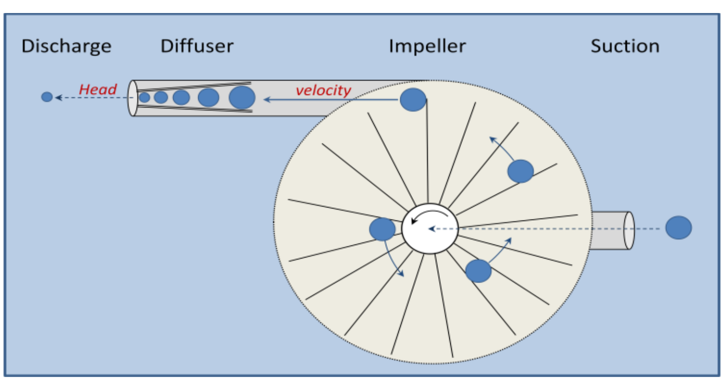
Compressor Performance - What shapes the curve?

Robert Moore, RMooreControls.com

Understanding what shapes a performance curve is helpful in understanding compressor operations. This document provides a simple description of the mechanisms involved and is the first in a series that lead to methods for optimizing compressors.

How compressors work

Suction gas enters the center or eye of the impeller. The rotating impeller accelerates the incoming gas, converting drive power to gas kinetic energy. The diffuser decelerates the gas, converting gas kinetic energy to pressure potential energy. The gas is then either discharged or routed to the eye of another impeller. The figure below illustrates compression with a radial impeller.



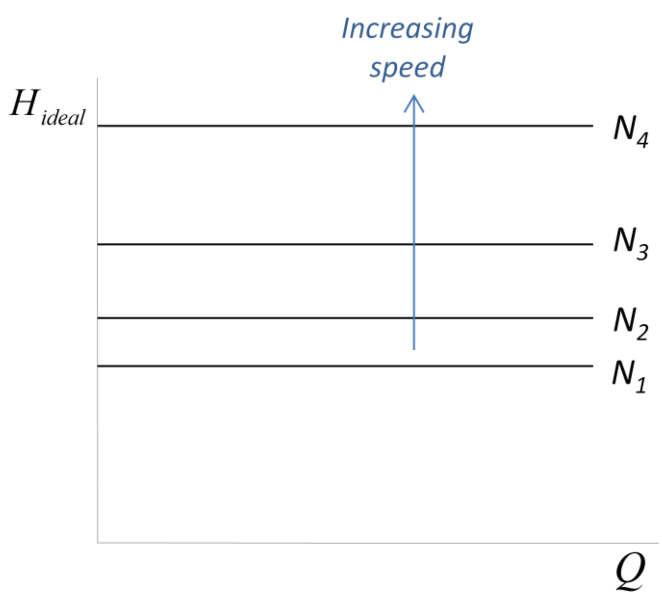
The kinetic energy of the gas leaving a radial impeller can be calculated from the impeller diameter and rotational speed. Ideal Head is the value of head that would result if all of the kinetic energy was converted to pressure potential energy.

$$v = \pi DN \qquad H_{ideal} = E_k = \frac{v^2}{2g_c}$$

v	gas velocity leaving the impeller
D	impeller diameter
N	impeller rotational speed
H_{ideal}	Head, gas pressure potential energy (per mass)... with 100% efficiency
E_k	gas kinetic energy (per mass)

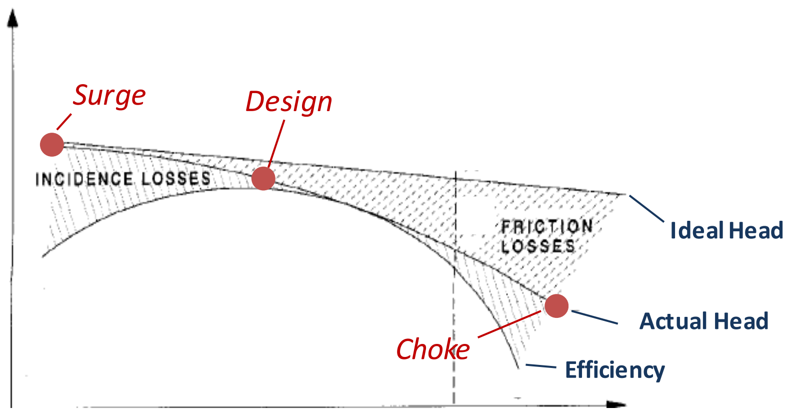
Ideal Head - Radial Impeller

Using the energy calculation we can construct the Ideal Head curve for a radial impeller. Note that head varies with the square of speed but is invariant with inlet volumetric flow rate.



Effect of Efficiency

Unfortunately there are losses in the compression process. Some of the work done by the impeller is lost to heat. Losses are due to collision and friction between the gas and compressor parts. Compressors are designed to minimize frictional and collision losses at a specific operating point in order to provide the required operating range. On either side of the design point, collision between the gas and compressor increases, resulting in decreased efficiency.

