Novel Flow-wise Grooves in Radial Turbomachines

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Long Abstract

Abstract

Flow-wise cover grooves have been introduced into centrifugal compressors and pumps, and other turbomachines, to utilize misoriented secondary flow in the control of impeller exit profiles and to improve diffuser entry conditions. The design background for these grooves is explained, as well as their computational foundation. Experimental results are presented and the favorable impact on performance is shown. Proper applications have improved surge margin without efficiency penalty and have worked with both vaneless and vaned diffusers.

Introduction

The core inspiration for the flow-wise grooved-covers (or close-coupled flow-guides, CCFG) is embodied in the laser velocimetry done in earlier investigations, (Japikse and Karon, 1989) and is a response to the characteristics of conventional tests and CFD evaluations. The stage used for this study is based on a small turbocharger compressor wheel as documented by Japikse and Karon, ibid. Figures 1a-c illustrate the great variations found in the flow field at the diffuser inlet. In fact, the flow field is essentially fighting itself in the tight confines of the impeller blade passage as the secondary flow regime develops and causes large blockage and then large mixing losses. Considerable energy is involved in this mixing, since the C_θ values vary by 70 m/s out of a base level of just 160 m/s for the core flow (see Figure 1b). Likewise, the absolute flow angle varies by 20° out of a base of 46° (see Figure 1c). Fortunately, this process is often located near the shroud surface, and therefore should be amenable to flow-wise cover grooves for open front-face impellers. The results of this study have revealed strong problems in circumferential distortion (both vaneless and vaned diffusers), plus some very strange wall pressure patterns, especially for the highly pinched vaneless diffuser (Japikse and Krivitzky, 2016). It is believed that the grooved cover may lessen these effects. Figure 2, below, shows an embodiment of the CCFG, Close-Coupled Flow Guide, or flow-wise grooved-cover concept. The CCFG concept is much broader than the work of this present study and is presented in the patent, US 8,926,276 B2 (and other patents pending). In principle, there are a myriad of ways that a more desirable coupling between the diffuser and the impeller can be forced; the flow-wise cover groove is one part of this process.

It was a bit difficult to initiate a cover design of this type, since it had never been done before. Hence, there are no useful guidelines from prior experience! So, the study was begun by examining CFD results for operation of the test impeller at various operating points.

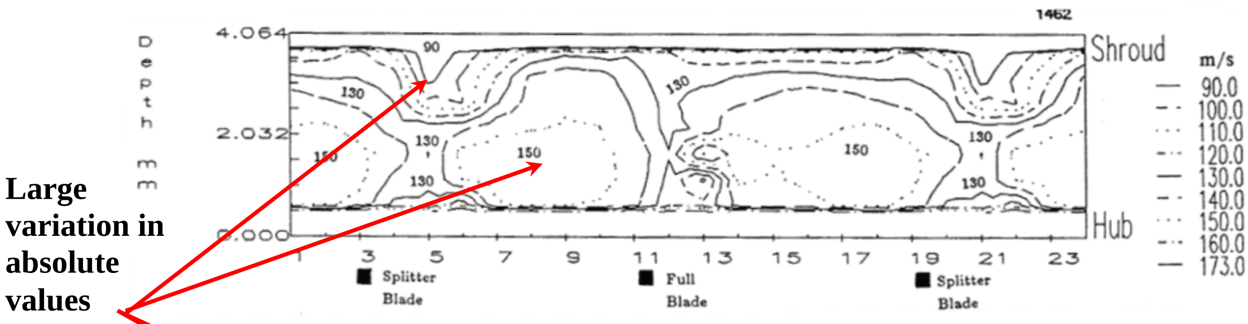

Figure 1a. **L2F measurements: C_m; near diffuser inlet, r = 1.1r2; 80 krpm, 0.303 lbm/sec**

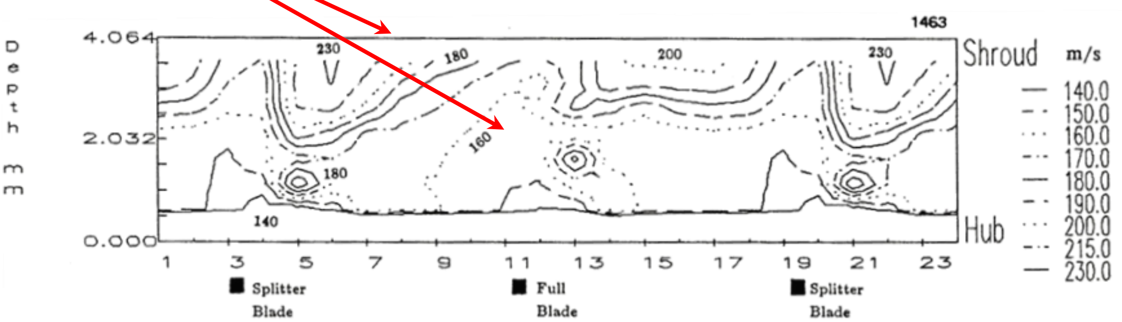

Figure 1b. L2F measurements: C_{Θ}; near diffuser inlet, r = 1.1r2; 80 krpm, 0.303 lbm/sec

