THE CAH MAIN FORCED LUBRICATION SYSTEM

ELECTRICAL SUPPLIES

BY

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Introduction

The CAH propulsion system was described by Captain P. B. Archer, R.N. in the June 1973 issue of this *Journal*. His statement that auxiliaries for the main propulsion system are to be entirely electrically driven has provoked the correspondence printed in the June 1974 issue. This expresses some anxiety particularly as regards the forced lubrication, the argument being that that system should not be entirely dependent on electrical supplies.

This article outlines the reasoning that led to the adoption of an electrically operated system.

Background

A functional diagram of the forced lubrication system as fitted in each unit in the CAH is given in FIG. 1. The three pumps in each unit are driven by 90kW watertight motors, the starters of which provide indication and control from the ship control centre (SCC) and allow automatic control by pressure switch. Two separate electrical supplies are provided to each motor through automatic change-over switches which will respond to loss of supply voltage or to frequency.

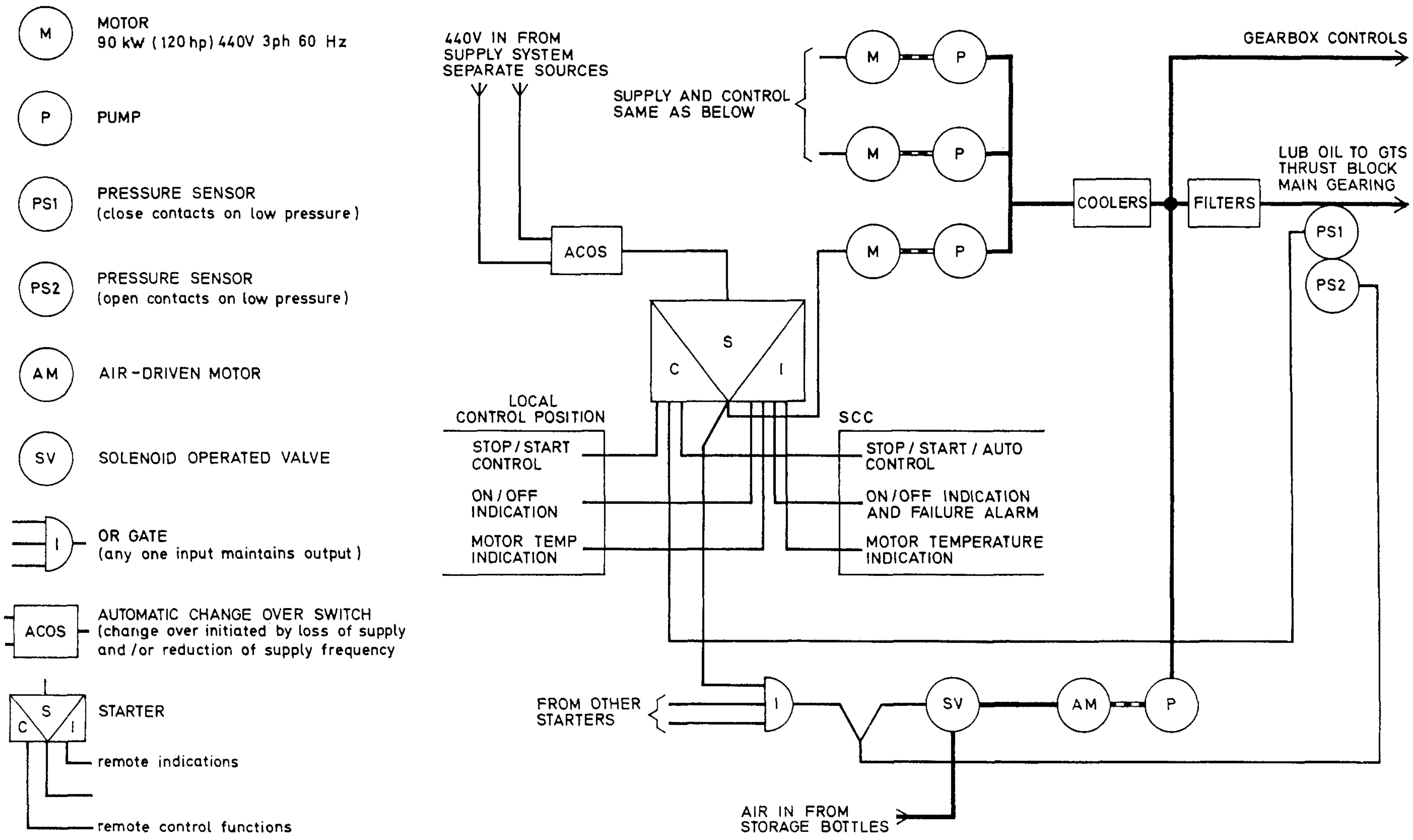

FIG. 1—FUNCTIONAL DIAGRAM OF FORCED LUBRICATION SYSTEM—IDENTICAL SYSTEMS FITTED IN EACH UNIT

