lowing the system to cool. Figure 5-10 shows both rising and cooling temperature profiles obtained from HyPneu for the pump, lines, orifice and tank. The results indicate the average steady state temperature is around 190°F which agrees with the theoretical calculation.

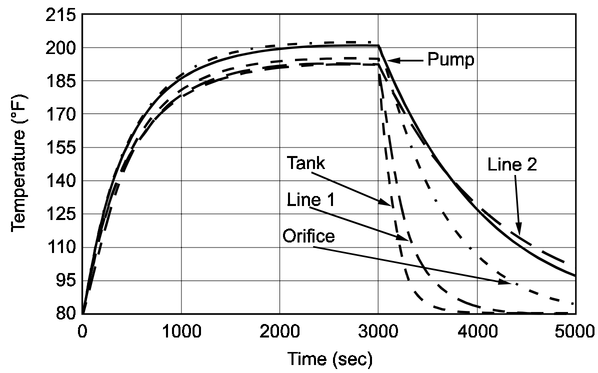

Figure 5-10. Heating and Cooling Temperature Profiles of Pump, Orifice, Lines, and Tank.

5.7 Thermal Duty Cycle Analysis

Many times, a hydraulic machine is expected to carry out a series of loading applications over a prescribed distance or period of time in a recurring manner. In other words, the machine is commanded to follow a specific work cycle that defines the intended job function to a given application task. The machine and its components will naturally response to the imposed work cycle and reflect a corresponding duty cycle. Speaking differently, a work cycle represents the stressing severity while a duty cycle is the resultant strain pattern. In thermal analysis, the stressing parameters are heat generation or removing sources, whereas the temperature is the strain parameter. A knowledge of the thermal duty cycle is essential in heat control for any hydraulic system.

To illustrate the thermal duty cycle analysis procedures, let's first consider the lumped model approach previously described in the *Thermal Steady State Analysis* section. Assume that the work cycle is divided into *n* operating intervals as shown in Fig. 5-11. Each operating interval has a time elapse of $r_i t_p$ with a heat load of h_i. Parameter r_i is the time ratio of the time elapse at the i^{th} operating interval to the work cycle period, t_p. This is a typical periodic step function. The profile functions that define the maximum (upper) and minimum (lower) steady state boundary of a first order differential system responses to a periodic step input can be analytically derived. The detail of the derivation can be found in the companion ***Hydraulic System Control and Optimization*** book in the Computerized Fluid Power Series.

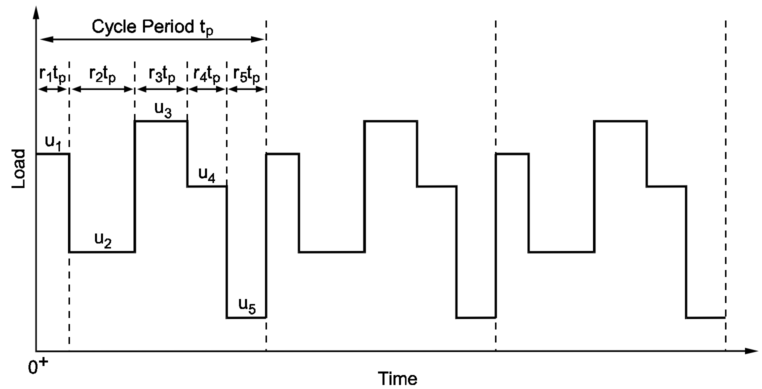

Figure 5-11. Periodic Step Function Work Cycle.

However, without getting involved with cumbersome analytical procedures, we can obtain a duty cycle (output) from a given work cycle (input) as depicted in Fig. 5-12 by the following reasoning. Consider a first order system with a time constant τ and assume that at time t = 0 both input and output are null. Right after this point, namely at $t = 0^+$,the input jumps to a new amplitude U_1. Dynamically the output follows an exponential decay curve with the time constant τ to "catch" the input. At $t = t_2$, the input jumps to the other new amplitude U_2. At this moment, the output will immediately change its direction toward the new equilibrium value even the output has not reach the first equilibrium value. Note that, at time t_2, the output takes the last value before input changed as the initial point and continues to chase the new equilibrium value exponentially. This "jump-and-chase" occurs whenever the input changes. Accordingly, the duty cycle travels between the upper and lower boundaries.