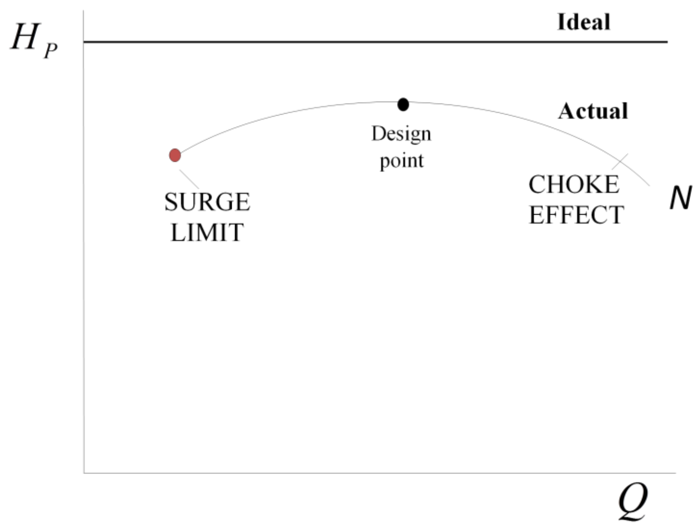


SURGE
The Surge Point represents the minimum inlet volumetric flow where a compressor can maintain performance. As inlet flow is decreased, the effect of collision become more significant. Below the surge point the effect will destabilize the flow pattern and cause the compressor's head to fail. Loss of head triggers a cycle of flow reversals which if left unabated can be damaging to the compressor.

CHOKE or STONEWALL
Choke (or Stonewall) is the inlet volumetric flow rate that results in sonic velocities in the compressor. Attempts to exceed this limit results in a rapid reduction in head and can be damaging to the compressor.

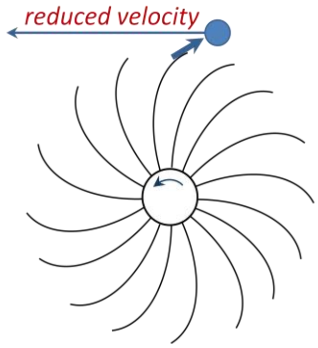
Polytropic Head - Radial Impeller

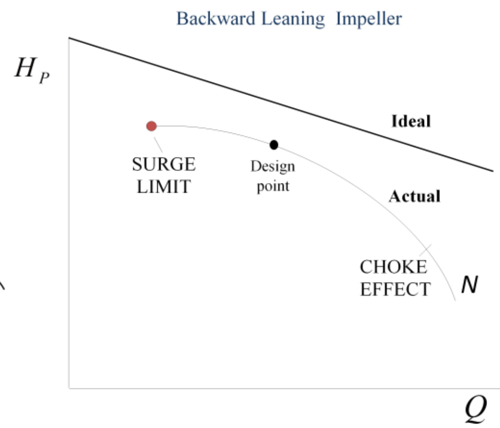
Imposing the limitations of efficiency on the Ideal Head produces the Polytropic Head Curve. The straight line of the Ideal Head curve becomes a parabola with limitations on flow.



Polytropic Head - Backward Leaning Impeller

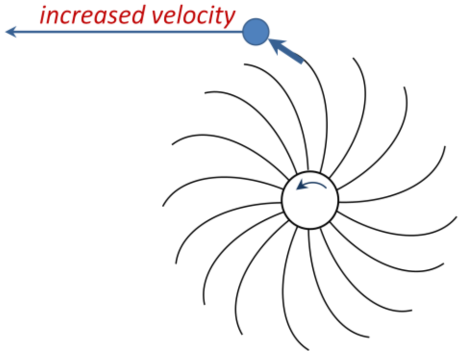
The tip of most impellers leans in a direction opposite rotation. Flow through the impeller decreases the velocity of gas leaving the impeller. The greater the volumetric flow rate into the impeller, the greater the reduction in the exit gas velocity. The result is an Ideal Head curve that decreases with inlet volumetric flow.   When the effects of efficiency are imposed, a typical polytropic head curve results with the surge point coincident with maximum head.

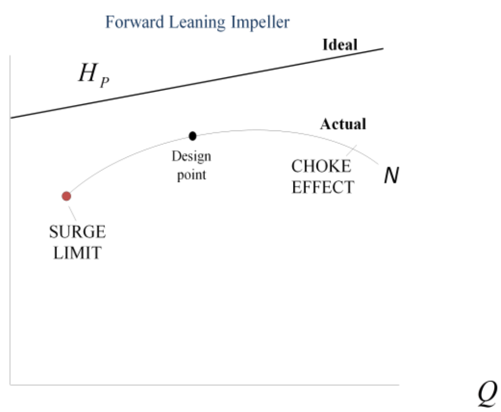




Polytropic Head - Forward Leaning Impeller

Forward leaning impellers lean in the direction of rotation. Flow through the impeller increases the gas exit velocity. The result is an Ideal Head curve that increases with flow rate. When the effects of efficiency are imposed, an unusual polytropic head curve appears, with surge occurring closer to minimum head.





Conclusions

This description of compressor performance should illustrate the following.

- Impellers convert drive power to gas kinetic energy
- Diffusers convert kinetic energy to pressure potential energy

- Ideal Head vs. Q is a straight line, the slope of which is determined by the impeller lean angle
- The effects of gas friction and collision change the shape of the curve and create limitations in compressor performance at low volumetric flow rates
- Surge does not necessarily occur at maximum head.

This is the first in a series of posts leading to methods for optimizing compressor performance.

References:

1. *Compressor Handbook* . Ed. Paul C. Hanlon. New York: McGraw-Hill, 2001. Print.