In arriving at this arrangement, a number of alternatives were considered. In the absence of main steam supplies, engine-driven pumps would have to be either diesel or gas turbine operated; these were, however, rejected because of their maintenance and watchkeeping requirements. Shaft-driven pumps could have met the needs of the system at mid range shaft speeds and above, but would have needed electrical support to maintain pressure at low shaft speeds. On examination, such a system can be shown to have improved characteristics when the electrically-driven pumps are run continuously instead of intermittently when the pressure fails. This leads to the conclusion that it would be advantageous not to incorporate a shaft-driven pump provided that the integrity of the supplies to the electric motors can be guaranteed. It is considered that the supply arrangements adopted related to the number of pumps provides the necessary integrity; nevertheless, an air-driven pump is fitted as an ultimate safeguard.

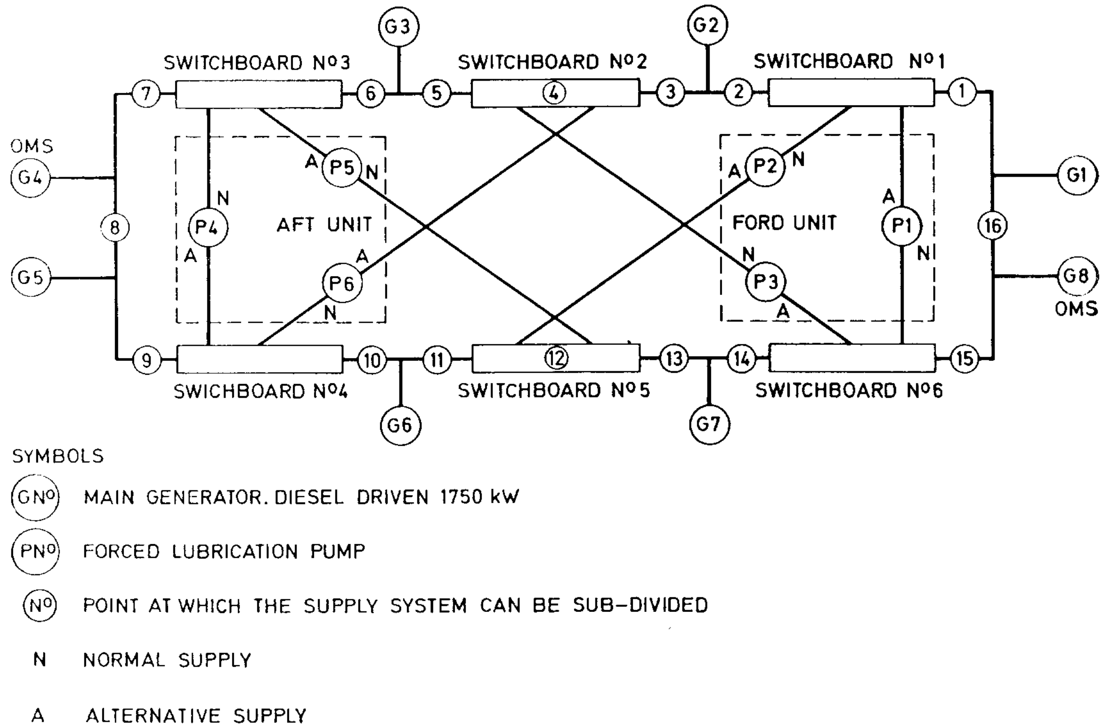

FIG. 2—DIAGRAM OF POWER SUPPLY SYSTEM SHOWING ARRANGEMENT OF SUPPLIES TO THE FORCED LUBRICATION SYSTEM

The Power Supply System

The power supply system is shown in diagrammatic form in FIG. 2, in which the numbering used is not related to the ship system but is for reference in this article only.

