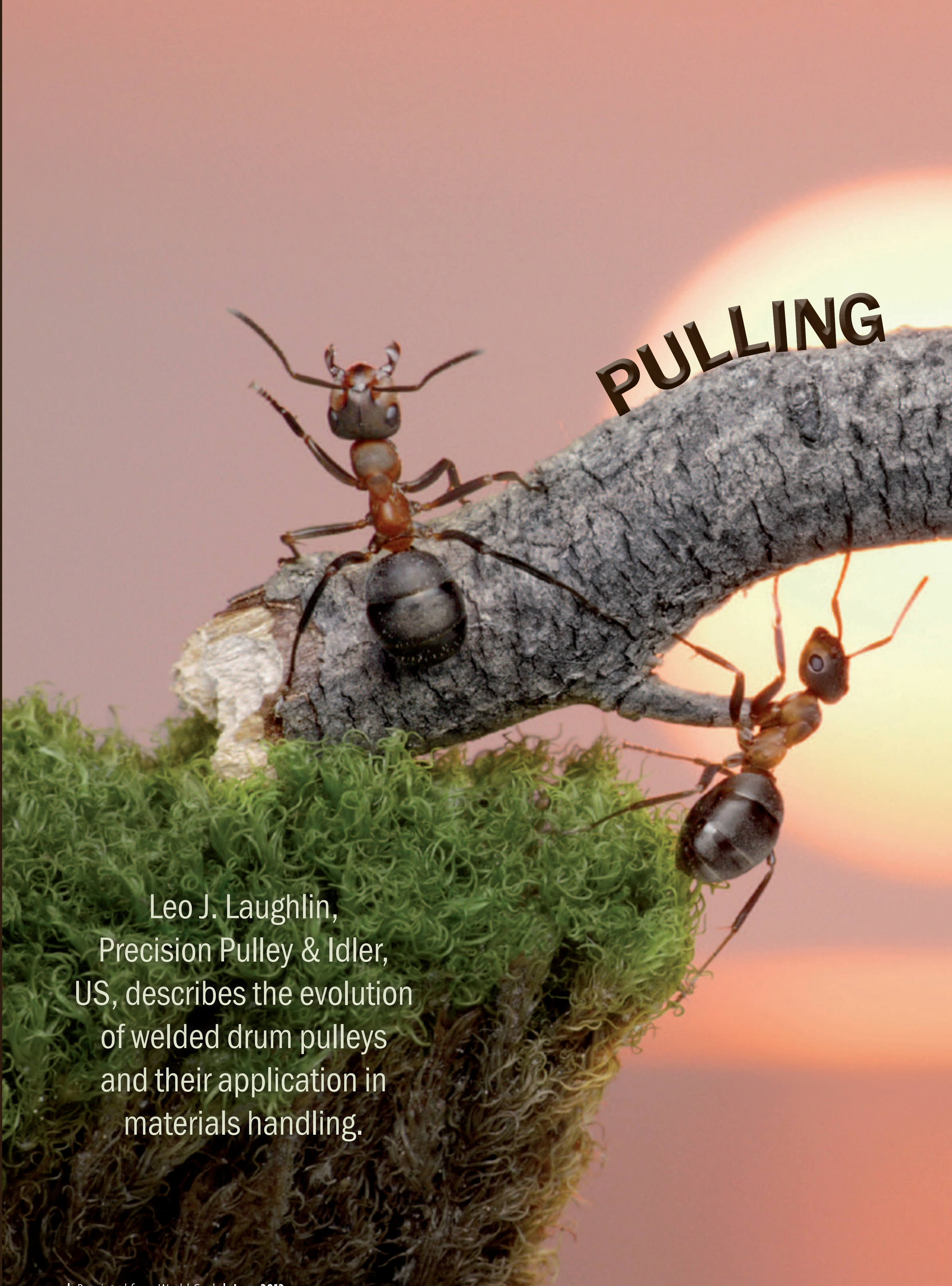

PULLING

Leo J. Laughlin, Precision Pulley & Idler, US, describes the evolution of welded drum pulleys and their application in materials handling.

