Performance Analysis

This section describes a hydraulic analysis of a fluid coupling that is designed to operate either in a forward or reverse mode when a set of turning vanes are respectively withdrawn or inserted into the flow between the driving and driven rotors. The flow path is subdivided into a set of stream tubes and an iterative method is used to adjust the cross-sectional areas of these stream tubes in order to satisfy radial equilibrium. Though the analysis requires the estimation of a number of loss coefficients, it predicts coupling performance data that are in good agreement with that measured in NAVSSES tests of a large reversible coupling intended for use in a ship drive train.

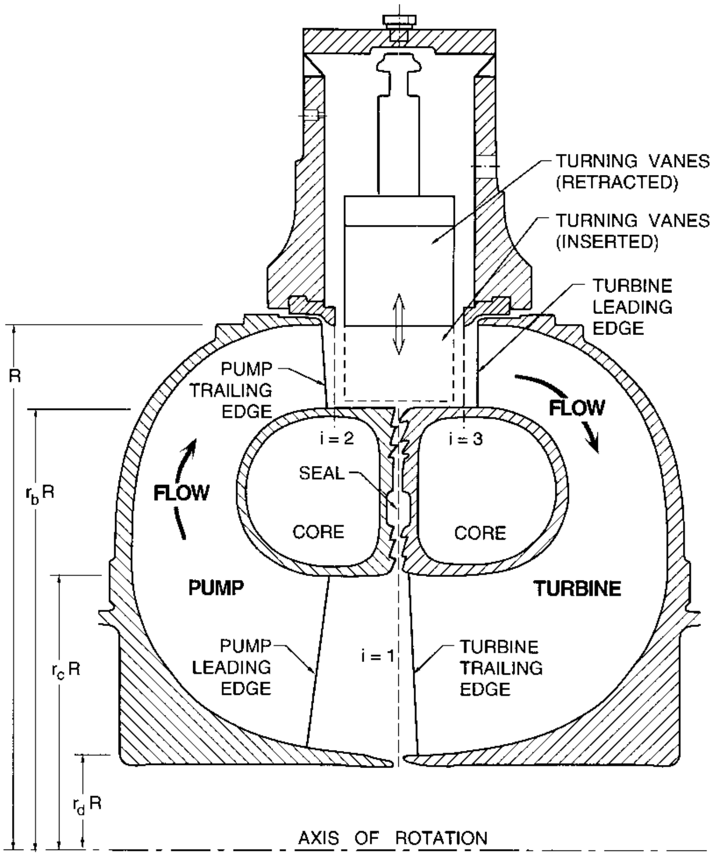

Figure 1: Cross-section of reversible fluid coupling showing key locations in the fluid cavity.

We develop a general hydraulic analysis of a fluid coupling that includes the variant described above, namely a reversible fluid coupling. This device was developed and built by Franco Tosi in Italy in conjunction with SSS Gears Ltd. in the U.K. and is described in detail in Fortunato and Clements (1979), Clements and Fortunato (1982) and Clements (1989). Tests on the device were conducted by the US Navy (NSWC Philadelphia) and are documented in Nufrio *et al.* (1987) (see also, Zekas and Schultz (1997)). In the following sections, we utilize overall coupling performance data obtained by NSWC and several investigations of flow details carried out by WesTech Gear Corporation.

As shown diagrammatically in Figure 1, the reversible fluid coupling has an added feature, namely a set of guide vanes. With the vanes retracted the device operates as a conventional fluid coupling and the direction of rotation of the output shaft is the same as that of the input shaft. When the vanes are inserted, the direction of rotation of the output shaft is reversed. In traditional terms, the reversible fluid coupling can, in theory, operate over a range of slip values from $S = 0$ to $S = 2$ (S equals 1 minus the ratio of the rotation rate of the driven shaft to that of the driving shaft).

A number of recent papers have demonstrated how complex and unsteady the flow is in torque converters (see, for example, By and Lakshminarayana (1995), Brun *et al.* (1996), Gruver *et al.* (1996)). Due, in part, to the need to operate the machines over a wide ranges of slip values, the incidence angles on the impeller blades tend to be very large thus generating substantial flow separation at the leading edges as well as much unsteadiness and high turbulence levels. To accommodate these violent flows and to force the flow to follow the vanes at impeller discharge, the solidity of the impellers is usually much larger than would be optimal in other turbomachines. Though several efforts have been made to compute these flows from first principles (By *et al.* (1995), Schulz *et al.* (1996)), such complex, unsteady and turbulent flows with intense secondary flows are very difficult to calculate.

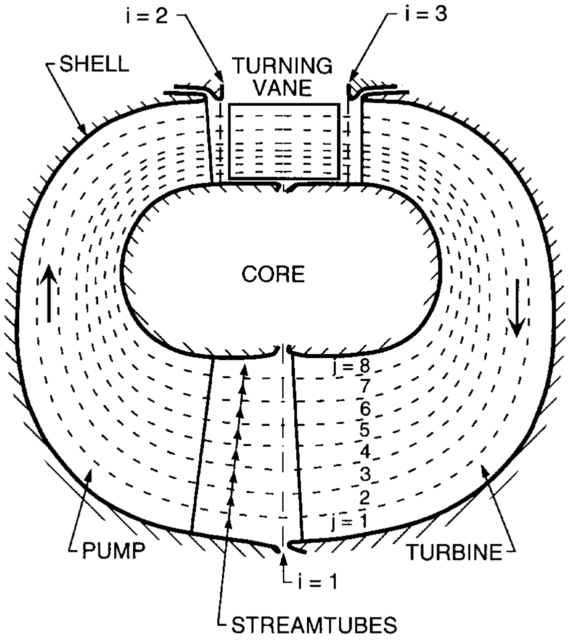

Figure 2: Sketch showing the subdivision of the flow into stream tubes.

In the sections that follow we present a simple one-dimensional analysis of the flow in a reversible fluid coupling. This one-dimensional analysis may be used as a first order estimate of the coupling performance. Alternatively it can be applied to a series of stream tubes into which the coupling flow is divided. Such a multiple stream tube analysis (or two-dimensional flow) as depicted in Figure 2 allows accommodation of the large variations in flow velocity and inclination that occur between the core and the shell of the machine.