There are six switchboards from which bulk electrical supplies are taken, Nos. 2 and 5 being capable of sub-division into two equally loaded sections. Interconnecting breakers are remotely operated from a console in the SCC adjacent to the Machinery Control Console from which the forced lubrication system is operated.

Eight main generators are provided, with the intention that up to six can be used simultaneously if needed to meet operational power demands. The remaining two are an allowance for either breakdown or maintenance. G4 and G8 in the diagram are situated outside the machinery spaces to cover the need for salvage generators, though they are not intended exclusively for salvage duties. Generators will not be run in parallel except for load transfer.

All generators are diesel driven, are intended to be run without local watchkeepers, and have remote starting facilities on the electrical control console to enable them to be run up ready for load in 20 seconds. Supplies of starting air, ready-use fuel, and cooling water for each generator are as far as possible obtained from separate sources to avoid the simultaneous failure of more than one generator for a common reason.

FIG. 2 shows that the supply system could be operated with one, two, three, four, or six generators connected according to the load demand. Calculations predict that normal seagoing loads will be adequately met by three or four generators, and that six generators will seldom, if ever, be required simultaneously except in the highest state of readiness for damage.

Generator Failure

Information from sea shows that generator failures are not uncommon. A surprising number are attributed to maloperation or errors in drill, either electrical or mechanical; of the remainder, all but a few are caused by minor breakdowns in switchgear or supporting equipment affecting cooling water supplies or fuel. A general failure rate can be assessed as one generator failure per ship per fortnight.

