The Two Pump Problem

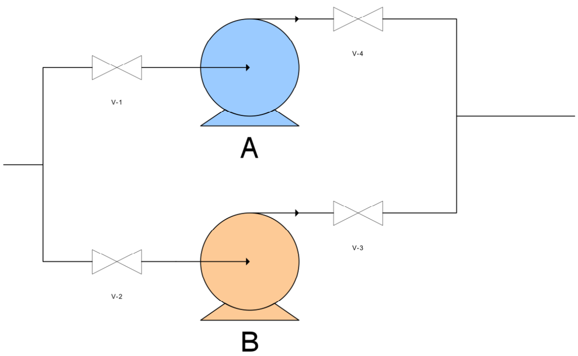
RCM Notes series

Dr Mark Horton, Numeratis.com, July 2013

1 Introduction

This note discusses the analysis of a simple two pump system that arises frequently in discussions about RCM and operational policy, although rather less frequently in practical applications.

A system consists of two pumps, labelled A and B, either of which is capable of delivering the pressure and flow required to support the downstream process.



The typical question that arises is the choice between two operating regimes[*].

1 Pump A is designated as the duty pump, and B as a standby. If pump A fails, pump B is used until A is repaired; then pump A is brought back on line and B resumes its standby duty.
2 One pump is operated as the duty pump for a set period, with the other acting as the standby. At the end of the each period the roles of duty and standby pump are swapped.

This note compares the two operational policies for failures that have economic consequences.

[*] A third policy not considered here is where the two pumps run in parallel. This configuration is commonly used to save power, since the motor rating needed to generate the required pressure and flow from a single pump is often far more than the combined rating of two smaller pump motors. The parallel configuration may also have some reliability benefits over installation of a single, large pump, because one pump by itself may be able to generate 80% or more of the required output.

Assumptions

1 All failure modes for duty and standby pumps that have an age-related component have been managed separately and effectively, leaving only those with a random characteristic to be considered.
2 A multiple failure does not lead to safety or environmental consequences.
3 The consequences of a multiple failure are summarised in a single cost C_{mf}. The downtime due to a multiple failure is not considered directly.
4 Where the duty/standby pump assignment alternates on a periodic basis, it is possible to revert to the previous duty pump immediately if the standby does not start successfully on changeover.
5 The failure-finding task carried out on the standby pump has a negligible effect on the chance of a multiple failure occurring. Similarly, the additional chance of inducing a multiple failure caused by the swap over process itself is assumed to be negligible.
6 The mean time between failures for the duty pump and for the standby pump are independent of the operational policy chosen.
7 The failure-finding interval or swap-over period is much less than either pump's mean time between failures, so that the assumed exponential survival curve is approximately linear.
8 Testing or swapping over the duty and standby roles does not result in a significant impact on either pump's reliability.

Terms

T_c Changeover period for the alternating duty pump policy

T_{ff} Failure-finding interval for the fixed duty/standby policy

C_{ff} Cost of a single failure-finding task

C_c Cost of a single changeover for the alternating duty/standby reassignment policy

C_{mf} Cost of each multiple failure

T_d Mean time between failures of a duty pump

T_s Mean time between failures of a standby pump

U Unavailability

Duty/Standby Analysis

This policy dedicates one pump as the duty equipment, the other as its standby. The standby pump only operates if the duty pump has failed; as soon as the designated duty pump is repaired, it is started and the standby pump is taken off line.

This is a standard economic failure-finding calculation. The rate of expenditure on a maintenance policy which failure-finds the standby pump at an interval T_{ff} is

$$C = \frac{C_{ff}}{T_{ff}} + C_{mf}\frac{T_{ff}}{2T_s T_d}$$

This leads to an optimum failure-finding interval of

$$T_{ff} = \sqrt{\frac{2T_s T_a C_{ff}}{C_{mf}}}$$

at which the overall cost per unit time is

$$C = \sqrt{\frac{2C_{ff}C_{mf}}{T_s T_a}}$$

Alternating Role Analysis

At the beginning of a period, one pump is on line and the other off line. If the duty pump fails, the standby pump starts and takes over from the duty unit. At the end of the period, assuming that no failures have occurred, the roles of duty and standby pump are reversed.

The average unavailability of the standby pump over a single period is

$$U = \frac{T_c}{2T_s}$$

The expected rate of multiple failures is

$$\frac{T_c}{2T_d T_s}$$

so the overall cost per unit time of multiple failures is

$$C_{mf}\frac{T_c}{2T_d T_s}$$

and the total cost per unit time, including the cost of changeovers, is

$$C_{mf}\frac{T_c}{2T_d T_s} + \frac{C_c}{T_c}$$

This can be solved in exactly the same way as the failure-finding calculation, to yield an optimum changeover interval

$$T_c = \sqrt{\frac{2T_s T_a C_c}{C_{mf}}}$$

The cost per unit time at the optimum interval is

$$C = \sqrt{\frac{2C_c C_{mf}}{T_s T_a}}$$

Discussion

There are a few things to note here.

First, the relative cost of the two policies depends completely on the relationship between the cost of a changeover and the cost of failure-finding. If they are the same, then the optimum changeover interval is equal to the optimum failure-finding interval. If the cost of a changeover is trivial, then more frequent changeovers result in higher overall availability than less frequent role changes.

Second, if the cost of changing roles is lower than that of failure-finding, then lower cost is achieved by swapping roles at the optimum interval than by failure-finding; of course, the reverse is also true.

The calculations are based on the assumptions listed above. When comparing these two operational policies, the negative aspect most often cited for the swap over policy is that the pumps age together. The implication is that, if there are any age-related failure rates that are not fully managed, both pumps become less reliable; the hazard rate of each pump increases with age, so the overall hazard rate for the combined functional group may increase rapidly.

This argument is appealing at first sight. Mechanical components that are in use become worn, and are subject to fatigue and erosion. Even if we assume that most age-related failure modes can be managed successfully by condition-based maintenance, planned overhauls and replacements, there is a chance that some failures whose probability increases with age could be missed, or that maintenance may not be completely effective in restoring a component's function.

Looking at the duty/standby configuration, the picture becomes less clear. Perhaps the duty pump could be affected by age-related failure modes that are not fully managed; but the same is also true of the standby pump.

- The standby pump may be affected by corrosion
- Bearing surfaces become flattened because the pump does not turn
- Product may become more viscous or deposit silt or sludge in the pipe work, pump and fittings
- Associated valves may seize over time

In other words, there is no clear, qualitative winner between the two policies. Everything depends on the detailed reliability of the two pumps in their operating context. Given that it is not possible to put forward qualitative arguments that favour either policy, what factors influence which policy should be chosen?

Factor	Comments
Management of age-related failure modes	Whichever policy is chosen, we must be confident that age-related failure modes have been fully managed. For example, it may not be feasible to choose a full duty/standby operational policy if age-related product silting is a significant problem.
Starting stresses	Frequent starting procedures may induce premature wear in some components. It is likely to be a more significant issue for the alternating policy, but it could also affect the duty/standby policy if the failure-finding interval is short.
Change-over procedure	If the alternating policy is chosen, it is important to describe the procedure in terms that enable the operators to identify any incipient failures. For example, it may be a requirement to document the maximum flow attainable on changeover in order to monitor impeller wear.
Standby testing procedure	The standby pump is not less important than the duty pump. It is important that the standby pump testing procedure identifies any potential failures. In addition, the operators or maintainers should ensure that the standby is fully available, and that any control systems that may have been disabled during the test are fully functional afterwards.

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