HYDRAULIC EQUIPMENTS

ASSESSMENT FOR R.N. USE

BY

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Introduction

The Naval Engineering Department of the Royal Aircraft Establishment (RAE) has a wide range of facilities for research and development work related to R.N. hydraulic system requirements. Some of the work was reported at the last Manadon Hydraulics Conference[1,2] and this paper is intended to update information on the facilities available for the assessment of hydraulic equipments at RAE (West Drayton).

Following a programme of research and development by RAE, Sea Systems Controllerate has decided that future designs of surface ship for the R.N. (including the Type 23 frigate) will use an aqueous polyglycol fire-resistant hydraulic fluid in the ships' hydraulic systems, and a fluid, Houghtosafe 200X (HS 200X), has been developed to meet the R.N. requirements[3,4]. Consequently, a significant proportion of the Hydraulics Section's effort has been directed towards the assessment of the performance of hydraulic equipments using this fluid, and related problems such as sampling and contaminant assessment. The work is carried out in collaboration with the Petroleum Chemistry and Technology Division of RAE, which was responsible for the initial development of HS 200X. The work at RAE enables the user experience to be fed into the development and assessment programmes, and provides a centre of expertise on R.N. hydraulic equipments and fluids.

Facilities are now available for testing hydraulic pumps, motors, servo valves and filters to MOD test specifications. Reductions in manning levels at RAE have forced a move towards unmanned operation of test rigs and this, combined with a requirement for increasingly complex test cycles, has led to the introduction of microprocessor-based control and logging systems. The process has not been without its traumas, but RAE is now reaching a stage where tests can be run 24 hours a day, 7 days a week, with technicians making periodic checks during normal working hours but otherwise leaving the rigs unattended.

This article describes the main facilities at West Drayton for hydraulic equipment testing, and goes on to discuss the results of the recent test programme. The discussion is inevitably limited because of the constraints of commercial confidentiality.

Pump Test Rigs

Hydraulic pumps are required to run continuously in either small, self-contained systems or large ring main systems, and consequently the pump duty tends to be the most arduous of the hydraulic equipments in a system. So RAE's test facilities initially concentrated on pump performance. Until 1984, three pump test rigs were available at West Drayton: one '250 kW' rig and two '75 kW' rigs.

The 250 kW rig has a variable speed motor, a loading circuit capable of running reversible flow ('over centre') closed loop pumps, and a control and data logging system. It is currently set up to test pumps for ship stabilizer and steering gear applications.

The original 75 kW rigs had fixed speed (1800 r.p.m.) d.c. motors with poor speed stability and a heavy maintenance requirement. They incorporated open loop hydraulic circuits, very simple control systems, and had no data logging facility. They were unable to meet current test requirements in terms of drive speed, flexibility and control systems requirements and were therefore scrapped.

New rigs were needed to meet current and foreseen testing requirements. To give increased flexibility, drive systems, hydraulic loading circuits and control systems are now designed as portable modules which can be assembled into complete test rigs in a varieity of configurations.

In-service running speeds, dictated by the ship's 60 Hz supply, are not easily reproduced from a 50 Hz mains supply. To overcome this problem, a 50/60 Hz, 18 kVA motor/generator set is run continuously to drive one pump under test at 1800 r.p.m. For pumps up to 80 kW input power a solid state rectifier/inverter set has been installed. Both systems use standard induction motors and the design of the drive module now enables pumps and motors to be mounted either horizontally or vertically, depending on the application of the pump under test. For higher powers, a 115 kW variable speed d.c. motor with its own rectifier and control cabinet has recently been installed as an additional pump drive.