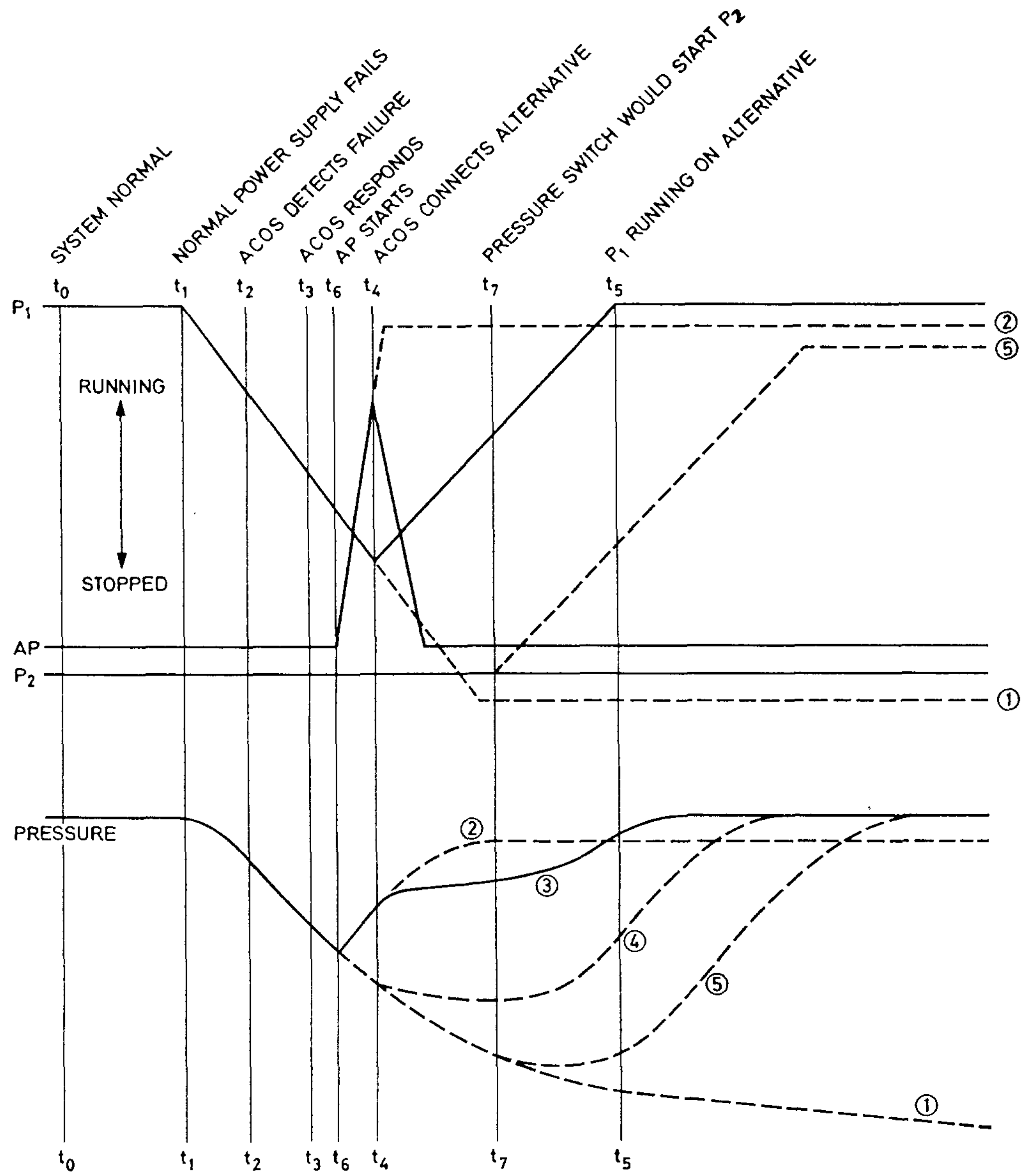

FIG. 3—AVAILABILITY AND PRESSURE DIAGRAM FOR ONE UNIT WITH ONE PUMP RUNNING

Although quality standards laid down for all equipment in the supply system for the CAH are very high and wherever possible controls are simple and automatic, nevertheless it would be unwise to assume that failures will be any less frequent than in other ships. Random failures will take place and will require corrective action either by starting and connecting a stand-by generator or by supplying the dead section by closing inter-connecting switchgear. Of the two, the use of a stand-by generator is preferred as it immediately increases electrical reserves and improves the integrity of supplies to important machinery; judgement will, however, be required in the event of generators being out of action for maintenance or repair. If a skilled operator is available, restoration of supplies after a failure should take only a few minutes but, when cruising at night, it might take longer should the watchkeeper have to call for assistance.

The Forced Lubrication System

FIG. 2 shows the sources of electrical supplies to each pump in the forced lubrication system. Although one pump will be sufficient to meet the requirements for lubricating oil when no manoeuvring is taking place, it is intended that in normal circumstances two electrically-driven pumps will be run in parallel in each unit with the third on automatic stand-by supported by the air-driven pump. System operation is best explained by means of availability diagrams which relate the use of various combinations of pumps according to generators running; first, however, the effect of supply failure on a single pump should be understood.

FIG. 3 shows the sequence of events following a failure of supply to P1 when P2 and the air-driven pump are in the stand-by condition:

At t_0 the system is running normally.

At t_1 the normal supply to P1 fails.

At t_2 the automatic change-over switch detects the failure. A pre-set time delay in the range 0·3 to 3 seconds is then applied to avoid unnecessary operation of the COS in the event of the disturbance to the supply being of a transient nature.

At t_3 the normal supply contactor in the COS opens. A further delay is then applied, adjustable from 0·3 to 3 seconds, to allow the motor regenerative voltage to fall before the alternative supply contactor closes at t_4. Without this delay there is likely to be a dangerously large inrush of current from the alternative supply to suppress the magnetic fields remaining in the motor.

At t_4 the motor will begin to accelerate to its normal speed which is reached at t_5. The interval t_1–t_5 is likely to be in the range of 10 to 15 seconds.

The air-driven pump motor solenoid valve is held closed by a supply taken from the motor side of each starter. There will be an effective, though failing, supply at this point until t_6 is reached when motor regenerative voltage reduces to a value low enough for the solenoid valve to open. At this time the pump will start, but it will stop at t_4 when the alternative supply is connected. The stand-by electric pump will not start unless pressure falls to a low value.

The lower diagram in FIG. 3 shows the probable effect of the above sequence on system pressure. It can be expected to fall along curve (1) from t_1 until t_6, when the air driven pump should cause it to restore along curve (2). At t_4 the air-driven pump will stop and restoration will continue on curve (3). Curve (4) shows the probable recovery path if the air-driven pump should not start, and curve (5) results from P2 starting without the air-driven pump if P1 should not have an alternative supply.