THEIR WEIGHT

Many of the conveyor pulleys used in heavy mining applications use an end disc welded to a hub. This method of pulley construction is quite versatile as the manufacturer will burn an end disc from a steel plate and weld it to a standard hub. However, it also has its limitations, as the weld that joins the hub to the end disc is the most stressed point in the pulley.

Figure 1 shows a pulley finite element analysis (PFEA) stress output of the radial stresses in a welded hub-end disc pulley. PFEA analysis is developed by Precision Pulley & Idler exclusively for drum pulley design. Even though this pulley has been designed as a mine duty pulley, with a life of 100,000 hours, the plot shows how the stresses are concentrated at the hub weld. This concentration of stresses is responsible for the majority of pulley failures.

Figure 2 illustrates the common failure mode of the majority of welded steel pulley failures. However, high stress is only one aspect of the problem. The shape of the weld plays an important part.[1] The profile or blending of the weld to the end disc can dramatically affect the stress concentration factor at this critical junction.

The welding of this joint will also leave residual weld stresses in the joint. As the weld cools, it will shrink and pull at the joint. Thermal stress relieving (TSR) will increase the life of the pulley by a factor of approximately five.[2] TSR has become a standard addition to turbine and large welded steel pulleys; however, it would be a challenge to do on a large scale to all conveyor pulleys and it would do nothing to change the heat-affected zone in the end disc. Many blame the welding and will attempt to re-weld the hub to the end disc, as shown in Figure 3. The problem is that the crack is through the parent material (the end disc) and adjacent to the hub weld. The additional welding does not fix the problem and only postpones the failure.

Pulley geometry is a key factor in designing a pulley. Pulley diameters are often determined by the belt manufacturer and the conveyor designer and not the pulley designer. In the 1970s, pulley diameters were 6 – 8 times the diameter of the shaft. As illustrated by Figure 4, these pulleys did not present a problem as most end discs worked well. However, today's belts have higher ratings and can wrap around smaller pulleys. As a result, today's pulley diameters are usually 3 – 5 times the shaft diameter. This adds to the design dilemma. Those pulleys with a diameter of less than three times the shaft diameter present a problem in manufacturing and will typically be of an integral hub design, where there is no end disc.

With advances in design, PFEA and Life programs can be used to design a pulley that will handle these limitations.[2,3] Even then, overloads can be a problem. A recent mine visit revealed that the customer applied a service factor to their counterweight. Rather than applying it to the tensions, they applied the service factor to the counterweight, increasing the counterweight beyond the design load of the pulleys. Other times the weight box is left open, allowing material to fall into the box and resulting in higher loads over time. While others think that more weight is better, a simple 10% increase in the running tensions can lead to a 10-fold reduction in the pulley life.[1]

Some have been increasing the end disc thickness beyond what is needed to address the issues of overloads. A heavier end disc will lower the stresses in the end disc and increase the life of the pulley, but this will also result in the pulley becoming more rigid. The problems involved with pulleys using keyless locking assemblies that are too rigid are well documented.[4]

