The Radial Flow Turbine

4.1 Introduction

There are two basic types of turbine suitable and used at present in turbochargers, the radial flow and the axial flow. The radial flow turbine is mainly used for small automotive or truck turbochargers; the axial type is commonly used for the large turbochargers applied to medium-speed stationary and railway traction engines and large marine engines.

The radial flow turbine is similar in appearance to the centrifugal compressor, but with the flow in the inward direction and nozzle vanes replacing the diffuser vanes. Historically, the radial flow turbine had a late start in the field of turbocharging and has been primarily developed for use in the small-size inexpensive automotive turbocharger. Its great advantage is that it maintains a relatively high efficiency when reduced to very small sizes. It can efficiently handle a high expansion ratio (approaching 4:1) and is also more robust and cheaper to manufacture than an axial turbine. Although well established in the automotive field, its use in larger turbochargers is at present limited by manufacturing techniques.

4.2 Elementary Theory

The turbocharger turbine is required to accept quite unfavourable inlet conditions if the pulse turbocharging system is used. The inlet might be divided into two or three separate sectors, each containing highly pulsating flow. It is indeed fortunate that the turbine is able to accept these conditions without a complete deterioration of its performance.

The radial inflow turbine consists of a scroll or inlet casing (figure 4.1), a set of inlet nozzles (sometimes omitted) followed by a short vaneless gap and the turbine wheel itself. Most small turbocharger turbines use a nozzleless casing to improve flow range at some penalty in peak efficiency, but also reducing cost. However, considering the more conventional type with nozzles, the function of the inlet casing is purely to deliver a uniform flow of inlet gas to the nozzle entries. The nozzles accelerate the flow, reducing pressure and increasing kinetic energy. A short vaneless space prevents the rotor and blades from touching and allows wakes coming off the trailing edge of the nozzle blades to mix out. Energy transfer occurs solely in the impeller, which should be designed for minimum kinetic energy at the exit.
Figure 4.1 Components of a radial flow turbine

The flow process through the turbine may be plotted on a temperature or enthalpy/entropy diagram (figure 4.2). Station 01 refers to stagnation conditions at entry to the casing. The gas will already have a significant velocity \( C_1 \) hence the stagnation pressure is \( P_{01} \). The inlet nozzles accelerate the flow from station 1 to 2. If this process were isentropic, the end point would be \( 2_s \). Energy transfer occurs in the rotor, between stations 4 and 5 (4 and 5 if isentropic) down to the exit pressure \( (P_5) \). The stagnation pressure \( (P_{05}) \) will be higher than \( P_5 \) since the exit velocity \( (C_5) \) will remain significant. Station 3 is the nozzle exit.

Figure 4.2 h-s diagram for a turbine stage

4.2.1 Velocity Triangles and Energy Transfer

The specific energy transfer in the rotor can be derived from the velocity triangles at inlet and outlet (figure 4.3). The absolute gas velocity entering the rotor is \( C_4 \), at an angle \( \alpha_4 \); its radial component is \( C_{r4} \). Since the rotor tip speed is \( U_4 \), the gas velocity relative to the rotor blades is \( W_4 \). At rotor exit the relative velocity