LESS IS MORE: IMPELLER FITS TO SHAFTS

By Marc Rubino

The proper assembly of impellers onto shafts is crucial to reliable centrifugal compressor rotor operation. Just like their human designers, these turbomachinery components are subjected to numerous, diverse stresses throughout their lifetimes. For instance, there are contact pressures that arise in bores from assembly, centrifugal loading due to rotor rotation, blade bending stresses due to gas loading and cover deflection, and axial stresses from stage pressure differentials and thermal gradients. Interference fits between the impeller and shaft permit efficient torque and power transmission. Sometimes, though, impellers are mounted to the shaft with excessive fit, causing costly difficulties in the overhaul shop.

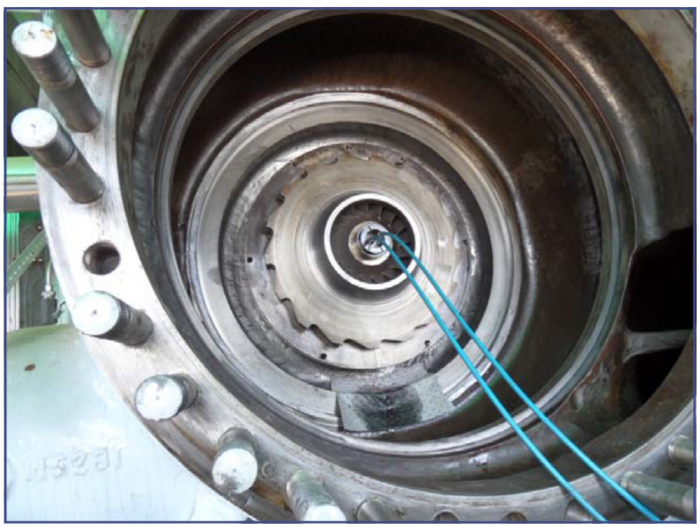

Figure 1

To meet service requirements, impellers are mounted to the rotor shaft with interference fits commonly known as shrink. The undersized bore, or disc inner diameter, relative to the shaft creates contact pressure and a means of transmitting torque, and is often designed with single or double keyways. Keys are usually considered to be redundant contingency torque transmission features. Consequently, all impellers require elastic deformation to facilitate assembly to the shaft. This is achieved by soaking the impeller with heat (torch, oven, induction) or hydraulic pressure. Hydraulically mounted impellers are found exclusively on overhung type rotors, while thermally mounted impellers are the standard for between-bearing rotors. In both methods, the bore is typically dilated approximately 0.005” larger than the shaft diameter prior to installation. After cooling or relief of oil pressure, an interference contact pressure develops between the shaft and impeller. This stress must be analyzed by the designer prior to rotor assembly. RMS generally designs wheels with fits up to 1.5 mil/in of diameter for impellers having tip speeds less than 1000 ft/s. Other manufacturers have been found to use heavy class fits up to 3.0 mil/in, particularly on vintage rotors, which make rotor disassembly problematic. Ultimately, the impeller fit to the shaft must maintain suitable contact at operating and trip speeds while maintaining adequate fatigue life.

In addition to the interference specified, the bore geometry can vary widely. In RMS’s service experience, it seems different OEMs favor different strategies for design. The most common styles for U.S. manufacturers are “straight-thru” and “differential” bores. A straight-thru bore has a single diameter for the entirety of the hub length. The straight bore design maximizes the surface area of the bore-to-shaft interference fit and theoretically reduces the fit needed. In contrast, the differential bore has a torque fit band that is axially longer and radially tighter than the centering, or alignment, fit band. They are separated axially in the bore by a machined relief. The differential style facilitates manufacturing and assembly by shortening the length of the torque transmitting fit, and reduces overall operational bore stresses. Other fit styles include supporting rings, polygonal, and integrally coupled.

RMS recently had to redesign the fit of a 1970s vintage impeller to a new shaft for an overhung type rotor assembly. Due to the heavy shrink fit, the impeller and shaft could not be separated. The fit was so great that a combination of heating the impeller, submerging the shaft in liquid nitrogen, and a hydraulic jack failed to disassemble the rotor. Fortunately, the shaft required replacement per contract anyway, and the rotor was destructively disassembled. Consequently, an existing fit was unable to be quantitatively identified. Regardless, RMS dimensionally inspected the impeller with a portable CMM for profile dimensions. A 2-D axisymmetric finite element model was created with the dimensions and weight from the existing impeller. RMS also measured impeller hardness and chemistry to properly identify material elastic properties. With the provided OEM compressor operating conditions data sheet, RMS was able to estimate gas horsepower and calculate a suitable impeller fit and stress versus power transmission capability. As a result, the new shaft taper size was specified to define the redesigned impeller to shaft fit that provided adequate torque transmission capability and substantial margin from yielding. This rotor overhaul is just another instance in which RMS demonstrates the experience and analytical tools needed to redesign your vintage equipment to ensure safe and reliable operation.

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