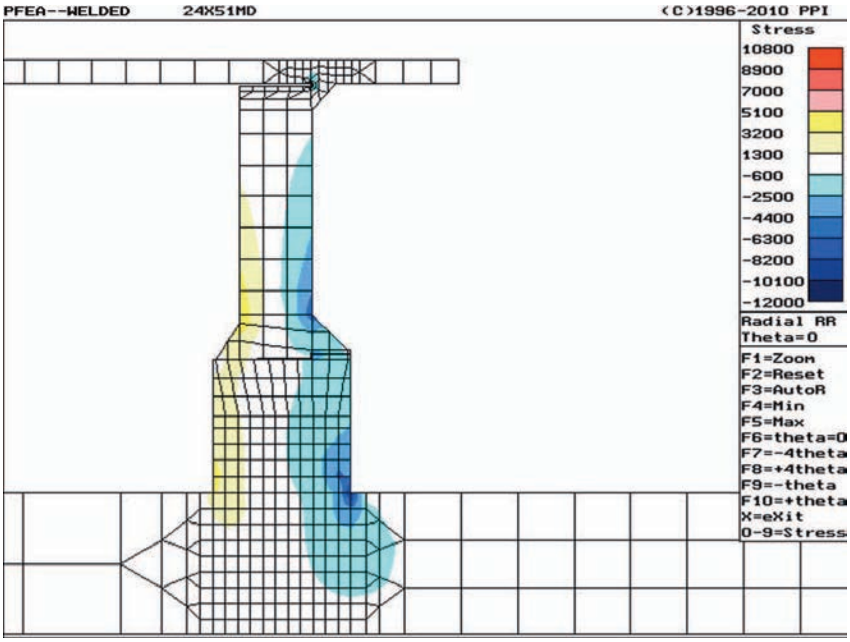

Figure 1. Pulley finite element analysis (PFEA) stress output of the radial stresses in a welded hub-end disc pulley.

Figure 2. A common welded steel pulley failure.

Figure 3. The hub shown here has been re-welded to the disc.

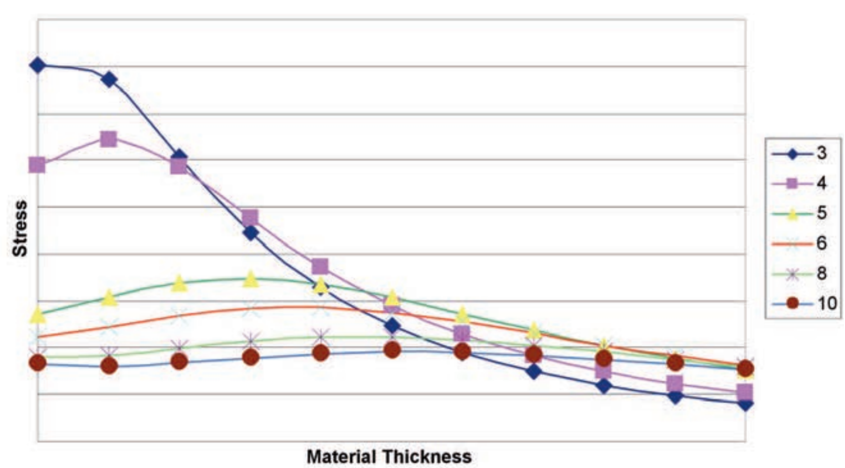

Figure 4. Stress plots for OD/SD.

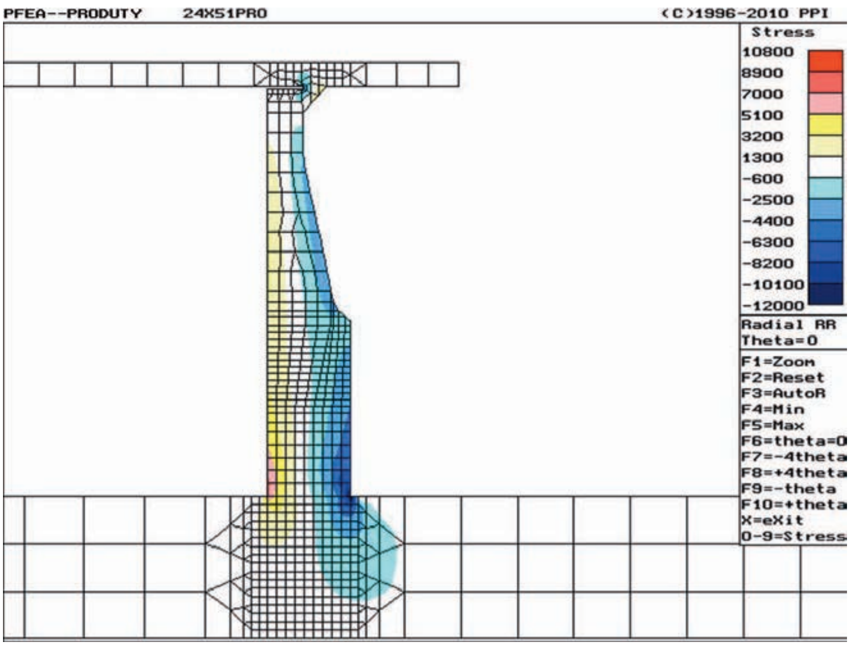

Figure 5. PFEA plot of the radial stresses for a profile end disc design.