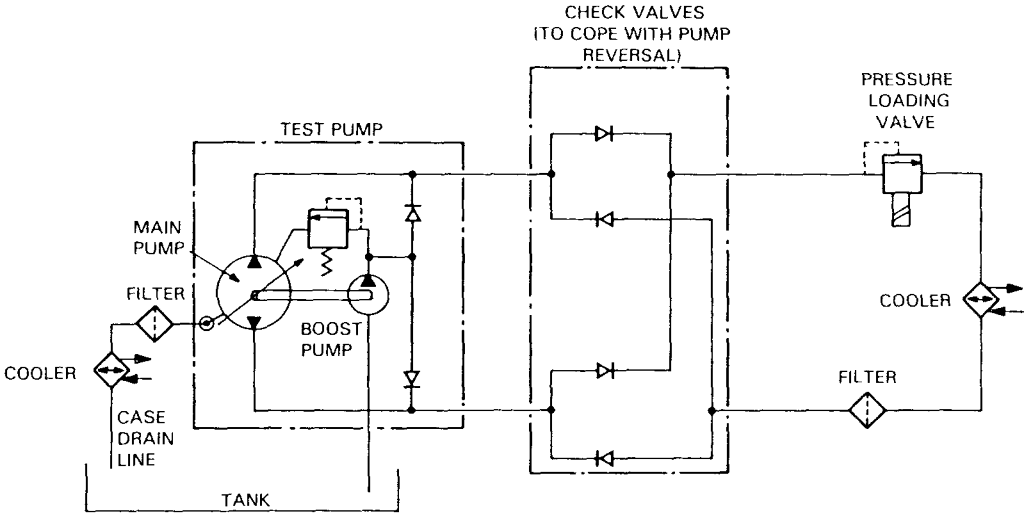

FIG. 1—HYDRAULIC CIRCUIT FOR TESTING VARIABLE DELIVERY PUMPS

The hydraulic loading circuit configuration will depend on both the type of pump and the required test schedule. Remotely controlled variable delivery pumps are tested on a circuit such as that shown in FIG. 1, while a pressure compensated pump with a start/stop test schedule is under test using the circuit shown in FIG. 2. All rigs have coolers and temperature controllers to maintain stable, repeatable conditions.

The majority of rig instrumentation is to be found on the loading module. Since transducers, particularly flowmeters, have a limited range, their range must be selected to suit the pump under test.

