

Design considerations for fans running at variable speed

This document gives an overview of the factors to be considered when converting a fan to variable speed operation. Although the use of variable speed drives may appear to offer large savings in operational costs, they also can be very damaging to fans, potentially resulting in loss of availability or even failure.

This following details the design considerations for variable speed operation, with particular reference to sinter fans for the steel industry, however the content is relevant to all centrifugal fan applications.

Fan Laws and Fan Speed

The output characteristic of a centrifugal fan follows a set of relationships between various parameters. These relationships are commonly known as “The Fan Laws”.

Speed changes give the following effects:-

- Volume Flow varies in direct proportion,
- Pressure varies with the square of the speed
- Power varies as the cube of speed.

This means that if you reduce the operating speed of your fan by 50%, you will get:-

- 50% of the original volume flow,
- 25% of the original pressure
- And the power would become 12.5% of the original usage requirement.

It can therefore be seen why variable speed can give substantial savings in absorbed power.

However speed changes can also result in accelerated fatigue damage to the fan, which can give a significant reduction in its operational life.

Although it may seem that a constant speed centrifugal fan is the same as one running at variable speed, this is not the case and they are designed differently.

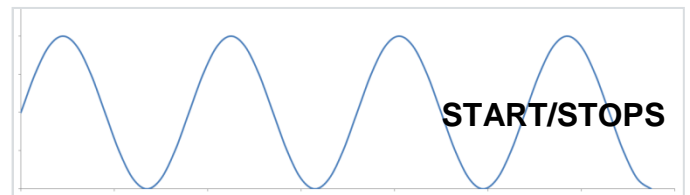
Retrofitting an existing constant speed fan to variable speed should never be carried out without proper technical evaluation.

Fatigue: Start/Stops and Speed Change Cycles

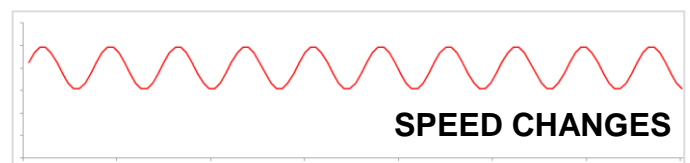
Metal fatigue, is a process of damage resulting from repeated application and removal of load. The resulting cyclic stresses can cause the growth of small cracks.

Fatigue damage can only occur where there are stress cycles. What this means is that the stress level is changed from a low value, to a higher value, then reduced to a lower value again.

For centrifugal fans, the most common example of these are start/stop cycles. Every time the fan impeller is started, run to full speed and then stopped, the stresses start at zero, increase to a significant level and then return to zero. This represents a complete fatigue cycle.



For most variable speed fans, the major contributor to potential fatigue damage is speed changes. Stress varies with the square of the speed. This means that a fan varying between 50% and 100% speed actually experiences a stress range equivalent to 75% of the stress at full speed.



Fatigue is a major consideration for variable speed fans and particularly in a retrofit situation. A variable speed retrofit to a fan which would have had another 20 years of useful life at constant speed could cause it to be irreparably damaged within a very short time (days, weeks or months) with the risk of catastrophic failure.

The design approach for a variable speed fan and a constant speed fan are different, even although the final product may look similar. There are many subtle differences in the engineering and construction, such as the types of weld classification and simple things like the welds being ground and polished in certain areas to ensure they have an acceptable fatigue life.

Natural frequencies and resonances can also lead to structural damage, cracks and unstable operation. For a constant speed fan there is only one set of parameters to consider when assessing dynamic excitation sources such as running speed or blade passing frequency.

However, in order to change to variable speed on an existing fan, it is essential to assess all excitation sources at all possible speeds to ensure there are no problems. It may sometimes be necessary to exclude certain speed ranges from the fan operating conditions, as they have not been designed out at the original engineering stage.

These speed exclusion bands may not be suitable for the production processes in which the fan is used.

Fan Structural Integrity Verification

Howden have devised a stringent set of rules for the assessment of fans. Each fan is designed to ensure it complies with our acceptance criteria for:-

- static stress,
- fatigue,
- dynamics, and
- rotordynamics.

Finite Element Analysis is a widely used design tool in this process.

Howden are experts in the design of rotating machinery and have the technical knowledge and experience to assess whether a switch to variable speed operation is structurally acceptable for a customer's operating requirements.

Summary – Before VSD Retrofit

Howden would recommend the following before implementing a variable speed drive retrofit:

- Checking the actual operating duties of the existing fans to ensure they would not be in stall or an unsuitable part of the fan curve.
- Check the bearings and auxiliary equipment to ensure they are suitable for variable speed operation.
- Check the foundations are suitable and there is no coincidence between foundation and fan natural frequencies (critical speed) in the operating range.
- Calculate impeller fatigue life under variable speed control. This will require a finite element analysis. Note with an older constant speed fan the life could

be considerably reduced by using variable speed control and new impellers may be required.

