COUPLING BUCKLING ANALYSIS

By Christopher Sykora

RMS was contracted to perform a Root Cause of Failure Analysis (RCFA) for a major oil refinery in the Southwest US. The high speed coupling (flexible disc type) on their coker compressor train had a bad habit of failing during startup, multiple times in recent years. The coupling had been designed to meet the margin requirements of API 671 during maximum predicted, peak torque delivered from the induction motor/gearbox. However, the coupling still had repeated failures that resulted in a permanent deformation of the flexible disc web into the shape of a spiraling wave and eventually, shearing of the metal & complete separation on one side. A picture of the failed coupling is shown in Figure 1. Due to the shape of deformation, a buckling induced failure mode was suspected.

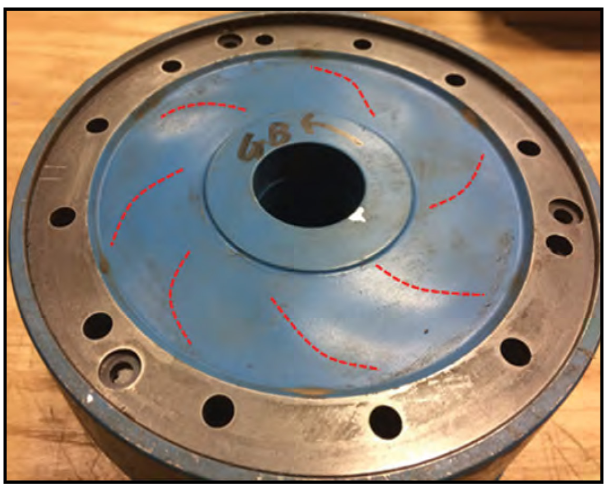


Figure 1: Spiral Buckled Coupling (Left) & Completely Failed Other End (Right)

Buckling is a failure mode that is quite different from the more typical tensile overload or cyclic fatigue scenarios. Buckling is a sudden, non-linear increase in lateral deformation of a structure when compressive loading exceeds a critical level. Since buckling is an instability failure, it is largely dependent upon the stiffness of the structure, rather than its material strength. The structure can typically still support some load after buckling, but capability is significantly reduced and as in this case it can quickly lead to shear/bending failure. The large deformations associated with buckling might also be a problem (even if the metal hasn't failed) if they interfere with other equipment (i.e. thin walled casing deforming into a rub situation). Some classic examples of buckling failures are columns in compression and thin walled cylinders experiencing external pressure or axial compression. Figure 2 shows some examples of these.

For this RCFA, the couplings were inspected for cracks and the material tensile strength and ductility were determined. None of these steps produced any evidence of material defects that could have been the cause of the failure. So a finite element analysis (FEA) was used to investigate the buckling capability of the as-built coupling. This served as an independent check on the coupling manufacturers stated design limits. The analysis geometry was based on a detailed Faro arm inspection of the as-built coupling with the minimum inspected thicknesses. A steady stress analysis with maximum speed, torque, & misalignment bending was performed first and it verified that the steady stress in the coupling was less than the tensile strength measured for the 4340 steel material.

The buckling capability of the coupling was predicted in the FEA by doing a nonlinear structural analysis with the torque load incremented in many small steps from zero to high load. While this analysis technique increases computational time due to the many small steps, it is the most accurate method of predicting the buckling. When the coupling structure reaches the load at which buckling begins, there is a significant increase