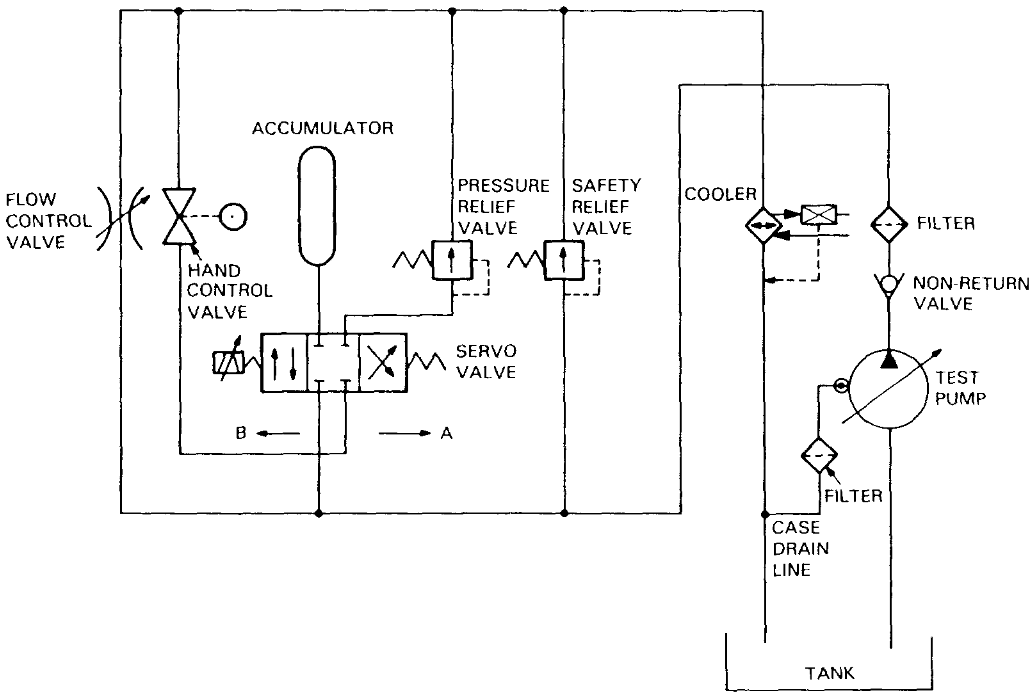

FIG. 2—HYDRAULIC CIRCUIT FOR TESTING PRESSURE COMPENSATED PUMPS

The 250 kW rig has a control system produced in-house, using a Texas 5TI Programmable Logic Controller (PLC) to switch through sets of flow rates and pressures which are pre-set. Data is logged automatically by a Solatron Computer Logger which 'handshakes' with the PLC and provides some data processing. Protection of the rig, including the pump on test, is provided by electromechanical switches which stop the pump motor if temperatures or pressures go outside preset limits.

TABLE I—*Pump Test Rigs: Summary of Modules Available*

PUMP DRIVE SYSTEMS

	Power (kW)	*Speed* (r.p.m.)	*Type*
1	250	200 – 1760	Variable frequency a.c. motor and controller.
2	44	300 – 3000	Standard 4-pole induction motor with variable frequency power supply.
3	12	1800	Standard 4-pole induction motor on 60 Hz supply from motor/generator set.
4	120	0 – 2000	d.c. motor with solid state rectifier.

PUMP LOADING CIRCUITS

	Power Absorption (kW)	*Type*
1	150 at 40°C	Closed circuit reversible flow pressure controllable.
2	50 at 40°C	Closed circuit reversible flow pressure controllable.
3	10 at 50°C	Open circuit variable flow (for pressure compensated pump).
4	250 at 40°C	Closed circuit reversible flow pressure controllable.

CONTROL SYSTEMS

	Type
1.	Texas programmable logic controller & Solartron data logger.
2.	Commodore Pet computer and Solartron Orion data logger (2 systems).
3.	Texas programmable logic controller and MDL 500 data logger.

It was intended to provide each of the old 75 kW rigs with a control and logging system similar to that of the 250 kW rig, and in 1982 a specification was produced, making use of a Texas 5TI PLC for control and a Solatron Orion system for data logging and alarm protection on each rig, with a CBM Pet computer processing the data off-line. Changes in the testing requirements not only resulted in the need for new rigs mentioned above, but also in the need for more powerful and flexible control systems. The specification was modified, therefore, to use a Pet computer to control both the test cycle and the data logger, and to file the data on floppy disc for off-line analysis. Using a 'menu' system, the test cycle, alarm units and data logging schedule can all be changed far more easily than by reprogramming a PLC and data logger.

A summary of Drive Systems, Loading Circuits and Control Systems available in modular form is given in TABLE I.

Motor Test Rigs

A large motor test rig for running low speed, high torque tests on motors up to 20 kW was commissioned in 1985, and a small motor test rig is under consideration. This section describes the design of the large motor test rig, which is intended to assess the suitability for applications such as winch drives.

Test Rig Design

The large motor test rig circuit can be split into three main systems (Fig. 3): the loading box, the mineral oil power pack (providing shaft drive), and the fire-resistant fluid power pack providing hydraulic load.

(*a*) *Loading Box*. In this system the two motors under test are connected by a common shaft in a 'back-to-back' arrangement. The hydraulic circuit is arranged so that the inlet of one test motor is connected to the outlet of the other and, to close the loop, the outlet of this motor is connected to the inlet of the first motor. Thus the motors' drive shafts will tend to rotate in opposite directions but are restrained from doing so by the common shaft, which provides the loading mechanism. A non-return valve arrangement between the motors ensures that the fluid in the circuit always travels through the flowmeters and filters in the same direction. This allows the main circuit flow to be monitored and the filters to protect each motor from any debris generated by the other.

