Stall in Axial Flow Gas Turbine Compressors

This lecture describes the inception of stall in an aero engine compressor over a range of speeds and the post stall behaviour. Reference is made to the varying matching and system response as the speed is increased and the effects demonstrated on a single shaft gas turbine.

The stage nearest to stall moves from the front to the rear as speed increases from idle to max. The stall inception moves from front to rear as the matching changes. The compressor always develops rotating stall but as speed increases the post stall behaviour changes from rotating stall to surge.

At the highest of speeds the surge is limited by Combustor flame out. Comparison with low speed data obtained by I J Day from Cambridge is qualitatively similar except at high speed where there is clear evidence of time delays due to the wave propagation times.

Surge and Stall in Axial Compressors

The behaviour of axial flow compressors is illustrated by a number of stalls induced on a Viper Engine. Stalls were induced by

1) Over fuelling at low speed

2) Inbleed of a separate source of compressed air into the combustor

The stalls were measured with several rings of kulite pressure transducer along the length. Accurate measurements of flow and pressure ratio were obtained using slow response measurements. These latter instruments do not correctly measure the surge cycle but are adequate for defining rotating stall characteristics.

Figure 1 shows the engine. Figure 2 shows the overall characteristics as measured many years ago on a rig. Figure 3 shows the expected working line the low speed zone of "part span" rotating stall a zone in which the engine can accelerate and the Deep Rotating Stall characteristics for two speeds. The Running Line is shown for the Deep Rotating Stall. The engine in this state cannot accelerate. Figure 4 shows a typical cycle for a mid power surge induced by inbleed.

The overall results are shown in Figure 5 it can be seen that the surges are in 4 distinct groups low power overfuels leading to deep rotating stall. Mid power inbleeds with the engine decelerating to surge with a fixed inbleed here the stalls could either end in rotating stall or violent repetitive surges. High Power surges had only one cycle before the engine flamed out and had to be relit.

Compressor Matching

The expected variation of stage performance is shown in Figure 6. With the front severely stalled on the running line at low speed, the front more stalled at surge at mid speeds; and the rear stalling on the surge line at high speed these are the classical results for a high speed compressor off design.

Low Speed Stalls

Up to 62% speed this compressor is always in "part span" rotating stall on the working line and above as the stage chics show the machine is predicted to be severely in stall at the front. However when throttled the machine jumps onto a new characteristic Deep Rotating stall. The process can be seen in figures 7 and 8 where kulite measurements are shown for front, middle, rear and around the circumference. These show multicells as the compressor is throttled developing into a single cell; the multicells are strong at front and not really visible at the back. The Big Cell is in phase in the centre and rear and out of phase in the front, at the front low flow high pressure at the rear low pressure stalled flow.

The movement from one state to the other is shown in Figure 9 where the data from Figure 8 is contour plotted and repeated. This enables the stall development at the front to be visualised, the big cell travels more slowly than the multiple cells and the small cells get enveloped as one cell grown and slows down.

Mid Speed Stalls

The mid speed stalls come in two distinct groups, ones that end in deep rotating stall and ones that end in cyclic surge. This can be seen in Figure 5 where a distinct change in post stall behaviour can be seen.

Stalls that end in Rotating Stall

Figure 10 shows 5 kulites at the front of the compressor before the stall at about 83% compressor speed. There is no evidence of the permanent multicelled rotating stall however, there is a sharp blip that moves around the compressor and then becomes the big deep rotating stall; the blip travels at 55% of compressor speed and the big cell at 40% of compressor speed. The same stall is presented as a plot of pressure time and circumferential position in Figure 11. This shows one cell growing and slowing; the first big cells is early different from the subsequent cells as the compressor establishes itself on the Rotating Stall characteristic on the Rotating stall operating line. These results are very similar to those described by I J Day in this lecture series.