Turbomachine Dynamics

Turbomachines very often constitute important components of piping systems and knowledge of their unsteady or transient response is frequently critical to an understanding of how the whole system will respond to transients or instabilities. Transient responses are usually analyzed by time domain methods (especially because non-linear effects can be handled by those methods) and some guidance in this regard is provided in Section (Bnfd). However, for a variety of reasons ranging from the complexity of the internal flows to the need to treat cavitation, frequency domain methods have distinct advantages when dealing with instabilities in systems involving turbomachines. In this section and those which are indicated herein, we seek to provide a framework for such frequency domain methods and to provide some transfer function data for pumps, turbines and cavitating flows. There are a few notable contexts in which *both* time domain methods and frequency domain methods are utilized in analyzing a hydraulic system; an example is the work of Amies *et al.* (1977) on aircraft hydraulic control systems where both transient and stability analyses were performed.

As described in Section (Bngc), the flow fluctuations downstream of the turbomachine (subscript 2) are related to the inlet fluctuations (subscript 1) using the conventional transfer matrix:

$$\begin{Bmatrix} \tilde{p}_2^T \\ \tilde{m}_2 \end{Bmatrix} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{Bmatrix} \tilde{p}_1^T \\ \tilde{m}_1 \end{Bmatrix} \tag{Bngi1}$$

where p^T and m are total pressure and mass flow rate and the tilde denotes the fluctating component which is assumed to be a linear perturbation on the mean flow quantities denoted by the overbar. These fluctuating quantities will be functions not only of the particular frequency under consideration but also of the mean flow conditions. Such an analytical structure is more suitable for stability analyses and can only with considerable difficulty be modified to include non-linear effects.

The transfer functions for many simple components are readily identified (see Brennen 1994) and are frequently composed of impedances due to fluid friction and inertia (that primarily contribute to the real and imaginary parts of T_{12} respectively) and compliances due to fluid and structural compressibility (that primarily contribute to the imaginary part of T_{21}). More complex components or flows have more complex transfer functions that can often be determined only by experimental measurement. For example, the dynamic response of pumps can be critical to the stability of many internal flow systems (Ohashi 1968, Greitzer 1981) and consequently the transfer functions for pumps have been extensively explored (Fanelli 1972, Anderson et al. 1971, Brennen and Acosta 1976). Under stable operating conditions (see Sections (Nrc), (Nsi)) and in the absence of phase change, most pumps can be modeled with resistance, compliance and inertance elements and they are therefore dynamically passive. However, the situation can be quite different when phase change occurs. For example, cavitating pumps are now known to have transfer functions that can cause instabilities in the hydraulic system of which they are a part. Note that under cavitating conditions, the instantaneous flow rates at inlet and discharge will be different because of the rate of change of the total volume, V, of cavitation within the pump and this leads to complex transfer functions that are described in more detail in Section (Nsi). These characteristics of cavitating pumps give rise to a variety of important instabilities such as cavitation surge (see Section (Nri)) or the Pogo instabilities of liquid-propelled rockets (Section (Mbfn)). Much less is known about the transfer functions of other devices involving phase change, for example boiler tubes or vertical evaporators. As an example of the transfer function method, in Section (Nrm) we consider a simple homogeneous multiphase flow.

Further information on transfer functions is provided in Section (Nrp) where non-cavitating pumps are addressed, in Section (Nrq) that addresses cavitating pumps, in Section (Nrr) that addresses turbines and in Section (Nrs) that addresses propellers.