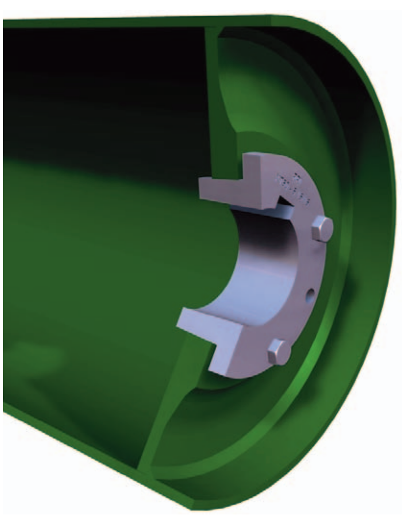

Figure 6. Precision Pulley & Idler's ProDuty drum pulley.

Similar problems also exist with tapered adapter mount systems. Even though these systems were designed to handle high bending moments, they do have limits. Early bushing problems caused by a very rigid end disc can manifest themselves as a squeak, which is a prelude to fretting corrosion. More often, the pulley will walk.

While the pulley analysis would suggest that pulley diameters be limited to a minimum of 6 times the shaft diameter, this is not practical. It would increase the cost of the reducer, as it would require a larger reduction, and it would cause problems in underground mines where space is limited.

Staying with a welded end disc pulley design presents a dilemma for the engineer. If the end disc is too thin, there is a significant risk of end disc fracturing next to the hub weld; but, if the end disc is too thick, it will put too much load on the shaft connection, which can cause problems. Often there is a fairly narrow window of end disc thickness that will meet all conditions.

One of the challenges faced is knowing that the running tensions are accurate. While momentary overloads are accounted for in the design, the design has limited allowance for a steady state overload. If this overload factor is only included in the design of the end disc and not the shaft, the pulley will often become too rigid for the shaft connection. The solution is to apply the service factor to the whole pulley assembly, including the shaft, by increasing the diameter at and/or between the hubs. However, this is not always acceptable as it does add cost.

There are two inherent problems with a welded end disc design: first, the weld; second, the disc. The weld adds weld stresses, heat-affected zone and a notch effect. The best improvement for the hub to end disc weld is to not weld. In addition, the disc is cut out of plate steel and it is constant thickness, as shown in Figure 1, but the stresses are not constant and decrease as the disc radiates outward to the rim. The cross section (thickness) of the disc could be reduced along the radius as the disc radiates out away from the hub without any increase in stress. Then the end disc would be able to flex and not overload the shaft connection. Figure 5 is a PFEA plot of the radial stresses for a profile end disc design.

The resulting design is the ProDuty® drum pulley (Figure 6). It removes the weak point of a welded drum pulley by removing the hub weld, replacing it with a smooth machined radius to control and lower the stress concentration factor in the transition.

In addition, the disc is tapered to reduce its rigidity without increasing the stress. This design required an update to PFEA to a third generation of the program. It involved hundreds of thousands of runs during the year-long design phase. The ProDuty design balances the stresses such that there is no spike in stress in the disc. Figure 7 compares the ProDuty design to a conventional welded hub.

The design results in a five-fold increase in end disc life because there is no hub weld. There is also no stress peak from the uncontrolled profile of the hub weld, which increases the projected life another five-fold, giving the user a virtual infinite life.

With a pulley designed for infinite life, the expected problem would be wear of the rim. Therefore, it is recommended that all ProDuty pulleys be lagged, so as to provide a replaceable wear surface.

