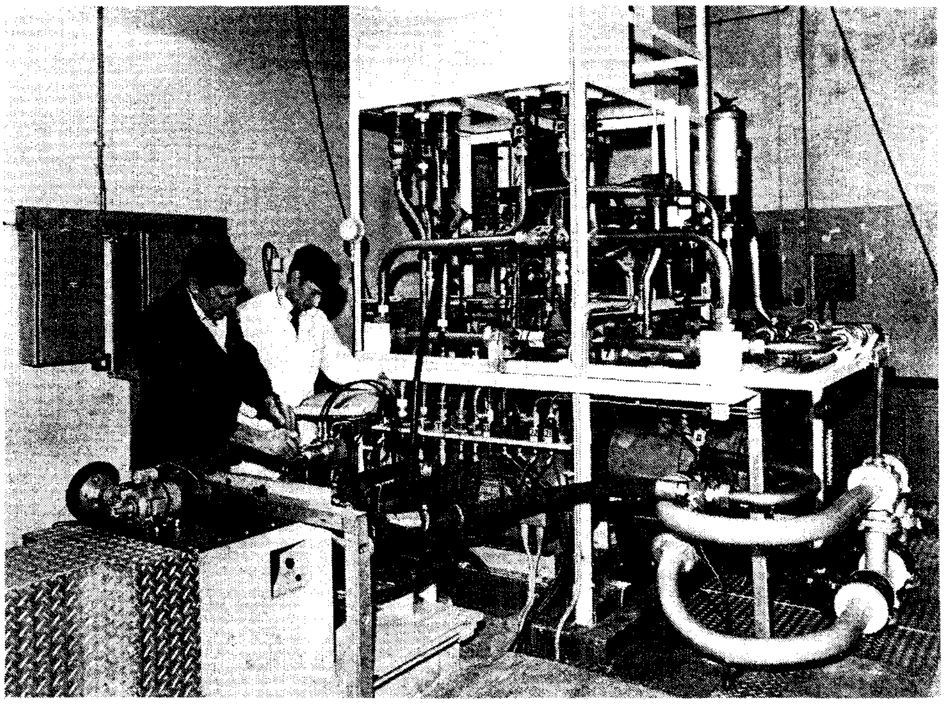

FIG. 6—PUMP TEST RIG FOR CONTROLLABLE-PITCH PROPELLER PUMPS

pressures, excessive leak-off usually occurs through excessive clearances of the pistons in their barrel.

Sometimes the pump is required to be tested on cyclic load patterns. In these cases, a cam is fitted to the operating lever of the servo control valve or swash plate and the flow and displacement of the servo piston or swash plate is measured on an X—Y plotter.

Motors are tested in a similar manner using a hydraulic pump as the 'A' end and measuring the output of the motor against a dynamometer. Pressures, temperatures, flow rates, and leak-offs are measured as before, with the motor operating against a specified load.

In all cases it is vital throughout the test that the hydraulic fluid is kept clean, and strict contamination controls maintained during connecting and disconnecting the equipment. On completion of testing, all openings are capped and operating shafts protected. The whole component is then sealed in an evacuated polythene bag.

Re-installation of the Refitted Component

As illustrated by the foregoing, a great deal of time and expense has been lavished on the component to ensure that it is not degraded during any phase of the repair. Often these efforts are negated by careless re-installation of the component into the system or by flushing a dirty system through a clean component. This can and must be avoided.

As a guide, the following sequence is recommended:

(*a*) Complete the installation of pipework and dirt-tolerant components before sensitive components are put into place. This may require dummy blocks to be made to establish the fixed pipe runs.

(*b*) Complete the hydraulic circuit using jumpers to take the place of sensitive components. The system is then filled and pressure tested, and flushing is carried out until the required system cleanliness is reached.

If care is taken during the installation of the refitted component, further flushing is not necessary. To ensure this however, embargoes must be placed on operations such as the following:

(*a*) Welding.

(*b*) Brush or spray painting.

(*c*) Chipping, drilling, grinding, or caulking.

As a further precaution, temporary clean areas should be constructed by means of polythene-sheet tents and personnel access controlled. Installation of all pipe hangars and seatings for machines should be completed before any installation of new equipment is commenced. All open ports and pipe ends should be plugged with suitably-sized ELF caps.

When fitting new or repaired equipment, the specified tightening torques must not be exceeded. This is particularly important where Keelaring couplings are fitted, as the hardened collet will bite too deeply into the pipework and start a stress raiser that could result in subsequent failure by fatigue. If the system is to be painted, it is important that the area of pipework in the vicinity of any coupling should be left bare and protected by mastic tape where exposed to the weather.

When refilling the system, it is recommended that a charging pump with a built-in filter is used. The area surrounding the filler cap should be wiped clean before the cap is removed. All pistons should be placed in the retracted position where possible and the reservoirs of filter assemblies filled separately.