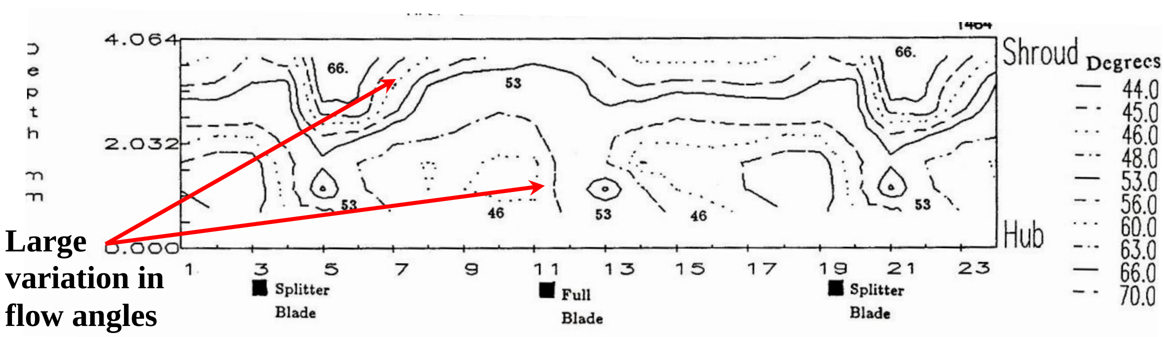

Figure 1c. L2F measurements: α; near diffuser inlet, r = 1.1r2; 80 krpm, 0.303 lbm/sec

Design Studies for the CCFG with Vaneless Diffusers

Figure 3 shows the pitch-wise averaged values of absolute frame flow angles at various spanwise locations from a proper CFD analysis of the design case performance. The evidence of secondary flow evolution near the shroud surface is strong. The core flow settles into a pattern of nearly constant flow angle (a log spiral) of about 60° from 70% meridional distance and outward. The other (pseudo) streamtubes bend over much further towards tangential (the absolute flow angle approaches 75°) and will lead to stall conditions in the diffuser at lower flow rates. These are the streamtubes that should be trapped in the cover grooves, hence forcing them to take on a flow angle nearly the same as the core value of 60°. These errant streamtubes seem to incorporate at least 10% and probably more of the passage height based on Figure 3.

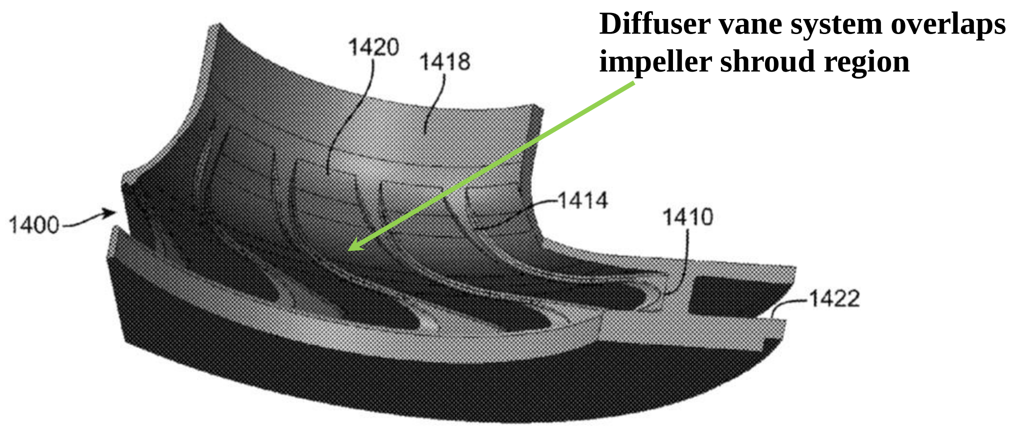

Figure 2. Embodiment of the flow-wise grooved cover CCFG (Close-Coupled Flow-Guide)

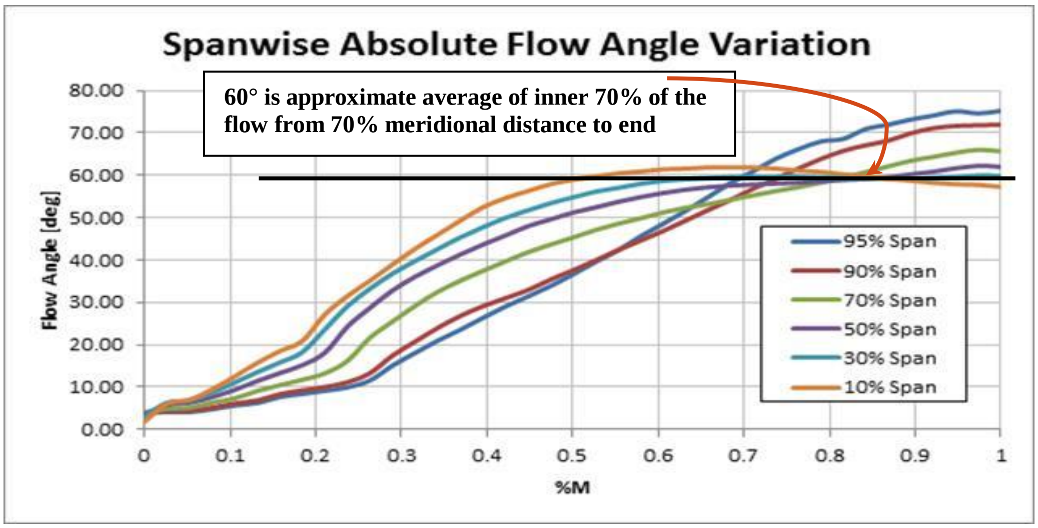

Figure 3. Blade-to-blade averaged flow angles at various % spanwise locations showing 1) crossovers at 70% - 80% meridional distance, 2) a group of angle traces that settle out to a level of about 60°, and 3) two traces that rise to higher angles; impeller at 4° incidence

Etcetera.

References

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[4] Japikse, D., (2015). Structures and methods for forcing coupling of flow fields of adjacent bladed elements of turbomachines, and turbomachines incorporating the same. US Patent 8,926,276