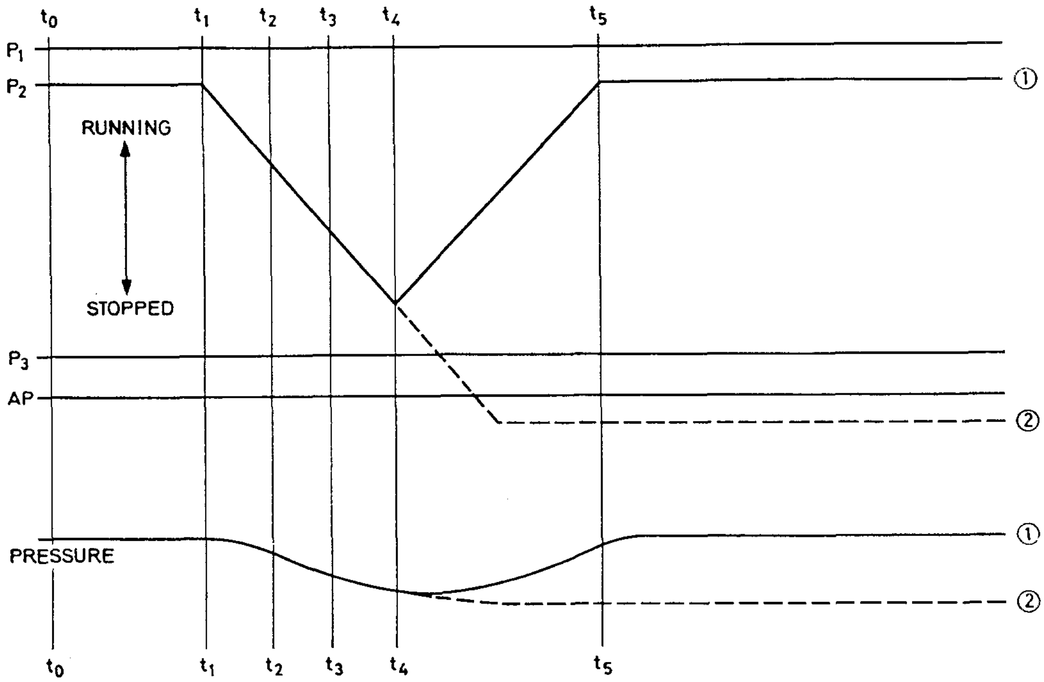

FIG. 4—AVAILABILITY AND PRESSURE DIAGRAM FOR ONE UNIT WITH TWO PUMPS RUNNING

It is not yet possible to give precise values to the quantities shown in FIG. 3 as they are at present under investigation at the shore test facility at Ansty. There could be advantage if the rate of fall of pressure is faster than depicted, because the stand-by electric pump and the air pump could then be arranged to start earlier in the sequence by operation of their pressure switches; this will not be known until prototype test work is further progressed.

FIG. 4 shows a comparable availability diagram and pressure curve when two pumps, P1 and P2, are running following the same failure time sequence as FIG. 3. In this case pressure could be expected to fall along curve (2) but would recover along curve (1) when P1 connects to a good alternative supply at t_4. The air-driven pump would not start because the supply to its solenoid valve would not be interrupted; and the stand-by pump would not start because pressure would never fall sufficiently low to operate its pressure switch.

Normal Operation

The performance of the forced lubrication can now be related to the main supply system.

It has been stated that three generators will often be adequate to meet operational loads at sea. Referring to FIG. 2, it will be seen that generators G1, G3, and G6 can be chosen as an example which requires that the supply system is sub-divided at points (3), (8), and (13). If G1 should fail in these circumstances, P1 will lose both its supplies and P2 and P3 will lose their normal and alternative supplies respectively; the after unit will not however be affected. These events are depicted in FIG. 5 which shows a series of availability diagrams dependent upon which pumps are selected for running or stand-by duties. G1 fails at t_1, followed by failure of G3 at t_2 before any corrective action is taken following the first failure. Loss of G3 and G6 are also shown at t_4 and t_5 respectively. It will be seen that, if only three generators are in use, concurrent loss of two out of three can reduce one unit to complete dependence on its air-driven pump until corrective action is taken;

