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# Aspec Newsletter

## Introduction

This is ASPEC Engineering's annual newsletter for 2006. The objective of the newsletter has been to share knowledge and experience gained during the course of our work for the benefit of clients and colleagues. I would like to extend best wishes to all of our readers for the Christmas and New Year period and thank you for your continuing support.

by Frank Gatto *(fgatto@aspec.com.au)*

## Rotating Steel Shafts

Rotating steel shafts are used throughout the materials handling, mining and port industries whenever power transmission or the mounting of rotating components is required. Shafts are typically one of the most critical components in a mechanical system and as such shaft failure can be potentially disastrous, and can lead to large repair/replacement costs and long down times. As a result owners, operators and designers of such components need to be aware of the issues involved in the design of rotating steel shafts and some general principles of good shaft design.

Typically, the five main issues considered when designing shafts are;
- Ensuring the shaft will not fail in fatigue over the design lifetime.
- Ensuring the shaft has sufficient static strength for maximum loadings.
- Ensuring the deflection of the shaft is not excessive for any mounted components.
- Ensuring the natural frequency, or "critical speed", of a rotating shaft is well above any operating frequencies.
- Designing the shaft so that it is easily inspectable.

### Design for Fatigue

AS1403 is the current Australian standard used in the design of rotating steel shafts. There are a number of similar international standards including the German standard DIN743 and the FEM Rules. The rationale behind AS1403 is to design the shaft for an infinite fatigue life under the applied operating loads, utilizing an appropriate safety factor.

The methodology described in AS1403 is to size the diameter of the shaft by ensuring that the stress calculated from the combined axial, bending and torsional loading is less than the fatigue limit of the steel used in the shaft. The stress at each axial location on the shaft is increased using design factors for stress raising features and a size factor depending on the diameter. Stress raising factors account for features such as keyways, notches, interference fits etc. which can significantly increase the local stresses in the shaft.

The number of stress raising features should be minimized wherever possible, and they should be located away from highly stressed regions of the shaft. The use of large, smooth radii at changes in section will also minimize local stresses. The size factor allows for the reduced strength of shafts that is observed as the diameter is increased.

Overall the standard is quite useful; and is similar to international methods in its approach, however it does differ from these international codes in some important areas, including:

- AS1403 makes no differentiation between the stress concentration factors associated with bending or torsional stress. Rather it quotes a single concentration factor for the overall combined stress. The stress concentration factor for bending or torsion can be significantly different depending on the feature. For example, for a press fitted component, the stress concentration factor in torsion has been shown to be around 65% of that in bending.
- AS1403 makes no allowance for stress relieving features incorporated into the shaft. Some examples of stress relieving features are shown in figure 1 below. These have been shown experimentally to reduce fatigue stresses by up to 60%.

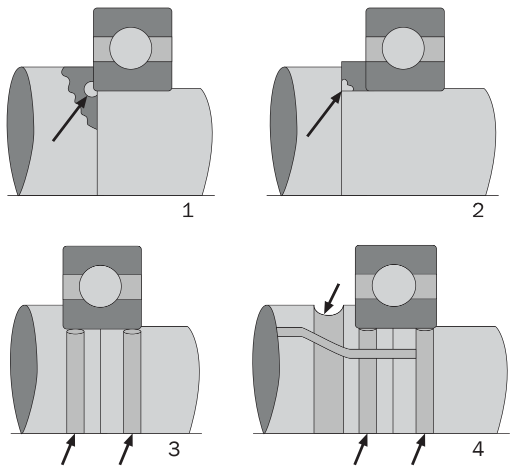


Figure 1. Examples of Stress Relieving Features -
For a shaft step with a bearing seat:
1. Rounded engraved groove at step.
2. Rounding out with a spacer ring.
3. Rounded out discharge notches.
4. Additional discharge notches.

- AS1403 does not include the effect of the surface finish on the fatigue strength of the shaft.
- The single "size factor" quoted in AS1403 is made up of the "metallurgical factor" and "geometry factor" that is used in other methods. The metallurgical factor accounts for the reduction in the strength of quenched and tempered steels as the diameter increases, mainly due to uneven cooling of the shaft during fabrication. The geometry factor accounts for changes in the stress gradients that occur in the shaft as the diameter increases. The relative importance of these effects varies depending on the shaft diameter, and as a result these factors have been separated in a number of other standards, whereas AS1403 does not.
- AS1403 is misleading in its treatment of shrink fitted components. In figure 6 of the standard (shown below), a stress concentration factor is quoted for three different nominal fits. However, the stress concentration due to a fitted component has more to do with the contact

pressure between the shaft and fitted component, not the fit used. The standard would also seem to suggest that with increasingly tight fits and contact pressures, the stress concentration will increase. However tests have shown that with increasing contact pressure, the stress concentration tends to asymptote at a constant value, and the likelihood and severity of fretting of the shaft surface, which is can be another indicator of fatigue damage, will in fact decrease. Thus, great care should be taken when considering the effect of shrink fitted components, and wherever possible the manufacturers recommendations for stress concentration due to locking devices etc. should be used, which is allowed for in the AS1403.

