## Reaction Turbine, Continued

Put $\rho = \frac{U}{V_1}$ then

$$\eta_b = \frac{2\rho(2\cos\alpha_1 - P)}{1-\rho^2 + 2\rho\cos\alpha_1} \quad (25.1)$$

For the maximum efficiency $\frac{d\eta_b}{d\rho} = 0$ and we get

$$(1-\rho^2 + 2\rho\cos\alpha_1)(4\cos\alpha_1 - 4\rho) - 2\rho(2\cos\alpha_1 - \rho)(-2\rho + 2\cos\alpha_1) = 0 \quad (25.2)$$

from which finally it yields

$$\rho_{opt} = \left(\frac{U}{V_1}\right)_{opt} = \cos\alpha_1 \quad (25.3)$$

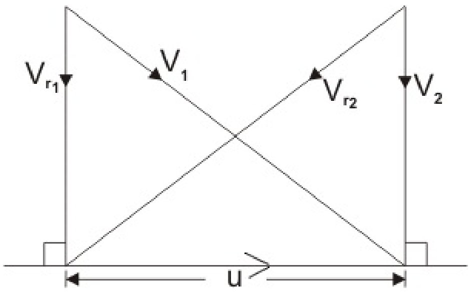


**Figure 25.1 Velocity diagram for maximum efficiency**

Absolute velocity of the outlet at this stage is axial (see figure 25.1). In this case, the energy transfer

$$E = U\Delta V_W = U^2 \quad (25.4)$$

$(\eta_b)_{maximum}$ can be found out by putting the value of $\rho = \cos\alpha_1$ in the expression for blade efficiency

$$(\eta_b)_{\max} = \frac{2\cos^2\alpha_1}{1+\cos^2\alpha_1} \quad (25.5)$$

$$(\eta_b)_{impulse} = \cos^2\alpha_1 \quad (25.6)$$

$\eta$ is greater in reaction turbine. Energy input per stage is less, so there are more number of stages.

### Stage Efficiency and Reheat factor

The Thermodynamic effect on the turbine efficiency can be best understood by considering a number of stages between two stages 1 and 2 as shown in Figure 25.2

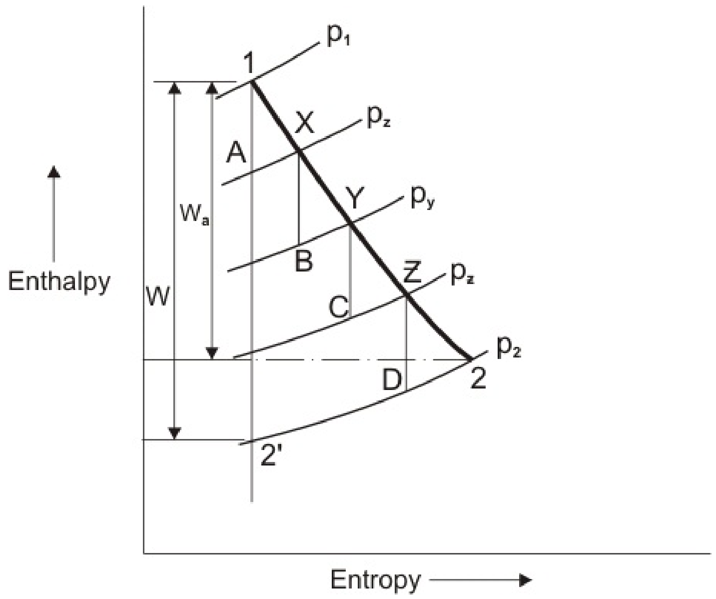


**Figure 25.2 Different stage of a steam turbine**

The total expansion is divided into four stages of the same efficiency $(\eta_s)$ and pressure ratio.

$$\frac{P_1}{P_x} = \frac{P_x}{P_y} = \frac{P_y}{P_z} = \frac{P_z}{P_2} \qquad (25.7)$$

The overall efficiency of expansion is $\eta_o$. The actual work during the expansion from 1 to 2 is

$$Wa = \eta_o W$$

or,

$$\eta_o = \frac{Wa}{W} = \frac{actual\ enthalpy\ drop\ (1-2)}{isentropic\ heat\ drop\ (1-2')} \qquad (25.8)$$

$$\text{Reheat factor (R.F.)} = \frac{Cumulative\ \ enthalpy\ drop\ (isentropic)}{Isentropic\ \ enthalpy\ \ drop\ \ (overall)}$$

or,

$$R.F = \frac{\Delta h_{1A} + \Delta h_{xB} + \Delta h_{yc} + \Delta h_{zD}}{\Delta h_{12}} \qquad (25.9)$$

R.F is 1.03 to 1.04

If $\eta_s$ remains same for all the stages or $\eta_s$ is the mean stage efficiency.

$$\eta_s = \frac{\Delta h_{1x}}{\Delta h_{1A}} = \frac{\Delta h_{xy}}{\Delta h_{xB}} = \frac{\Delta h_{yz}}{\Delta h_{yc}} = \frac{\Delta h_{z2}}{\Delta h_{zD}} \qquad (25.10)$$

or,

$$\eta_s = \frac{\Delta h_{1x} + \Delta h_{xy} + \Delta h_{yz} + \Delta h_{z2}}{\Delta h_{1A} + \Delta h_{xB} + \Delta h_{yc} + \Delta h_{zD}} \qquad (25.11)$$

$$= \frac{actual\ \ enthalpy\ \ drop}{Cumulative\ enthalpy\ drop\ (isentropic)}$$

We can see:

$$\eta_0 = \eta_s \times R.F \qquad (25.12)$$

This makes the overall efficiency of the turbine greater than the individual stage efficiency.

The effect depicted by Eqn (25.12) is due to the thermodynamic effect called "reheat". This does not imply any heat transfer to the stages from outside. It is merely the reappearance of stage losses an increased enthalpy during the constant pressure heating (or reheating) processes AX, BY, CZ and D2.