(*b*) *Shaft Drive Power Pack*. This system provides the power to rotate the shaft connecting the test motors. The power pack has a variable delivery axial piston pump, the output of which drives a hydraulic motor which is linked to the test motor connecting shaft by a chain drive incorporating a 2.5:1 reduction ratio. Speed can be varied by adjusting the output of the pump, which is controlled by a Moog servo valve. The power pack can alter the direction of rotation of the

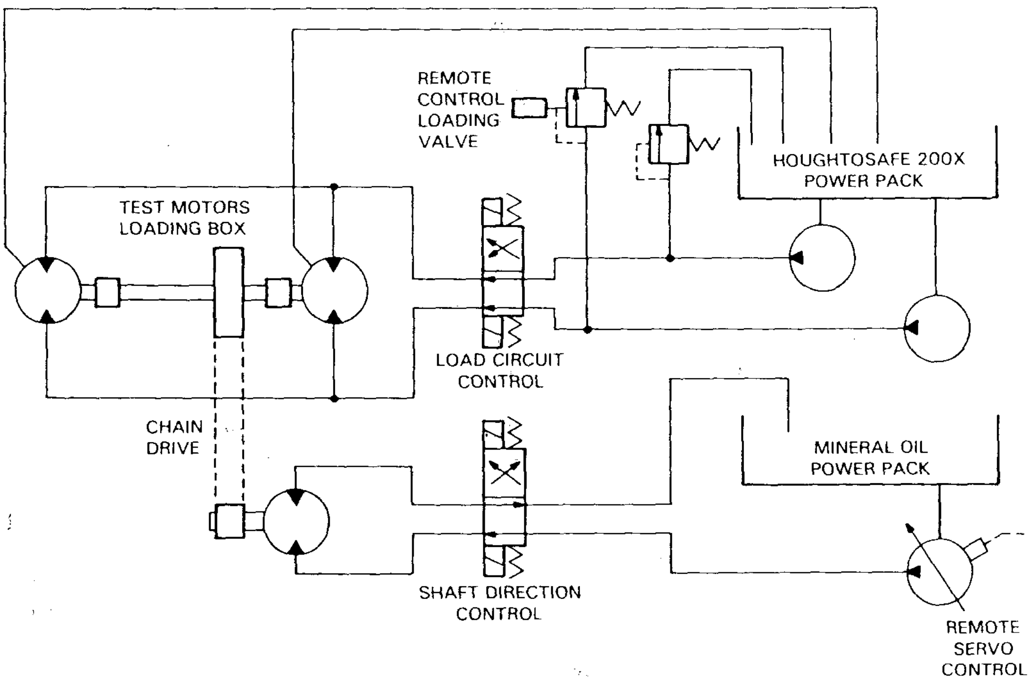

Fig. 3—Motor Test Rig: general arrangement

shaft by a directional control valve which reverses the direction of rotation of the power pack drive motor. Since the circuit is entirely separate from the test fluid, a mineral oil system was used for cheapness and high power density.

(*c*) *Fire-Resistant Fluid Power Pack*. This circuit provides the hydraulic load against which the test motors have to operate. Two internal gear pumps are fitted, one to supply high pressure fluid to one side of the motor test circuit and the other to supply low pressure (boost) fluid to the other side. The power pack can switch the high and boost pressures to opposite sides of the test motors using a directional control valve. The magnitude of the pressure in the high pressure circuit can be varied by a remotely controlled loading valve.

Test Rig Control

Control is accomplished from a separate console, the rig being capable of operation in either manual or fully automatic modes.

The manual control consists of:

(*a*) Selector switches to control drive motor direction, test motor load direction, and auto/manual selection.

(*b*) Potentiometers to control test motor load magnitude and speed.

The automatic controls consist of:

(*a*) A data logger capable of outputting signals to the test rig to control drive motor direction, load direction, test motor speed and test motor load. It can also scan up to 14 thermocouple inputs and 15 other analogue inputs.

(*b*) A computer to control the logger and store the logged data. Software allows the operator to set up and alter the test cycle, and to select, scale and annotate the parameters to be displayed on the monitor. It can also define the data to be stored on floppy discs, and enable dumps to be made to discs at predefined intervals or after specified events.

The control console also houses an automatic shutdown panel and all the necessary instrumentation to monitor the motors under test.