Before starting up for the first time, the system must be bled. Variable displacement pumps are run up in the neutral position and the level of oil in the reservoir checked. Each directional control valve should now be operated in turn until all rams are in the extended position, while bleeding from the ends of the pistons until all air is expelled. Indications of a good bleed are:

(*a*) No fluid-air foam in the tank.

(*b*) No unusual noises in the hydraulic system.

(*c*) No jerky movements of piston rods, motors, etc.

Finally, during commissioning, the following precautions should be observed:

(*a*) Any new part replaced during the course of the repair should be considered to be dirty and should therefore be flushed before installation.

(*b*) Any replenishment oil should be considered to be contaminated, and should therefore be tested in advance and embarked through a filtering system.

(*c*) Any new pipes should be considered to be dirty, and so be flushed separately before being connected into the completed system.

Remember that contamination can be caused by liquids and air as well as solids. Liquids can be acidic and cause oxidation corrosion. Air, as well as providing the oxidant, can be the cause of erosion and impact type damage. Fine silt can cause erosion of moving parts and, in addition, can choke fine clearances and prevent the lubrication of the moving parts. This is a common cause of hang-up or stickiness of spool valves.

How Clean is Clean?

In the preceding paragraphs, much emphasis has been placed on the necessity for keeping hydraulic systems and their components clean, but *clean* is a relative term and so standards of cleanliness must be specified. For the Royal Navy, these standards are laid down in BR 3038—*Hydraulic Standards and Practices,* and the design authority for the hydraulic systems decides on the contamination class that must be maintained.

A field monitoring kit has been issued to most ships and establishments to enable samples to be taken. A diagrammatic representation of this kit is shown in FIG. 7. Samples can be taken from running systems (dynamic sampling) or from reservoirs or bottles containing specimen quantities of the oil.

For dynamic sampling, the system pressure pushes the oil through the monitor and low pressure sampling can be carried out this way for pressures not exceeding 100 lb/in^2 (6·9 bar). For static samples a sampling pump is provided to pass the fluid through the monitor.

FIG. 7—SAMPLING KIT

As shown in FIG. 7, a number of adaptors is required to take a dynamic sample. This is a cumbersome process and the provision of an integral fitting is being investigated. After taking the sample, the monitor is removed and brought back to the laboratory for drying and mounting on a specimen slide.

To assist in rapid analysis of the sample, sets of standard slides for each of the contamination classes have been produced. The sample slide is placed alongside a selected standard slide and a comparison made under a microscope.

Exceptionally, if a quantitative analysis is required for a specific purpose, it can be undertaken by displaying the slide on a back-projection microscope. Either a full count can be undertaken or a reduced count made where only particles above a specified size, e.g. 15 micrometers, are considered. For all general requirements of condition monitoring, however, the comparison technique is perfectly adequate.

Flushing and Flushing Rigs

Hydraulic systems will need to be flushed whenever it is likely that particulate contamination has entered the circuit or whenever sampling analysis shows that the contamination class specified for the system has been exceeded. Flushing should be undertaken using the normal working fluid, operating at near normal temperature. The fluid should be circulated at sufficient velocity to achieve turbulent flow in the pipework, such that as many as possible of the particles adhering to the inside walls are dislodged and carried in suspension to the flushing rig filter. Here they are removed before the fluid is recirculated. To achieve these conditions, the hydraulic system should be broken down into suitable lengths of pipework or 'flow paths' to ensure that resistance to flow is kept sufficiently low to maintain turbulent conditions in the fluid.

The basic requirements of a flushing rig are therefore a pump and prime mover, a filter or filter pack, a fluid reservoir with heater, and flexible hoses and couplings.

Since the pipe bores and system volumes vary considerably from one hydraulic circuit to another, a range of flushing rigs has been provided, the most common units in this range are:

(*a*) Trolley units—5 gal/min at 350 psi powered by 110 V a.c. 60 Hz 3-phase at 11·7 amps.