Comparison

PFEA runs were performed on a 610 x 1295 mm pulley with a 152 mm shaft. This represents an OD/SD ratio of 4 and is typical of a mining conveyor pulley. PFEA was performed with 38 mm end disc and a profiled end disc that was tapered from 38 mm down to 19 mm. A load of 107,000 N (10.9 t) was applied. Figures 1 and 5 are the radial stress output from the runs. Table 1 summarises the results of the two runs.

The ProDuty design allows the end disc to deflect with the shaft, reducing the

Table 1. Comparison of PFEA runs on welded and profile pulleys

	Welded	Profile	(%)
Hub moment (Nm)	14,270	10,542	-26
Disc stress (M-Pa)	83	54	-34
Shaft deflection (mm)	0.56	0.84	50
Pulley weight (kg)	403	347	-14

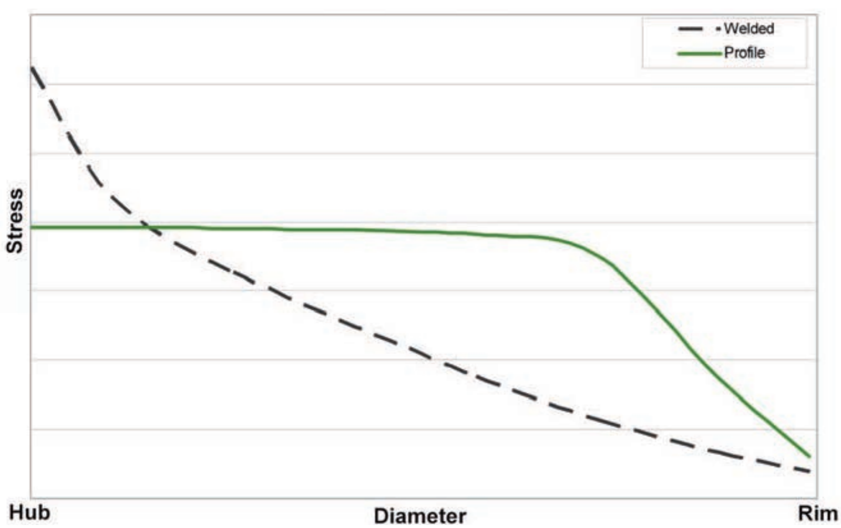

Figure 7. Comparison of welded vs profile hubs.

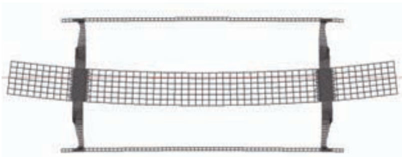

Figure 8. PFEA deflection plot of a ProDuty pulley.

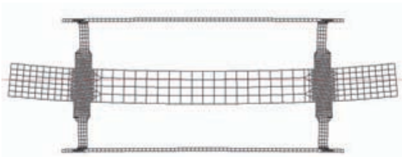

Figure 9. PFEA deflection plot of a welded end disc.

Figure 10. Shaft broken after 3 – 4 months of operation, 13 months after delivery.

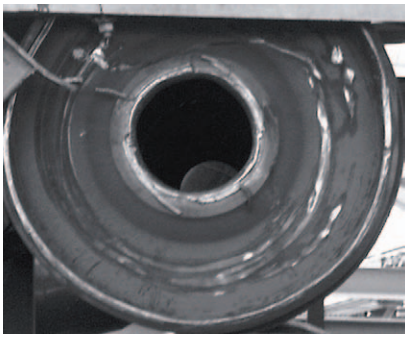

Figure 11. Reviews found that the pulley was 380% overloaded.

stress in the end disc and the bending moment that is transmitted through the shaft connection. Figure 7 compares the stress in the end disc as a function of the disc diameter. Figure 8 is a PFEA deflection plot of a ProDuty. While the stresses in the ProDuty end disc are less, the deflection is more. This design allows the end disc to deflect and absorb the load, reducing the load on the shaft connection. Figure 9 is a PFEA deflection plot of a welded end disc. The pulley dimensions and loading are the same; the difference is the end disc construction.

