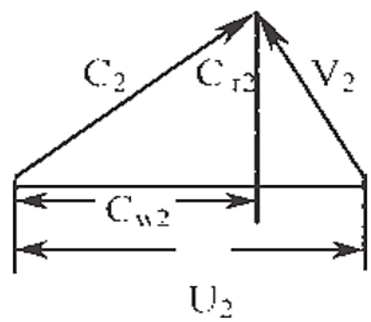
Sheet:2

1- Air leaving the impeller with radial velocity 110 m/s makes an angle of 25º30' with the axial direction. The impeller tip speed is 475 m/s. The compressor efficiency is 0.80 and the mechanical efficiency is 0.96. Find the slip factor, overall pressure ratio, and power required to drive the compressor. Neglect power input factor and assume $\gamma = 1.4$, $T_{01} = 298$ K, and the mass flow rate is 3 kg/s.



From the velocity triangle

$$\tan(\beta_2) = \frac{U_2 - C_{w2}}{C_{r2}}$$

$$\tan(25.5°) = \frac{475 - C_{w2}}{110}$$

Therefore, $C_{w2} = 422.54$ m/s.

Now, $\sigma = \frac{C_{w2}}{U_2} = \frac{422.54}{475} = 0.89$

The overall pressure ratio of the compressor:

$$\frac{P_{03}}{P_{01}} = \left[1 + \frac{\eta_c \sigma \psi U_2^2}{C_p T_{01}}\right]^{\gamma/(\gamma-1)} = \left[1 + \frac{(0.80)(0.89)(475^2)}{(1005)(298)}\right]^{3.5} = 4.5$$

The theoretical power required to drive the compressor:

$$P = \left[\frac{m \sigma \psi U_2^2}{1000}\right] \text{kW} = \left[\frac{(3)(0.89)(475^2)}{1000}\right] = 602.42 \text{kW}$$

Using mechanical efficiency, the actual power required to drive the compressor is: $P = 602.42/0.96 = 627.52$ kW.

2- The impeller tip speed of a centrifugal compressor is 370 m/s, slip factor is 0.90, and the radial velocity component at the exit is 35 m/s. If the flow area at the exit is 0.18 m^2 and compressor efficiency is 0.88, determine the mass flow rate of air and the absolute Mach number at the impeller tip. Assume air density $\rho = 1.57$ kg/m^3 and inlet stagnation temperature is 290 K. Neglect the work input factor. Also, find the overall pressure ratio of the compressor?

Slip factor: $\sigma = \frac{C_{w2}}{U_2}$

Therefore: $C_{w2} = U_2\sigma = (0.90)(370) = 333\,\text{m/s}$

The absolute velocity at the impeller exit:

$$C_2 = \sqrt{C_{r2}^2 + C_{\omega 2}^2} = \sqrt{333^2 + 35^2} = 334.8\,\text{m/s}$$

The mass flow rate of air: $\dot{m} = \rho_2 A_2 C_{r2} = 1.57 * 0.18 * 35 = 9.89\,\text{kg/s}$

The temperature equivalent of work done (neglecting ψ):

$$T_{02} - T_{01} = \frac{\sigma U_2^2}{C_p}$$

Therefore, $T_{02} = T_{01} + \frac{\sigma U_2^2}{C_p} = 290 + \frac{(0.90)(370^2)}{1005} = 412.6\,\text{K}$

The static temperature at the impeller exit,

$$T_2 = T_{02} - \frac{C_2^2}{2C_p} = 412.6 - \frac{334.8^2}{(2)(1005)} = 356.83\,\text{K}$$

The Mach number at the impeller tip:

$$M_2 = \frac{C_2}{\sqrt{\gamma R T_2}} = \frac{334.8}{\sqrt{(1.4)(287)(356.83)}} = 0.884$$