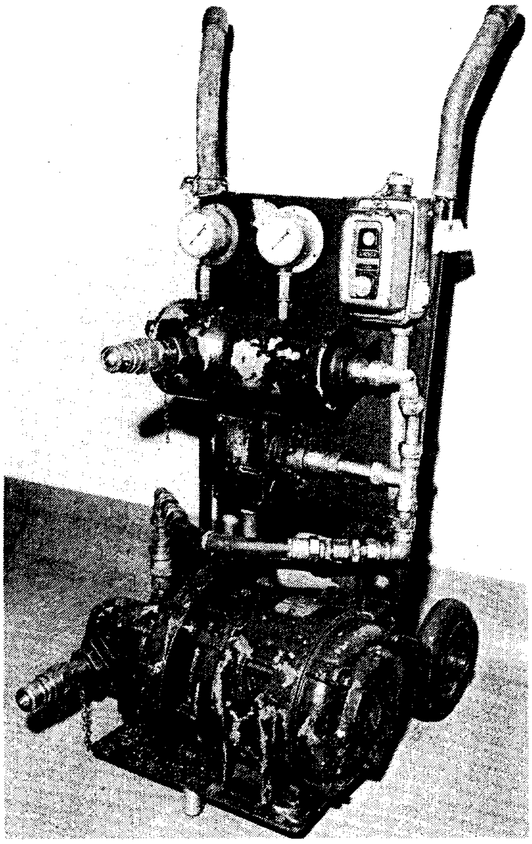

FIG. 8—TROLLEY UNIT

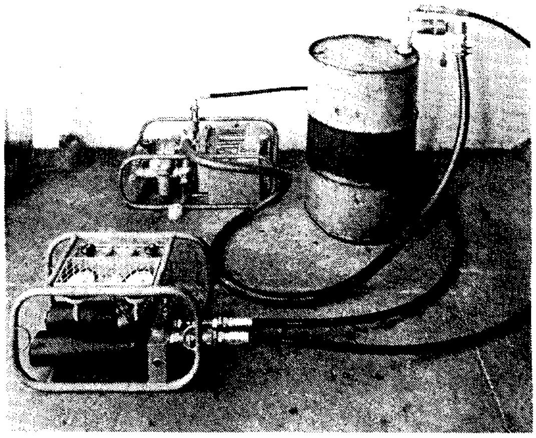

FIG. 9—PARTIKON SPLIT RIG

FIG. 10—LANDROVER-MOUNTED INTEGRAL RIG

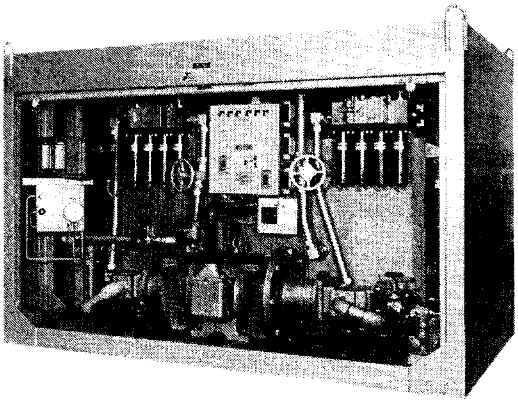

FIG. 11—THERMAL CONTROLS CO. LTD. RIG

(*b*) Low-pressure Partikon split rigs—16 gal/min at 600 psi powered by 110 V 50 Hz 3-phase motor at 40 amps.

(*c*) High-pressure Partikon split rigs—16 gal/min at 1200 psi powered by 415 V 50/60 Hz 3-phase motor at 21 amps.

(*d*) Landrover-mounted integral rigs—60 gal/min at 1000 psi.

(*e*) Thermal Controls Co. Ltd. 200 gal/min rig—200 gal/min at 1000 psi.

These are illustrated in FIGS. 8 to 11.

Although more efficient methods of removing particulate contamination from hydraulic systems are being made available, it should be remembered that flushing is no substitute for contamination control discipline during manufacture or repair, assembly, and installation operations. Flushing will not remove scale, surface corrosion, or adherent debris from pipe walls or internal surfaces of components. It will not remove large or heavy particles, particularly if these are lodged in vertical pipe runs in the system. Internal surfaces of reservoirs, accumulators, oil coolers, or actuator cylinders will not be cleaned easily by flushing as their large volume causes a reduction of the fluid velocity such that turbulent flow conditions may no longer exist.

Summary

The most common cause of failure of hydraulic components is contamination of the hydraulic fluid. This may be already present in new oil, or be introduced by fitting contaminated pipework or components. Contamination may be allowed to intrude by opening up a hydraulic circuit in a contaminated environment, or arise through corrosion and wear of hydraulic components during service. For this reason Tungum and cupro-nickel have been introduced to replace steel as the material for pipework in exposed power plants.

The failures may be catastrophic, causing breakage or blockage; intermittent, causing hiccups in performance that are difficult to diagnose; or a general degradation in efficiency or accuracy of control.

They can be prevented by strict adherence to contamination control procedures during replenishment of fluid, during repair of components and systems, during testing, and by regular sampling and analysis of the hydraulic fluid during service.

Hydraulic components are expensive to manufacture and failures have expensive consequences in equipment downtime and in subsequent repair. Hydraulic hygiene procedures are relatively cheap and add considerably to the reliability of systems and the life of components.

It has been said often that hydraulic systems should be designed to be more tolerant of dirt. It is true that, if clearances between running parts were large enough, a lot of dirt would wash through without damage. The penalty would be lower operating pressures and larger parts. However, as has been described above, slurries of abrasive particles may not cause scoring or jamming of running parts to any significant degree, but may cause control edges of piston valves to become worn resulting in a sloppy system. So there is only one maxim in hydraulics, whether in refit or in service—*Keep it clean.*

Acknowledgement

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