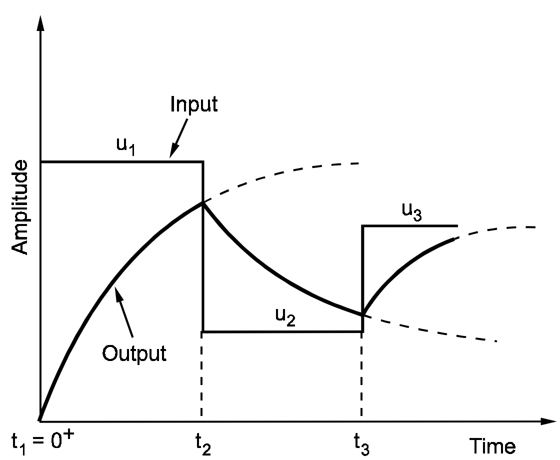

Figure 5-12. Response to a Step-Input Function.

It is much easier to investigate the duty cycle using computer approach. Figure 5-13 shows a hydraulic circuit has a 10 gpm pump driving a variable load. The load is 70% on the low value (around 278 psi), and 30% on the high value (around 1100) during one work cycle. The equivalent heat loads to the system are 4126 Btu·hr^{-1} for 70% time and 16330 Btu·hr^{-1} for 30%, respectively. Figure 5-14 shows the corresponding oil temperature duty cycle at pump outlet from HyPneu simulation. It clearly shows that, as expected, the oil temperature travels between an envelope confined by the upper and lower boundaries.

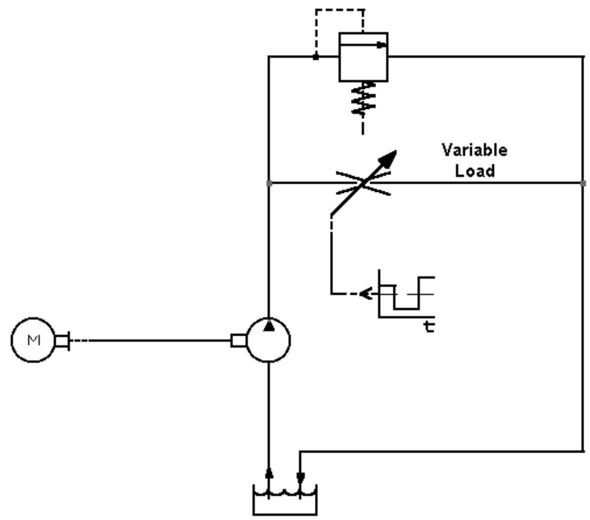

Figure 5-13. HyPneu Circuit for Thermal Duty Cycle Analysis.

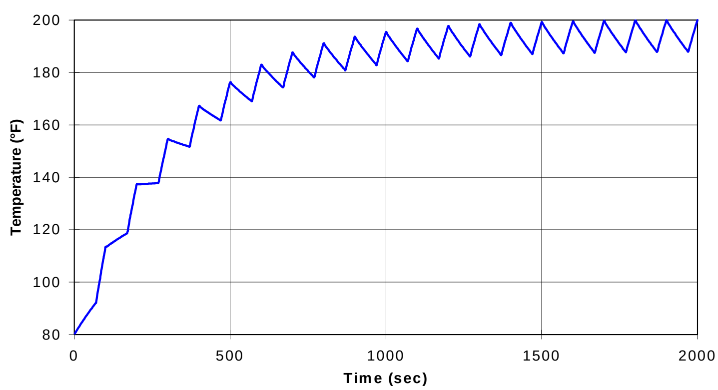

Figure 5-14. HyPneu Simulation Results for Thermal Duty Cycle Analysis.