Test Cycle

The test rig is designed to run test schedules which simulate typical ship duty cycles, similar to those in FIG. 4. In this example, half the test cycle is

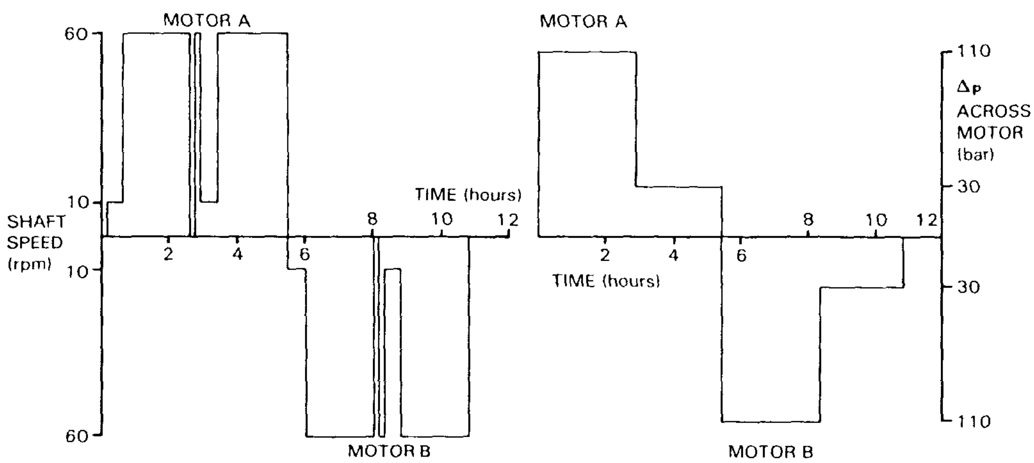

FIG. 4—MOTOR TEST RIG: TYPICAL TEST CYCLE

carried out on motor A, motor B acting as a pump, and the roles of the two motors are reversed for the second half. This is essentially an endurance test with the rig running continuously until 1000 hours (approximately 100 cycles) have been accumulated. At the beginning and end of each test the motors are stripped, examined visually, and relevant components measured. Any significant difference is analysed and reported.

Filter Testing

A complete description of the procedure adopted for testing mineral oil hydraulic filters was included in a paper[1] presented at the 1982 Manadon Hydraulics Conference. Since then, work has concentrated on the evaluation of filters for use on HS 200X systems, the main areas of concern being the compatibility of the element media and support structure with the fluid, and the efficiency with which filters will remove particulate contamination from HS 200X systems.

Material compatibility has been investigated using a hot soak test, generally in accordance with ISO 2941. This consists of submerging an unused filter element for 72 hours in HS 200X at a temperature of 100°C. A simple fabrication integrity test to ISO 2942 is used to check the media and construction before and after the hot soak test. A visual examination indicates whether the materials have been affected by the fluid.