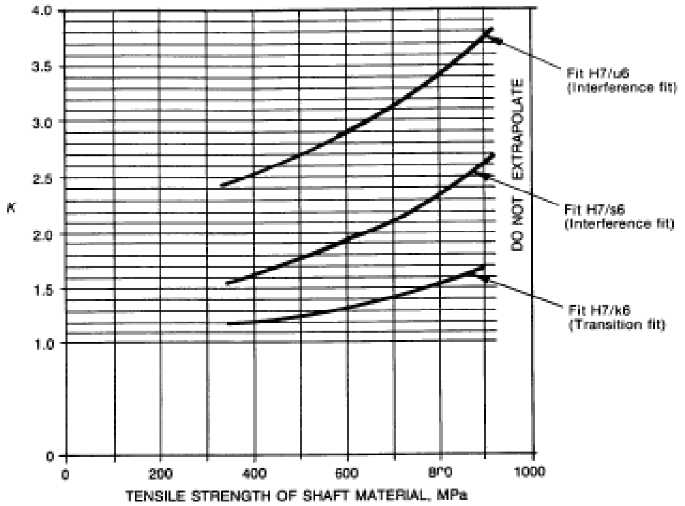


Figure 2. Fig 6 from AS1403: Stress raising factor K for fitted component without key or spline

These differences often tend to make the standard conservative in design, however it is important to keep these issues in mind especially when trying to get an optimal shaft design for a situation.

## Design for Strength

Often there are very high rare or "once off" loads that may be applied to the shaft during its lifetime that are not a major fatigue concern due to the low number of cycles associated with these loads. Example loads include: high start-up/stall torque from a motor and extreme load cases such as collisions. For these cases the design should be governed by the allowable stress method presented in AS3990. The use of higher strength steels may be necessary if the design is driven by strength concerns.

## Design for Deflection

Deflection can be the limiting factor of design, as it is important to ensure that shafts are designed such that their deflections are within acceptable limits. Excessive deflections of shafts can affect gear performance, cause rapid wear/damage to non-self aligning bearings and result in excessive noise and vibration. Typically the deflection of the shaft should not exceed the length/2000 at any gears or 8 mins of angular deflection at any bearings. Deflection of shafts is calculated using traditional beam deflection formulas, and as a result is dependent on the inertia, length and material used in the shaft. To minimize deflections it is important to ensure that shafts are a stiff as possible which can be achieved by ensuring that a shaft is as short as possible, or by increasing the size of the shaft. Most steels have similar elastic moduli, thus changing the material will have very little effect on reducing deflections.

## Design for Critical Speed

The natural frequency (critical speed) of a shaft should be much higher than the operational frequency of the shaft. This is to avoid resonance of the shaft which can result in excessive vibration causing rapid wear of any mounted components, excessive noise, deflection and fatigue of the shaft. The natural frequency of the shaft is given by the equation: Natural Frequency = $\sqrt{(\text{Stiffness}/\text{Mass})}$, meaning that the critical speed is dependent on the stiffness and mass of the shaft. Thus the design considerations for critical speed are very similar to that for deflection in that ideally the shaft should have a high stiffness to mass ratio, resulting in a high natural frequency.

## Design for Inspection

There are several material properties that are of importance when considering shaft specification. Not the least of these is the toughness of the steel. If a fracture mechanics approach is used the steel toughness is used to determine the maximum tolerable crack size for different locations in the shaft and also the rate of a fatigue crack growing in the shaft. Other fracture mechanics approaches provide information on the largest crack/flaw size that will not propagate a fatigue crack. All of this information is useful in determining the inspection interval of the shaft. It is an important aspect of the shaft design that the regions of higher stress range, where fatigue cracks are most likely to initiate, are able to be inspected to find the small flaws than can initiate a fatigue crack and that the shaft design results in a tolerable flaw size that can be detected.