The overall pressure ratio of the compressor (neglecting ψ):

$$\frac{P_{03}}{P_{01}} = \left[1 + \frac{\eta_c \sigma \psi U_2^2}{C_p T_{01}}\right]^{3.5} = \left[1 + \frac{(0.88)(0.9)(370^2)}{(1005)(290)}\right]^{3.5} = 3.0$$

3- A centrifugal compressor is running at 16,000 rpm. The stagnation pressure ratio between the impeller inlet and outlet is 4.2. Air enters the compressor at stagnation temperature of 20ºC and 1 bar. If the impeller has radial blades at the exit such that the radial velocity at the exit is 136 m/s and the isentropic efficiency of the compressor is 0.82. Draw the velocity triangle at the exit of the impeller and calculate slip. Assume axial entrance and rotor diameter at the outlet is 58 cm.

4- Determine the adiabatic efficiency, temperature of the air at the exit, and the power input of a centrifugal compressor from the following given data:

Impeller tip diameter = 1 m
Speed = 5945 rpm
Mass flow rate of air = 28 kg/s
Static pressure ratio p_3/p_1 = 2:2
Atmospheric pressure = 1 bar
Atmospheric temperature = 25ºC
Slip factor = 0.90

Neglect the power input factor.

5- A centrifugal compressor operates with no prewhirl is run with a rotor tip speed of 457 m/s. If C_{w2} is 95% of U_2 and η_c = 0.88, calculate the following for operation in standard sea level air: (1) pressure ratio, (2) work input per kg of air, and (3) the power required for a flow of 29 k/s.

6- A centrifugal compressor is running at 10,000 rpm and air enters in the axial direction. The inlet stagnation temperature of air is 290 K and at the exit from the impeller tip the stagnation temperature is 440 K. The isentropic efficiency of the compressor is 0.85, work input factor ψ = 1.04, and the slip factor σ = 0.88. Calculate the impeller tip diameter, overall pressure ratio, and power required to drive the compressor per unit mass flow rate of air.

7- Air enters axially in a centrifugal compressor at a stagnation temperature of 20ºC and is compressed from 1 to 4.5 bars. The impeller has 19 radial vanes and rotates at 17,000 rpm. Isentropic efficiency of the compressor is 0.84 and the work input factor is 1.04. Determine the overall diameter of the impeller and the power required to drive the compressor when the mass flow is 2.5 kg/s.

8- In an axial flow compressor air enters the compressor at stagnation pressure and temperature of 1 bar and 292K, respectively. The pressure ratio of the compressor is 9.5. If isentropic efficiency of the compressor is 0.85, find the work of compression and the final temperature at the outlet. Assume $\gamma = 1.4$, and $C_p = 1.005$ kJ/kg K.

9- In one stage of an axial flow compressor, the pressure ratio is to be 1.22 and the air inlet stagnation temperature is 288K. If the stagnation temperature rise of the stages is 21K, the rotor tip speed is 200 m/s, and the rotor rotates at 4500 rpm, calculate the stage efficiency and diameter of the rotor.

The stage pressure ratio is given by:

$$R_s = \left[1 + \frac{\eta_s \Delta T_{0s}}{T_{01}}\right]^{\frac{\gamma}{\gamma-1}}$$

or

$$1.22 = \left[1 + \frac{\eta_s (21)}{288}\right]^{3.5}$$

that is,

$$\eta_s = 0.8026 \quad \text{or} \quad 80.26\%$$

The rotor speed is given by:

$$U = \frac{\pi D N}{60}, \quad \text{or} \quad D = \frac{(60)(200)}{\pi(4500)} = 0.85 \text{ m}$$

10- An axial flow compressor has a tip diameter of 0.95 m and a hub diameter of 0.85 m. The absolute velocity of air makes an angle of 288 measured from the axial direction and relative velocity angle is 568. The absolute velocity outlet angle is 568 and the relative velocity outlet angle is 288. The rotor rotates at 5000 rpm and the density of air is 1.2 kg/m3. Determine:

1. The axial velocity. 2. The mass flow rate. 3. The power required. 4. The flow angles at the hub. 5. The degree of reaction at the hub.