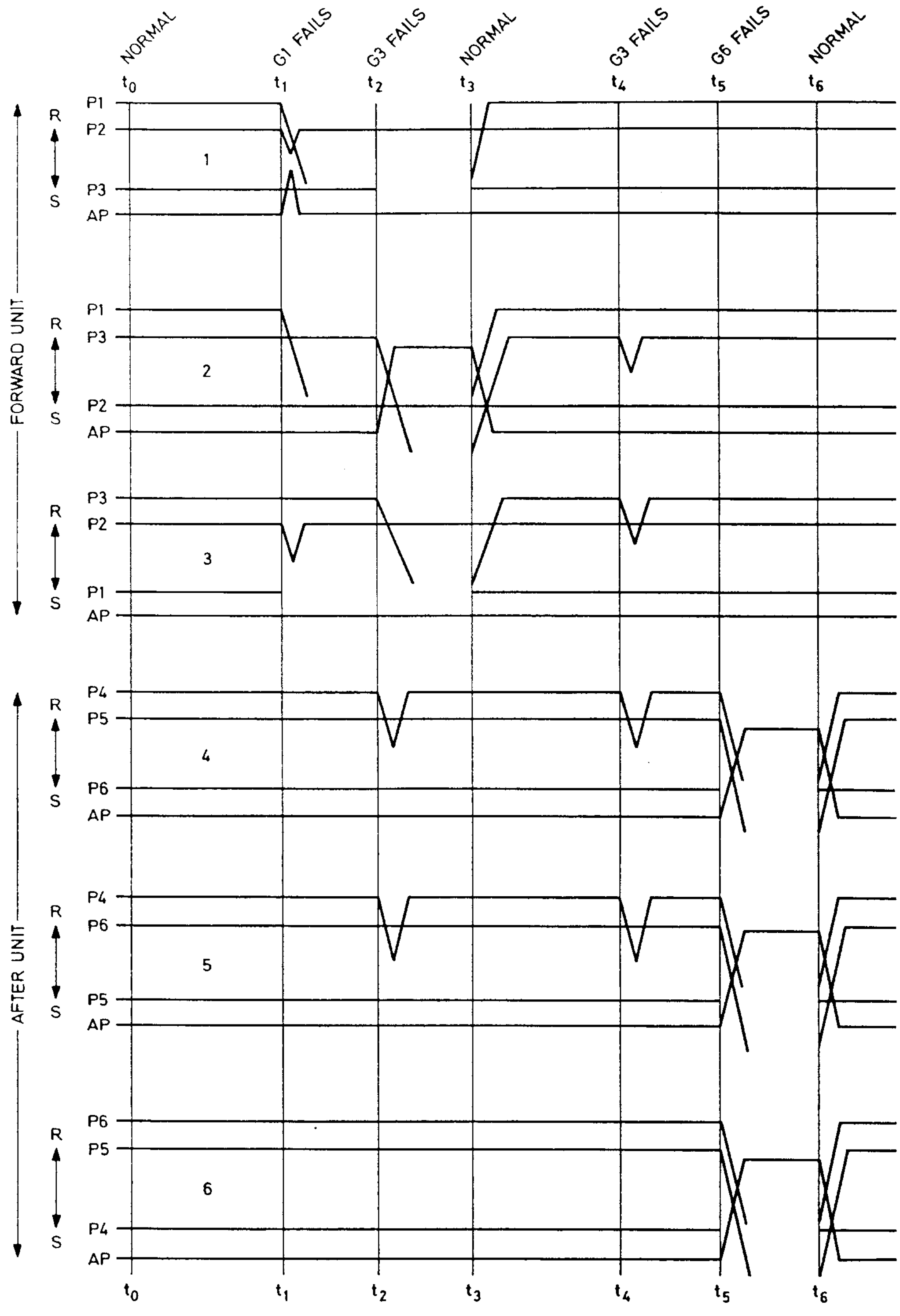

FIG. 5—AVAILABILITY OF PUMPS WITH THREE GENERATORS RUNNING

and this conclusion remains true in one unit or the other whichever combination of three generators is chosen.

FIG. 6 is a comparable diagram showing the effect on availability of lubricating oil pumps of concurrent failure of up to three generators out of four when electrical sub-division is at points (4), (8), (12), and (16). It will be seen that, despite concurrent failure of any three generators without corrective action, at least one electrically-driven pump and the air-driven pump will remain available in each unit.