## General Shaft Design Principles

In summary, the following issues are useful to remember when designing or assessing the design of a rotating steel shaft;

- Generally, the shaft diameter should be minimized. This will reduce fabrication costs and avoid reductions in the strength of the shaft due to metallurgical effects.
- Carefully consider the component mounting method used when designing the shaft – these can significantly affect the stresses in the shaft.
- Keep necessary stress raising features away from highly stressed areas on the shaft. Also use large, smooth radii at all corners and changes in section as this will minimize the effect of local stress concentrations, and help keep the size of the shaft down.
- Be aware of the beneficial effect that stress relieving features, such as relief notches, can have on the stresses in a shaft.
- Be aware that AS1403 is misleading in the area of shrink fitted components, and it is often a good idea to use the manufacturer's recommendations for the stress concentration due to locking elements etc. when designing a shaft.
- Keep shafts as short as possible. This will increase the stiffness of the shaft, reducing the deflection of the shaft while increasing the natural frequency (critical speed) of the shaft, allowing higher operating frequencies.
- The choice of steel used in the shaft is important for strength and fatigue, however when the design is driven by deflection or critical speed concerns, the type of steel used is less important as most steels have similar elastic moduli. The fracture toughness of the steel can also be important in specifying inspection intervals.
- It is important to design the shaft, and location of shaft mounted components, such that the shaft is easily inspectable.

Many thanks to Adam Mayers of Aspec Engineering *(amayers@aspec.com.au)*, Gary James of Minerva Engineers, and Peter Ford of MCA Australia for this article.

# Dust Emission Control ROM Point

This article covers the principles associated with the considerations and needs of run-of-mine (ROM) dump points to facilitate effective control over dust emissions.

All mining operations at some point, deliver what is won "at the coal face" to some point that represents the ores introduction into a subsequent bulk solids handling system. This may take the form of a hopper over a conveyor, crusher or a feeder-grizzly, etc. Usually, the method of delivery is via large volume carriers, economically sized to suit the operations production parameters. These carriers may well be front-end loaders or excavators, operating in the vicinity of the hopper, or for haulage operations it would be trucks, able to cater for the longer cycle times and distance. Alternatively, it could be a combination of both. At every point through this process, where the bulk commodity is transferred from one location to another there is a situation where dumping occurs, where material free falls. Wherever freefall occurs, the material becomes aerated in that it takes up air into the expanding interstitial spaces. When this material in freefall encounters an obstruction such as the tray of a truck, the walls or contents of a receiving hopper, the "interstitial air venting" (IAV) volume is effectively displaced by the collapsing body of material. In this volume venting process, the velocities involved become sufficiently severe to the point where the finer material fractions are transported "pneumatically" out of the collapsing body of material. This fine component of emitted material is referred to as the fugitive emission component in that it is no longer captive within an enveloping mass. Most often, it is simply referred to as dust.

## Dust, what is it?

Dust is simply fine material, nothing more, nothing less. In general terms, its fineness is sufficient to allow it to be readily transported by moving air. Here, the distinction is that dust has a propensity for dramatic transport. Dust, without dynamic association with air is never a problem. It is only when some action or interaction causes a sympathetic movement of air, which in turn, can entrain fine particular material and create that dust, that mass of airborne particulate which we are all familiar with, the airborne fugitive emission.

## How much dust is contained in each load?

Caterpillar 793C may contain anything approaching 300 cubic metes of coal. If we look at a typical particle size distribution of coal we will see that it is possible for a large percentage (as much as 20%) could fall within the typical "dust" range (of some coals) which means that there could be 60 m3 (or 45 tonnes) of "dust" in each load. Generally if the won coal is closer to surface overburden then the propensity for greater dust volumes is also greater through overburden contamination and other weathering factors.

## How do we control the dust?

There are several options that can be used to reduce dust emissions but each depends on the ability to control the air flow and restrict its potential to move on. Various options include:

• ROM dust enclosure. This enclosure generally takes the form of a three sided and roofed enclosure with curtains on the approach side.

• Devices to extract the dust from within the enclosure. These could take the form of an electrostatic precipitator, cyclone collector, wet scrubber, venturi scrubber or fabric filters. These devices can have significant capital and maintenance costs. Increase the moisture content of the material being delivered to the ROM.

• The use of a dust suppression system within the enclosure to capture fugitive emissions. This is achieved through the introduction of liquid aerosols (water sprays/fogger sprays) into the air.

• Air movement inhibitors such as wind fences, trees, shrubbery and anything that does not channel prevailing air movements.

The remainder of this article will focus on the erection of an enclosure over the ROM discharge point (refer to Figure 3). Such a simple device is only completely effective when the bulk material is delivered into the enclosure as a mass of material at rest and unaerated. This can only be achieved by a front-end loader, literally poking its bucket through the curtain into the enclosure before it commences a careful dump. This way, air is not displaced out of the enclosure during the dump process. For a rear dump truck using the same enclosure the discharge dynamics are different and inevitably air will be vented from the enclosure. The discharge dynamics for a rear dump truck are listed below:

• The air within the hopper enclosure is essentially still.

• If you reverse a truck up to and into a curtain it will displace some of the air content within the enclosure with it venting along the path of least resistance which usually means between the curtains at either end either side of the truck, or under the curtains.

