Discharge Flow Management

To this point the entire focus has been on the flow within the impeller or rotor of the pump. However, the flow that discharges from the impeller requires careful handling in order to preserve the gains in energy imparted to the fluid. In many machines this requires the conversion of velocity head to pressure by means of a diffuser. This inevitably implies hydraulic losses, and considerable care needs to be taken to minimize these losses. The design of axial and radial diffusers, with and without vanes to recover the swirl velocity, is a major topic, whose details are beyond the scope of this book. The reader is referred to the treatise by Japikse (1984).

Such diffusers are more common in compressors than in pumps. Typical pump configurations are as follows. Axial flow pumps often employ a set of stator vanes before (or in) the axial diffuser in order to recover the swirl velocities. Special care needs to be taken to match the swirl angles of the flow exiting the impeller with the inlet angles of the stator vanes. It is advisable, where possible, to measure the impeller discharge flow directly before finalizing a design. In some designs, the axial diffuser will be followed by a spiral collector or "volute" in order to recover the energy in the remaining swirl and axial velocities.

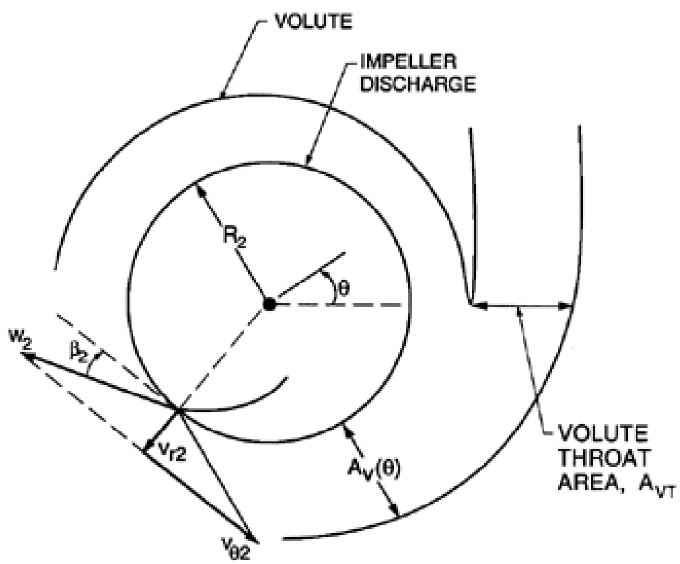

Figure 1: Volute flow notation.

In the case of centrifugal pumps, a radial flow diffuser with vanes may or may not be used. Often it is not, and the flow discharges directly into the volute. The proper design of this volute is an important component of centrifugal pump design (Anderson 1955, Worster 1963, Stepanoff 1948). The objective is to design a volute in which the flow is carefully matched to the flow exiting the impeller, so that the losses are minimized and so that the pressure is uniform around the impeller discharge. The basic concept is sketched in figure 1. The flow discharges from the impeller with a velocity, $v_{\theta 2}$, in the tangential direction and a velocity, v_{r2}, in the radial direction, given by

$$v_{r2} = Q/2\pi R_2 B_2 \qquad \text{(Mbdd1)}$$

where B_2 is the impeller discharge width. For simplicity, it will be assumed that the discharge from the impeller is circumferentially uniform; in fact, nonuniform volute flow will lead to a nonuniform flow in the impeller that is unsteady in the rotating frame. Though this complication is often important, it is omitted from the present, simple analysis.

If we further assume radially uniform velocity at each angular location in the volute (also an assumption that needs to be modified in a more accurate analysis), then it follows from the application of conservation of mass to an element, $d\theta$, of the volute that the discharge flow will be matched to the flow in the volute if

$$v_{\theta 2}\frac{dA_V}{d\theta} = v_{r2}R_2B_2 \quad \text{(Mbdd2)}$$

This requires a circumferentially uniform rate of increase of the volute area of $dA_V/d\theta = v_{r2}R_2B_2/v_{\theta 2}$ over the entire development of the spiral. If the area of the clearance between the cutwater and the impeller discharge is denoted by A_{VC}, and the volute exit area is denoted by A_{VT}, then A_V should have the following linear behavior:

$$A_V = A_{VC} + \frac{\theta}{2\pi}A_{VT} \quad \text{(Mbdd3)}$$

It follows that $dA_V/d\theta = A_{VT}/2\pi$ and hence

$$\phi^{-1}\tan\beta_2 - 1 = \frac{2\pi R_2B_2\tan\beta_2}{A_{VT}} \quad \text{(Mbdd4)}$$

Consequently, for a given impeller operating at a given design flow coefficient, ϕ_D, there exists a specific area ratio, $2\pi R_2B_2\tan\beta_2/A_{VT}$, for the volute geometry. This parameter is close to the ratio which Anderson (1955) used in his design methodology (see also Worster 1963), namely the ratio of the cross-sectional area of the flow leaving the impeller ($2\pi R_2B_2\sin\beta_2$) to the volute throat area (A_{VT}). For more detailed analyses of the flow in a volute, the reader is referred to Pfleiderer (1932), Stepanoff (1948), and Lazarkiewicz and Troskolanski (1965). For example, Pfleiderer explored the radially nonuniform distributions of velocity within the volute and the consequences for the design methodology.

One of the other considerations during the design of a volute is the lateral force on the impeller that can develop due to circumferentially nonuniform flow and pressure in the volute. These, and other related issues, are discussed in section (Mcj).