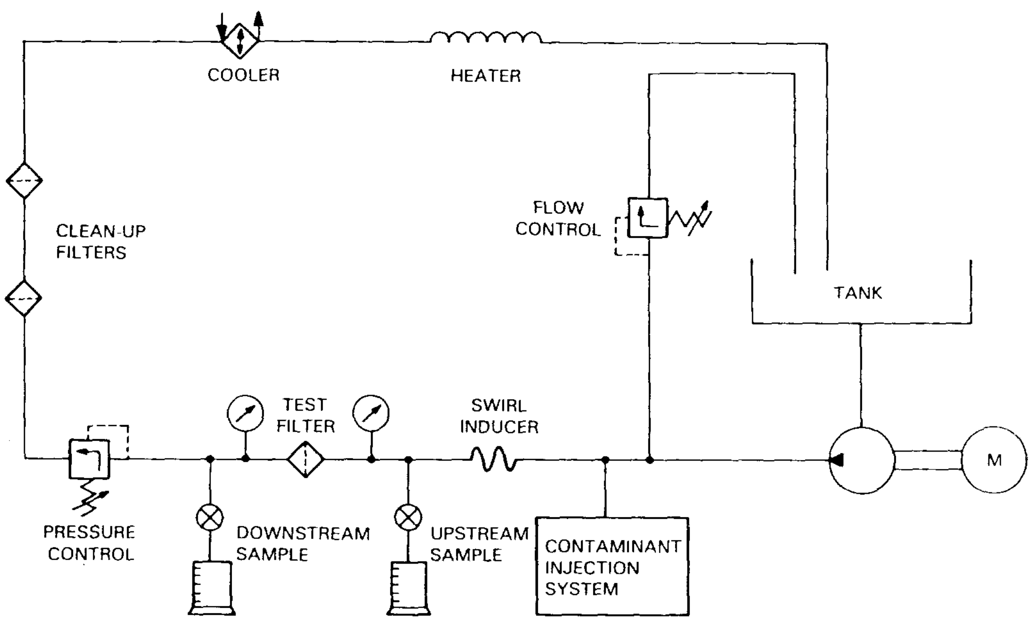

FIG. 5—FILTER EFFICIENCY TEST: SINGLE PASS TEST RIG

To assess a filter element's ability to remove contaminants from a hydraulic system, RAE uses a single pass test (FIG. 5). A new filter element is fitted into the rig and the hydraulic fluid circulated through it, with contaminant introduced upstream at a constant rate. Any contaminant which passes through the test filter is removed by a clean-up filter before the fluid is returned to the reservoir. The differential pressure (dp) across the test filter is monitored and the test is run until the dp reaches the maximum value recommended by the manufacturer. During the test, samples of the system fluid are drawn off at set time intervals from sampling points upstream and downstream of the filter. They are analysed for particle size and population and the retention efficiency calculated. A transmisson curve (FIG. 6) allows the MOD test rating to be deduced. Other organizations have designed multi-pass test rigs for this purpose, in which the contaminant is not removed downstream of the test filter but is recirculated and supplemented as necessary. It may be argued that this technique is more realistic, but in RAE's experience the retention of the single pass method has been justified by its simplicity and repeatability.

The filter efficiency test method developed for use on mineral oils has been adapted to run on HS 200X. While there have been few difficulties in running the test, problems have been experienced in obtaining quantitative estimates of the level of contamination in the samples, since the automatic particle counting method used with mineral oils has produced spurious readings with HS 200X. Consequently, manual counting using back projection microscopy is being used as an alternative.