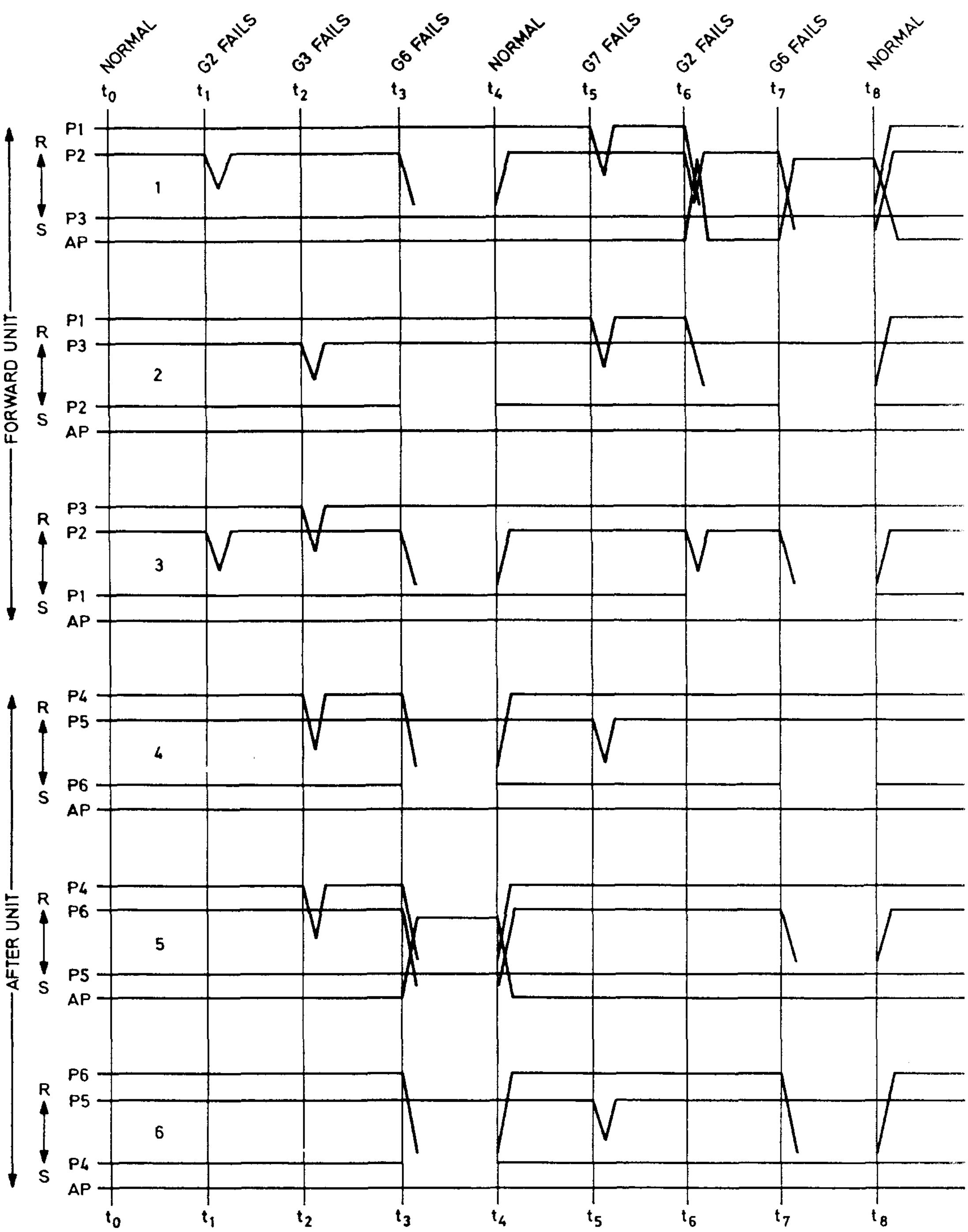

FIG. 6—AVAILABILITY OF PUMPS WITH FOUR GENERATORS RUNNING

Probable Number of Concurrent Generator Failures

It can be concluded from FIGS. 5 and 6 that the risk to the main machinery is very much reduced when four generators are in use rather than three, but the three-generator state should not be rejected without an investigation into the probable number of concurrent failures because there is little point in operating generators underloaded if it can be avoided.