• When the truck tray is sufficiently elevated to cause ore to rill and progressively cascade from the truck tray into the hopper or dump pocket further dislocating the enclosure entry curtain, the ore will displace progressively more air from within the enclosure.

• The cascading ore from the truck tray will induce sympathetic air movement on all exposed faces of the falling aerated ore stream through the mechanics of friction and entrainment.

• This induced air movement into the enclosure will displace more of the original air volume from within the enclosure.

• As the ore stream collapses on itself within the hopper or pocket the entrained air vents along the line of least resistance which is usually in concert with the rilling material (Thonon 1999).

• The vented air carries entrained dust into the air mass being displaced from within the enclosure.

• The vented air and dust is coincidentally displaced from within the dump hopper enclosure.

• The resultant air vented from within the enclosure will be greater that the volume of the material delivered and dumped.

• The dust content in the body of material may contain 20% dust and at some point all of it will be in free flight and aerated to some degree.

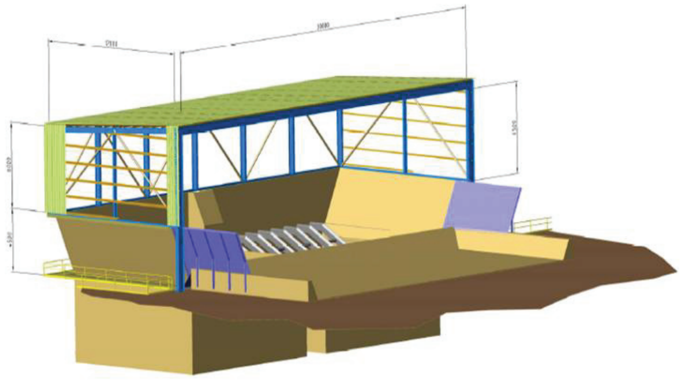

Figure 3. Diagram of a ROM Dust Enclosure
(wall cladding shown only on one side for clarity)

Historically, some operations have utilised what has been termed as "stilling" curtains, within such enclosures. This term can be a misnomer. Yes, stilling curtains do assist with FEL fed dump enclosures, but present a different scenario in association with truck rear dump operations. Conventional stilling curtains simply reduce the available volume of air within the enclosure that can become mobile from truck dumping. This in turn means that air movements within the enclosure as result from inducement and displacement become more violent and higher in velocity which may negate their potential value as effective controls. However, if the channelling curtains are configured correctly and used in association with a complementary agglomerative suppression system (water and fog sprays), the "un-dusted" air can vent via a controlled path while retaining the maximum possible dust laden air within the enclosure (refer to Figure 2). Of course in a perfect world of operational consistency, static environmental conditions and basic theory, this is all plausible, but, we simply do not live in a perfect world and some "dusted" air will inevitably become a fugitive emission.

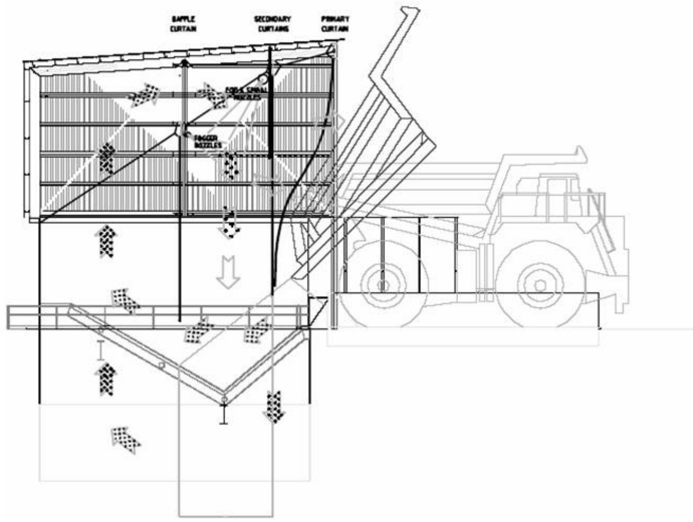

Figure 2. Example of a controlled air flow path
(three channelling curtains)

## Conclusion

A focus on the specifics of any problem is necessary to enable a choice over which is the best method to employ to minimize dust emissions. From a design perspective, it is possible to anticipate problems depending on the type of truck discharge likely to be encountered at a particular dump station; however the specifics of the truck and ROM point configuration must all be taken into account as well as the associated dynamic influences of each on the other. The varying influences of surrounding structures, truck operational consistency, and material “dustiness” all need to be taken into account.

Many thanks to Roger Turner of T&T Projects, and Jeff Brook of Aspec Engineering *(jbrook@aspec.com.au)* for this article.

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