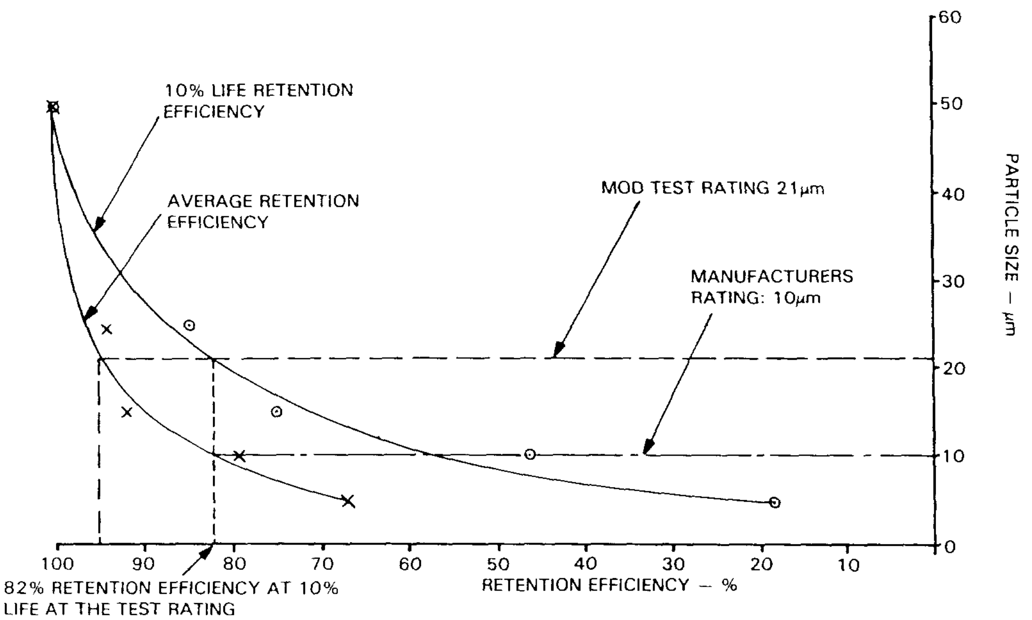

FIG. 6—FILTER EFFICIENCY: TYPICAL TRANSMISSION CURVE

Servo Valve Tests

It was required to test five servo-valves for 1500 hours each. A simple rig was used incorporating a pressure compensated pump to maintain a constant inlet pressure. A three hour test cycle was specified and this was achieved using a PLC and oscillator to give one hour cycling to 5% flow rate in each direction, one hour cycling to 100% flow rate in each direction, and one hour with no flow. The oscillation was sinusoidal at 1 Hz. Periodically hysteresis curves were taken under manual control to check for deterioration in valve performance. Because the pump capacity was considerably larger than that of the servo valves, the rig was adapted to test two valves in parallel, with consequent time and cost savings.

Sampling from HS 200X Systems

Work has been undertaken in conjunction with industry to adapt the standard shipboard field monitor hydraulic fluid sampling kit and slide preparation procedure for mineral oil systems to HS 200X systems.

The procedure for using the sampling kit is to connect it to the system and draw off 100 ml of the working fluid through a plastic monitor containing a membrane filter on to which the contaminant in the sample is deposited. The membrane filter is dried by filtered air and mounted on a glass slide, the membrane being made transparent by a mountant fluid. The slide is then compared with a master using the procedure given in Def. Stan. 05 – 43[5].

When the standard sampling kit was used on HS 200X it resulted in membrane distortion and rupture of the plastic monitor housing, caused by excessive pressure on the filter and backing pad. To overcome this, the standard support pad is replaced by a more rigid version made of porous plastic and a constant pressure sampling valve has been developed to limit the differential pressure across the monitor.

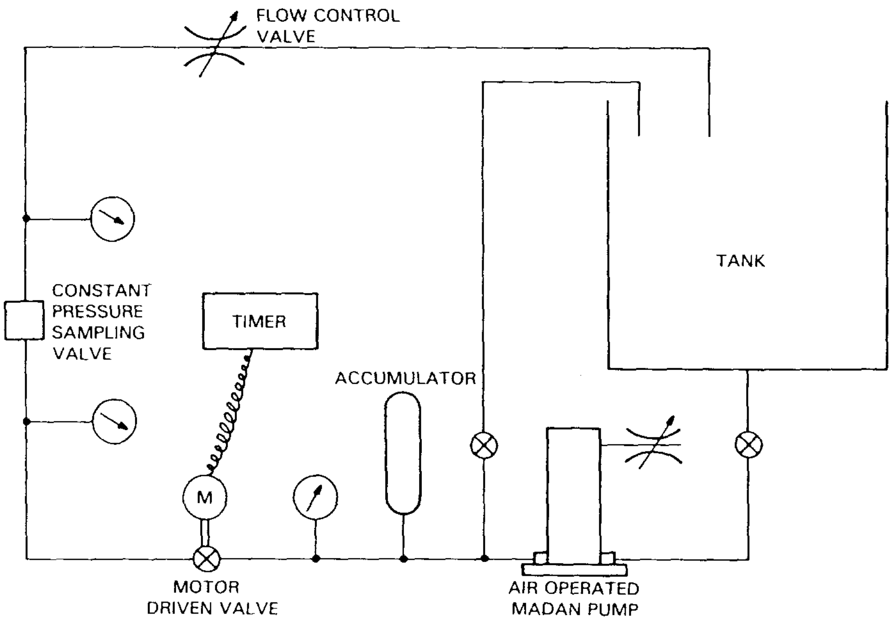

FIG. 7—CONSTANT PRESSURE SAMPLING VALVE: ENDURANCE TEST RIG

Experience showed that the standard membrane filter did not produce acceptable slides, so a solvent-resistant membrane is now used which permits the necessary flushing with iso-propyl alcohol and white spirit. At present a special flushing kit is required but work is under way to enable the standard sampling kit to be used for this operation. The change in filter material also necessitated a change in mountant.

