Rotor-Stator Interaction: Flow Patterns

In section (Mbfb), we described the two basic frequencies of rotor-stator interaction: the excitation of the stator flow at $Z_R\Omega$ and the excitation of the rotor flow at $Z_S\Omega$. Apart from the superharmonics $mZ_R\Omega$ and $mZ_S\Omega$ that are generated by nonlinearities, subharmonics can also occur. When they do they can cause major problems, since the fluid and structural damping is smaller for these lower frequencies. To avoid such subharmonics, turbomachines are usually designed with blade numbers, Z_R and Z_S, which have small integer common factors.

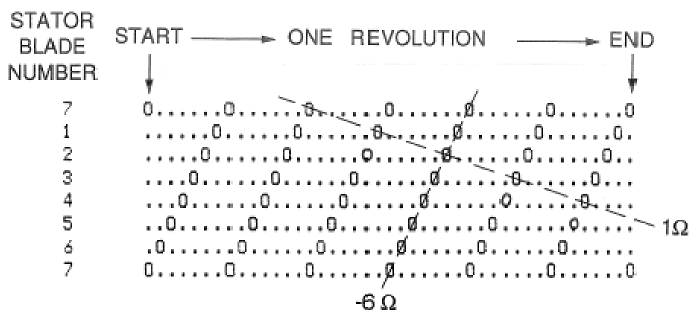

Figure 1: Encounter diagram for rotor-stator interaction in a turbomachine with $Z_R = 6$, $Z_S = 7$. Each row is for a specific stator blade and time runs horizontally covering one revolution as one proceeds from left to right. Encounters between a rotor blade and a stator blade are marked by an 0.

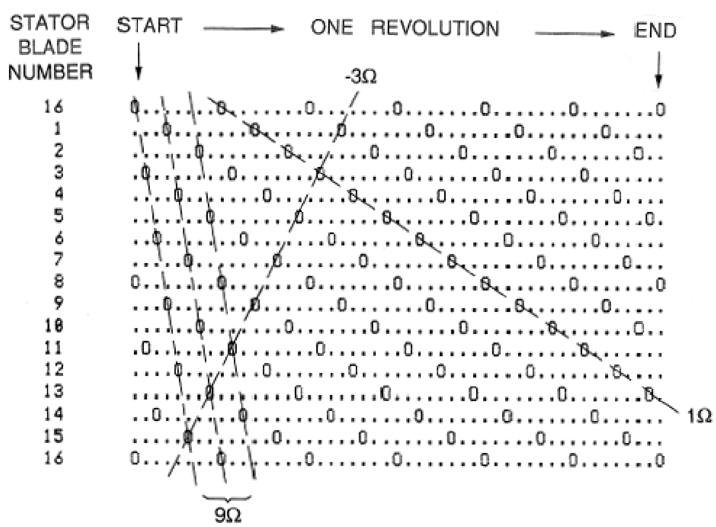

Figure 2: Encounter diagram for rotor-stator interaction in a turbomachine with $Z_R = 6$, $Z_S = 16$.

The various harmonics of blade passage excitation can be visualized by generating an "encounter" (or interference) diagram that is a function only of the integers Z_R and Z_S. In these encounter diagrams, of which figures 1 and 2 are examples, each of the horizontal lines represents the position of a particular stator blade. The circular geometry has been unwrapped so that a passing rotor blade proceeds from top to bottom as it rotates past the stator blades. Each vertical line represents a moment in time, the period covered being one complete revolution of the rotor beginning at the far left and returning to that moment on the far right. Within this framework, the moment and position of all the rotor-stator blade encounters

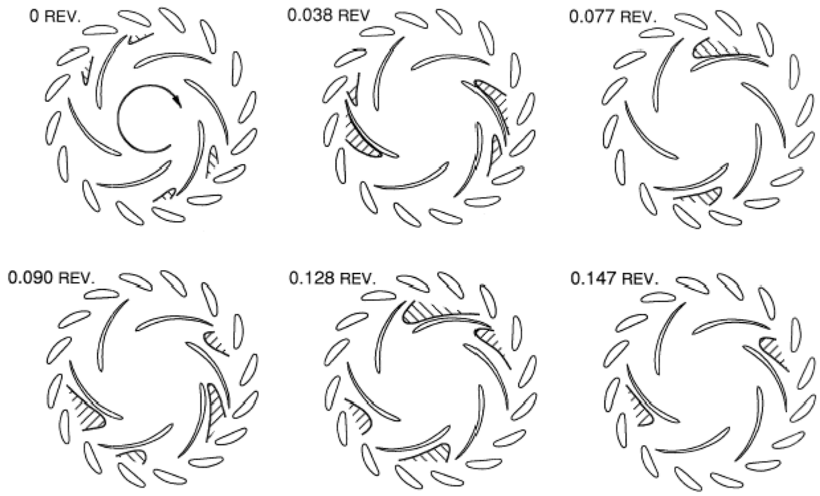

Figure 3: The propagation of a low pressure region (hatched) at nine times the impeller rotational speed in the flow through a high head pump-turbine. The sketches show six instants in time equally spaced within one sixth of a revolution. Made from videotape provided by Miyagawa *et al.* (1992).

are shown by an "0." Such encounter diagrams allow one to examine the various frequencies and patterns generated by rotor-stator interactions and this is perhaps best illustrated by referring to the examples of figure 1 for the case of $Z_R = 6$, $Z_S = 7$, and figure 2 for the case of $Z_R = 6$, $Z_S = 16$. First, one can always follow the diagonal progress of individual rotor blades as indicated by lines such as those marked 1Ω in the examples. But other diagonal lines are also evident. For example, in figure 1 the perturbation consisting of a single cell, and propagating in the reverse direction at 6Ω is strongly indicated. Parenthetically we note that, in any machine in which $Z_S = Z_R + 1$, a perturbation with a reverse speed of $-Z_R\Omega$ is always present. Also in figure 2, there are quite strong lines indicating an encounter pattern rotating at 9Ω and consisting of two diametrically opposite cells. Other propagating disturbance patterns are also suggested by figure 2. For example, the backward propagating disturbance rotating at 3Ω in the reverse direction and consisting of four equally spaced perturbation cells is indicated by the lines marked -3Ω. It is, of course, possible to connect up the encounter points in a very large number of ways, but clearly only those disturbances with a large number of encounters per cycle (high "density") will generate a large enough flow perturbation to be significant. However, among the top two or three possibilities, it is not necessarily a simple matter to determine which will manifest itself in the actual flow. That requires more detailed analysis of the flow.

The flow perturbations caused by blade passage excitation are nicely illustrated by Miyagawa *et al.* (1992) in their observations of the flows in high head pump turbines. One of the cases they explored was that of figure 2, namely $Z_R = 6$, $Z_S = 16$. Figure 3 has been extracted from the videotape of their unsteady flow observations and shows two diametrically opposite perturbation cells propagating around at 9 times the impeller rotating speed, one of the "dense" perturbation patterns predicted by the encounter diagram of figure 2.