STAGE EFFICENCY

The aerodynamic losses in the turbine differ with the stage configuration, that is, the degree of reaction. Improved efficiency is associated with higher reaction, which tends to mean less work per stage and thus a large number of stages for a given overall pressure ratio.

The understanding of aerodynamic losses is important to design, not only in the choice of blading type (impulse or reaction) but also in devising ways to control these losses, for example, methods to control the clearance between the tip of the turbine blade and the outer casing wall. The choices of blade shape, aspect ratio, spacing, Reynolds number, Mach number and flow incidence angle can all affect the losses and hence the efficiency of turbine stages.

Two definitions of efficiency are in common usage: the choice between them depends on the application for which the turbine is used. For many conventional applications, useful turbine output is in the form of shift power and the kinetic energy of the exhaust, $V_3^2/2$, is considered as a loss. In this case, ideal work would be $C_P(T_{01}-T_{3s})$ and a total to static turbine efficiency, η_{ts} , based on the inlet and exit static conditions, is used.

Thus, $$\eta_{ts} = \frac{T_{o1} - T_{o3}}{T_{o1} - T_{3s}} \qquad (15.1)$$

The ideal (isentropic) to actual expansion process in turbines is illustrated in Fig 15.1.

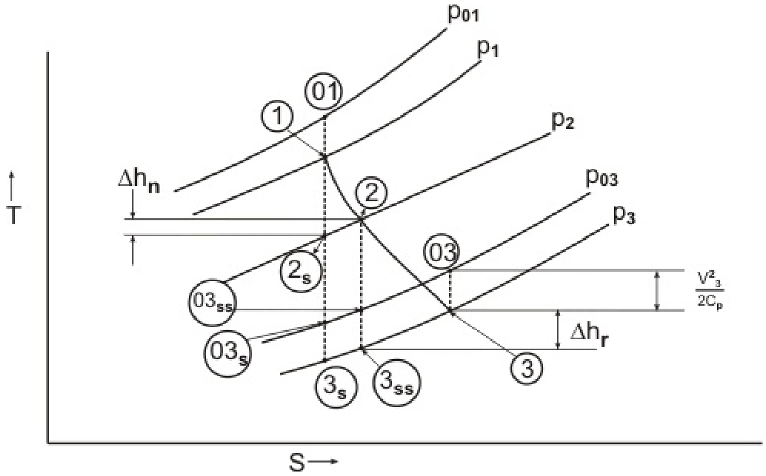

Figure 15.1 T-S diagram: expansion in a turbine

Further,

$$\eta_{ts} = \frac{T_{o1} - T_{o3}}{T_{o1}[1-(P_3/P_{o1})^{(\gamma-1)/\gamma}]}$$
$$= \frac{1-(T_{o3}/T_{o1})}{1-(p_3/p_{o1})^{(\gamma-1)/\gamma}} \qquad (15.2)$$

In some applications, particularly in turbojets, the exhaust kinetic energy is not considered a loss since the exhaust gases are intended to emerge at high velocity. The ideal work in this case is then $C_P(T_{01}-T_{03s})$ rather than $C_P(T_{01}-T_{3s})$. This requires a different definition of efficiency, the total-to-total turbine efficiency η_{tt}, defined by

$$\eta_{tt} = \frac{T_{01} - T_{03}}{T_{01} - T_{03s}} = \frac{1-(T_{03}/T_{01})}{1-(p_{03}/p_{01})^{(\gamma-1)/\gamma}} \qquad (15.3)$$

One can compare η_{tt} & η_{ts} by making the approximation,

$$T_{03s} - T_{3s} \cong T_{03} - T_3 = V_3^2/2C_p,$$

and using Eqs. (15.2) and (15.3) it can be shown that

$$\eta_{tt} = \frac{\eta_{ts}}{1 - V_3^2[2C_p(T_{01}-T_{3s})]}$$

Thus $$\eta_{tt} > \eta_{ts}$$

The actual turbine work can be expressed as,

$$W_t = \eta_{tt} C_p T_{01} [1 - (\frac{P_{03}}{P_{01}})^{(\gamma-1)/r}]. \qquad (15.4)$$

or, $$W_t = \eta_{ts} C_p T_{01} [1 - (\frac{P_3}{P_{01}})^{(\gamma-1)/r}].$$