The constant pressure sampling valve referred to above has been subjected to an endurance test using a specially designed rig (FIG. 7) which subjects the valve to a cyclic pressure set by the Madan pump at time intervals set by the timer.

Some results and Conclusions

A number of the pumps tested have failed to demonstrate the required reliability when run on HS 200X. Most failures have been due to rolling contact bearing fatigue: work in RAE[2] and elsewhere has shown that this is a factor which is particularly adversely affected by water-based fluids such as HS 200X. However, some of the more recent tests have been encouraging, with one design running for 8000 hours without any deterioration in performance. As with the motors, the majority of the pumps tested have been designed for mineral oil systems and adapted and derated for fire-resistant fluids. It is hoped to be able to undertake more rigorous testing with appropriately instrumented pumps to obtain further information on their performance.

To date, four different designs of hydraulic motor have been tested on the large motor test rig. In every case, the motor had been derated by the manufacturer—that is, a larger motor has been supplied for the duty cycle specified than would have been the case if the working fluid had been mineral oil. Three of the motors completed the 1000 hour run satisfactorily, giving some confidence in the ability of the basic design to meet the R.N. requirement. It was apparent, however, that different manufacturers applied different derating factors, presumably depending on their experience of operating on fire-resistant fluids and the degree to which the motors have been designed specifically for these fluids. Further work is proposed to examine the performance of selected motors under more arduous duty cycles to reduce the unnecessary bulk and cost which results from over-specification.

The servo valve test rig has been used to evaluate five different designs and the majority completed the test satisfactorily, with no significant difference from the performance which would have been expected with mineral oil. One side effect of the programme was that it highlighted the reduced corrosion protection afforded by fluids such as HS 200X in comparision with mineral oils. When systems are dismantled, mild steel components exposed to the atmosphere can start to corrode after a short time if a preservative is not used. The development of a suitable preservative, and appropriate techniques for its use, is the subject of a study by the Petroleum Chemistry and Technology Division.

It is recognized that the tests discussed so far are not completely realistic because the hydraulic test rig systems are significantly cleaner that the R.N. systems which they are intended to simulate. Since some equipment designs are likely to be more contaminant-sensitive that others, this is an aspect which we would like to address as part of the test programme. However, the problem of finding a representative contaminant and maintaining a specified level of contamination is far from easy to solve. For example, the silicon carbide contaminant used for filtration efficiency testing may produce a realistic contaminant size distribution, but it is very much more abrasive than normal system contaminant and is therefore not appropriate for equipments other than filters. RAE has had outline proposals for research in this area for several years but staff constraints have made it impracticable to implement them.

Some of the problems in adapting the filter test procedures developed for mineral oil systems to HS 200X have already been discussed. One consequence has been that the programme has been delayed significantly. However, it must be emphasized that the problems have been with the test techniques, and that the results RAE has obtained suggest that it should be possible to specify filters which perform satisfactorily on HS 200X, providing due attention is paid to aspects such as material compatability. The hot soak test has demonstrated that some manufacturers have offered filters with cadmium or zinc plated components which are attacked by HS 200X.

The adaptation of the sampling technique used for R.N. mineral oil hydraulic systems to HS 200X has proved far more difficult than expected, due to the complex rheological properties of the aqueous polyglycol fluid. However, a usable method of taking samples and preparing slides for comparative assessment of system cleanliness has now been developed, and work is continuing to simplify the process. Results of the endurance test on the constant pressure valve required for HS 200X systems have demonstrated that the design is likely to offer an acceptable service life.

As far as general system components are concerned, RAE's work has shown no compatibility problems with standard elastomers and other system materials, other than the expected aggressiveness of polyglycols towards light metals such as zinc, cadmium and non-anodized aluminium.

Efforts are continuing to increase the amount of useful information which can be extracted from a test, and a variety of on-line equipment health monitoring techniques are under consideration for this purpose.

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