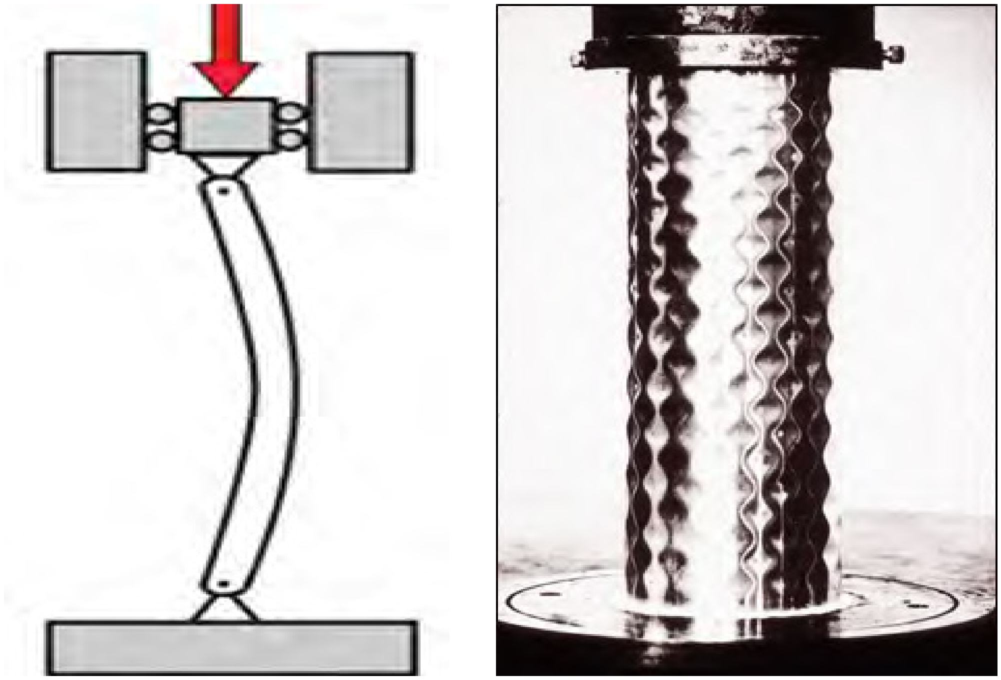

Figure 2: Column Buckling (Left) & Shell Buckling (Right)

in the slope of the graph of out of plane deformation vs applied load. Figure 3 shows the resulting graph from the analysis and the associated spiral pattern buckling deformation. The RMS analysis predicted buckling load capability very similar to the design rating specified by the coupling manufacturer. Subsequently, the manufacturer performed a static load test (also incremented in small steps) on a spare coupling that would further validate their original design predictions. Buckling occurred in the test at a slightly higher load than in the prediction since the coupling web thickness was closer to nominal than the minimum thicknesses used in the analysis.

This advanced analysis was a good opportunity for RMS to further exercise its broad analytical capabilities. Ultimately it was determined that the electric motor must have been producing a higher peak torque than was previously understood. Therefore, RMS recommended a higher torque rating value for the next coupling purchased. The higher rated coupling was installed and survived a unit startup test without any damage at all. It was disassembled, inspected, reinstalled, and the compressor train has been operating successfully ever since.

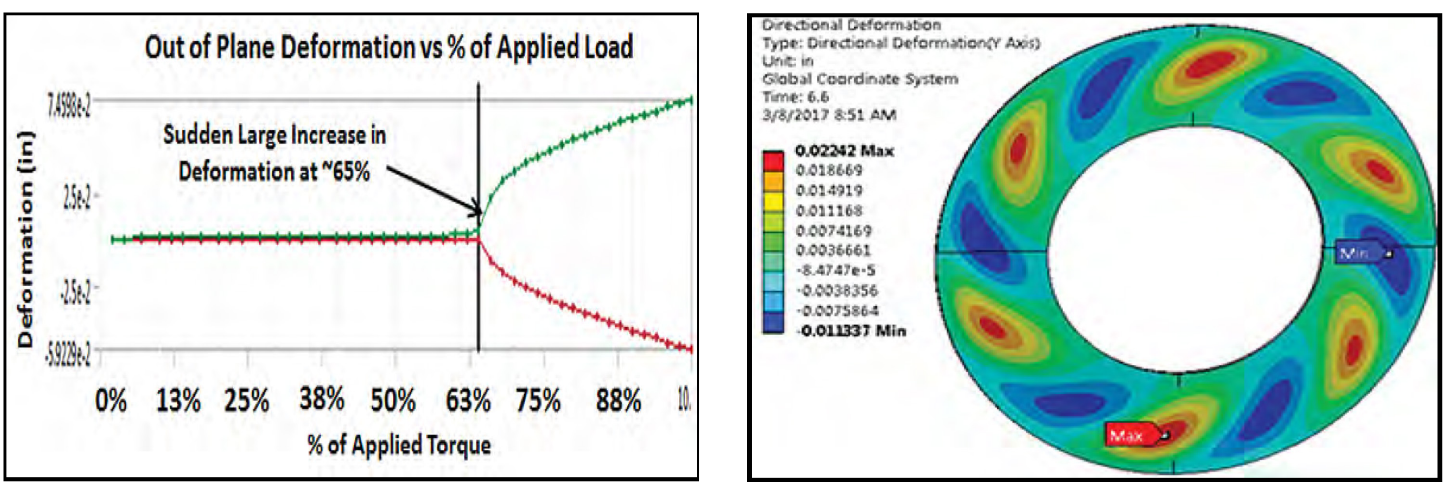

Figure 3: Deformation Graph (Left) & Buckling Shape (Right)

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