Key players in efficiency, surge and stall

Diffusion is a word that we all hear from time to time in turbomachinery work. Is it a concept that we can forget, or do we really need to understand it? You be the judge!

Start by remembering the Bernoulli Principle (*Hydrodynamica, 1738*), which says that the static and dynamic pressure (or dynamic head) are a constant along many streamlines. That constant is not only the sum of the two, but is the actual total pressure for the fluid along the chosen streamline.

Now let us consider the special case where a streamline is brought to rest, for example near the front of a blade. This happens whenever the flow splits around a blade with some flow passing over the suction side and the rest along the pressure side. The dividing line between the two is the stagnation line, and the flow is truly stagnant (no velocity) along this line. The actual mass flow along a single line is infinitesimal; the adjacent streamlines still convect very little flow.

So, the Bernoulli constant is now just static pressure since the flow has been diffused down to zero velocity. But this is now also the total or so-called stagnation pressure, and the dynamic pressure or head has been converted into a static pressure rise up to the full value of the Bernoulli constant, or stagnation, or total pressure! This is a simple example of diffusion and about the only case where all the kinetic energy is recovered into (static) pressure rise.

When common diffusers are considered, large flow fields are involved with considerable energy. In all such cases, our machines have just too much kinetic energy at some point in their processes to be efficient: We either lose the energy through dissipation, or we must intentionally diffuse the flow down to a practical level.

There are two means to do this. The oldest technique seems to go back to the time of the Romans and their experience with metering the flow from an aqueduct feed. For a given flow in a pipe, the velocity will drop if we allow the cross-sectional area to increase (mass conservation), and then the Bernoulli principle clearly shows that the static pressure rises as the velocity drops. Hence, we have a real diffuser!

Some enterprising Roman technologist seems to have used this principle to draw excess water from his certified spigot by using the pressure rise to actually draw more flow through his spigot! The other approach to diffusion is the conservation of angular momentum, r x Ct (radius times tangential velocity component), as in a vaneless diffuser; as the flow spirals out to a greater radius, the velocity drops.

But are these important? The vaneless diffuser appears in 20 million - 30 million turbochargers manufactured each year and thousands of other stages for refrigeration and process compressors. Vaned or channel-type diffusers appear in nearly all high-pressure ratio, radial-flow compressors for gas turbines, marine turbochargers, shop and industrial air compressors, and boiler feed and rocket turbopumps. Additionally, exhaust diffusers (usually annular in form) are used in many axial-flow compressors and turbines to drop the exhaust kinetic energy and achieve a static pressure rise before discharging to a combustor, a heat exchanger, or just the atmosphere, thus improving the stage efficiency!

So what is the verdict? Is the diffuser worth remembering and understanding? Yes, it accounts for many points of efficiency for most machines, and the stages would simply not be competitive in today's market without the very important diffuser. Good efficiency in turbomachines requires not only good rotating blading, but good diffuser designs as well. And, they need to be kept clean and free from fouling, or the performance of the stage will drop quickly; also, the sensitive nature of the flow states in these devices makes them a key player in stage stall and eventually surge. TI

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