ProDuty can reduce the weight of the assembly, while improving the performance. A 14% reduction in weight is typical.

Case study

In March 2010, a ProDuty pulley measuring 762 x 1980 mm with a 138 mm shaft was supplied to a mine. The pulley was designated as a drive snub with 30° of wrap.

The shaft broke in April 2011 (Figures 10 and 11). A review of the conveyor layout showed that the actual belt wrap was 194°, meaning the pulley was overloaded by 380%.

If this pulley had been a welded end disc construction, it would have only lasted hours before the end disc failed. Instead it was a profile design that lasted months, and even then it was the shaft that failed and not the end disc.

Conclusion

The amount of hub moment reduction varies and is usually seen from 25 – 50%. While any size pulley can see a reduction in hub moment, an OD/SD ratio greater than 8 can achieve a satisfactory life with a welded steel end disc. Those with an OD/SD ratio of 4 – 6 see the greatest life improvement. In addition, any pulley with an OD/SD ratio of 3 – 8 will see an improvement in product life from a ProDuty design.

Stress is not the only factor in designing a conveyor pulley. The deflection and balance of the design is important. An increase in rigidity of the pulley can lead to problems in other aspects. ProDuty brings turbine technology to all pulleys. It is a cost-effective alternative to welded end disc design that can improve the service life of conventional pulleys and provide a stronger-than-shaft design.

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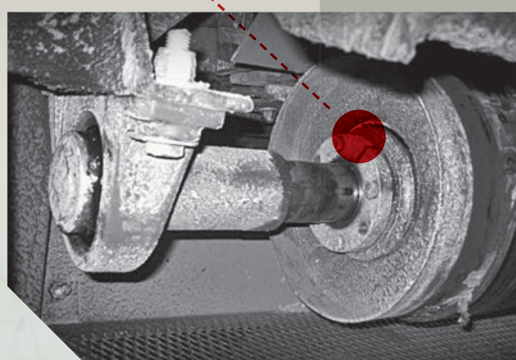

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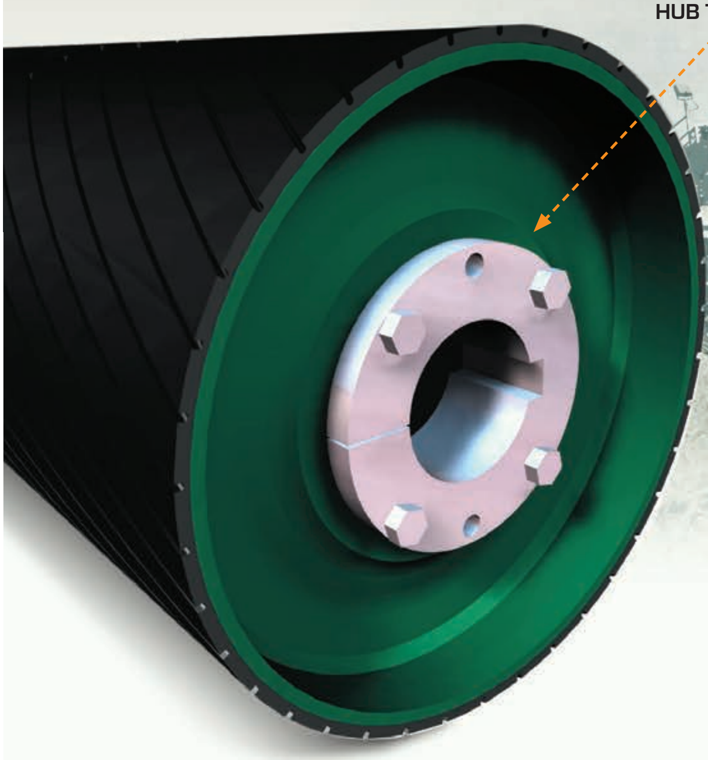

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