Assume that the MTBF for each generator is between 200 and 500 hours and that 15 minutes will be required to take corrective action following any failure; then, when the first random failure occurs, the probable number of failures of a second generator within the subsequent fifteen minutes will be between:

$$0{\cdot}25 \times \frac{1}{200} \text{ and } 0{\cdot}25 \times \frac{1}{500}$$
$$= 1{\cdot}25 \times 10^{-3} \text{ and } 5 \times 10^{-4}$$

The probable number of failures of a third generator within the same fifteen minutes will lie between:

$$(1{\cdot}25 \times 10^{-3})^2 \text{ and } (5 \times 10^{-4})^2$$
$$= 1{\cdot}6 \times 10^{-6} \text{ and } 2{\cdot}5 \times 10^{-7}$$

The probable number of failures of a fourth generator within the same fifteen minutes will lie between:

$$(1{\cdot}25 \times 10^{-3})^3 \text{ and } (5 \times 10^{-4})^3$$
$$= 2 \times 10^{-9} \text{ and } 1{\cdot}25 \times 10^{-10}$$

TABLE I—*Probable number of subsequent generator failures within fifteen minutes of a first generator failure*

	2 generators on load		*3 generators on load*		*4 generators on load*	
	MTBF 200 hrs	MTBF 500 hrs	MTBF 200 hrs	MTBF 500 hrs	MTBF 200 hrs	MTBF 500 hrs
Reduction to 3	—	—	—	—	First Failure	First Failure
Reduction to 2	—	—	First Failure	First Failure	$1{\cdot}25\times10^{-3}$	5×10^{-4}
Reduction to 1	First Failure	First Failure	$1{\cdot}25\times10^{-3}$	5×10^{-4}	$1{\cdot}6\times10^{-6}$	$2{\cdot}5\times10^{-7}$
Reduction to zero	$1{\cdot}25\times10^{-3}$	5×10^{-4}	$1{\cdot}6\times10^{-6}$	$2{\cdot}5\times10^{-7}$	2×10^{-9}	$1{\cdot}25\times10^{-10}$

TABLE II—*Probable number per year of* (*a*) *generator first failures and* (*b*) *subsequent generator failures within fifteen minutes of first failure*

	2 generators on load		*3 generators on load*		*4 generators on load*	
	MTBF 200 hrs.	MTBF 500 hrs.	MTBF 200 hrs.	MTBF 500 hrs.	MTBF 200 hrs.	MTBF 500 hrs.
Reduction to 3	—	—	—	—	(a) 90	(a) 36
Reduction to 2	—	—	(a) 68	(a) 27	(b) $1{\cdot}12\times10^{-1}$	(b) $1{\cdot}8\times10^{-2}$
Reduction to 1	(a) 45	(a) 18	(b) $8{\cdot}5\times10^{-2}$	(b) $1{\cdot}35\times10^{-2}$	(b) $1{\cdot}5\times10^{-5}$	(b) 9×10^{-6}
Reduction to zero	(b) $5{\cdot}6\times10^{-2}$	(b) 9×10^{-3}	(b) $1{\cdot}1\times10^{-4}$	(b) $6{\cdot}8\times10^{-6}$	(b) $1{\cdot}8\times10^{-7}$	(b) $4{\cdot}5\times10^{-9}$

TABLE I shows these figures related to various ship operating conditions. These figures can be translated into occurrences per year concurrent with the main engines and forced lubrication system being in use assuming that the main engines are operational for 4500 hours per year. The probable mean number of single generator failures can be assessed as:

$$\text{Number of generators running } \frac{4500}{\text{MTBF}}$$

TABLE II shows assessments made on this basis. A figure considered acceptable in the design of large chemical plants and nuclear installations is 3×10^{-5} per year, which can be expressed as one accident in 33,000 years; this does not however predict the time of the first accident.

If it is accepted that reduction from four generators running to one generator running will not create a dangerous situation, it will be seen that the foregoing figures are better than those acceptable for a nuclear installation. This is also true in one unit for the three-generator state but, as the other unit is then in the two-generator state, it must be rejected if the same order of probability is required overall. The MTBF figures and the fifteen minutes assumed for corrective action are, however, considered to be pessimistic for the CAH. Undoubtedly arrangements would be made for a higher standard of electrical watchkeeping if only three generators were to be run.

In any case, these figures do not relate to a failure of the forced lubrication system but only to a reduction to dependence on the air-driven pump which itself will run for nearly twenty minutes on available air supplies.

Conclusions

It can be concluded that:

(*a*) the forced lubrication system is inherently satisfactory for its task and that there is adequate redundancy to allow for failures;

(*b*) the needs of the forced lubrication system are adequately met by the electrical supply system;

(*c*) the probability of failure of electrical supplies has been taken into account in the design;

(*d*) provision of any additional engine-driven or shaft-driven pumps would have been superfluous.