- Carry out either a bump test of the existing impeller or an engineering analysis to determine impeller natural frequencies and ensure no dynamics problems.
- NDT existing impellers. Where fitted, this will require removal of wear liners to give access to structural welds. Any cracks would require proper repair and NDT. After inspection / repair, fit new wear plates and re-balance. Although possible on site it may be easier (lower cost) to carry out these steps in a Howden factory.
- Change fan coupling to a rubber block type, if site arrangement permits. This will give additional damping for torsional fluctuations.

Summary – After VSD Installation

- Check fan balance.
- Refine / determine actual exclusion speeds for the individual fan installation, if applicable.
- Approximately 3 months after the fan is back in normal service it should be NDT checked for cracks and thereafter on an annual basis, as a minimum.

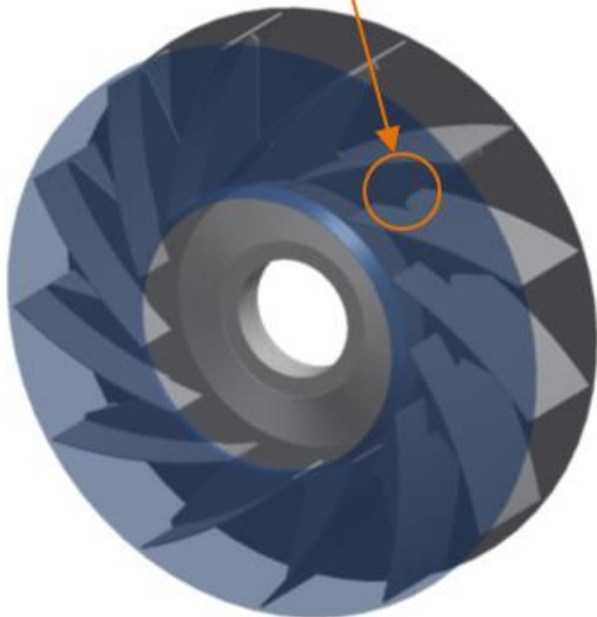
Case Study: L3N Sinter Fan



Variable speed drives were fitted to Waste Gas Sinter Fans in a steelworks and the operating regime changed. Instead of running at constant speed these fans were now running with several speed changes per day.

Soon after the change to variable speed, a routine inspection of the fan flagged numerous cracks at weld toe positions, some up to 50mm in length.

In addition full thickness cracks were noted at the centreplate cutaways, as shown in the photograph and image below.

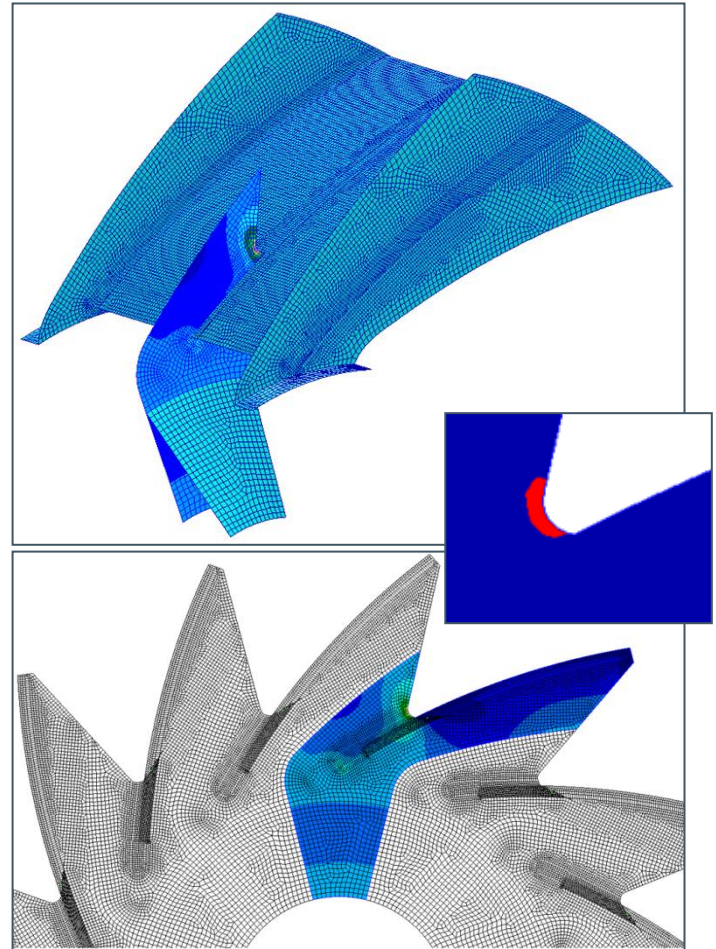


The depth and extent of the cracking observed resulted in the fan being deemed unsafe to use and immediately taken out of service.

Howden were asked to carry out a Finite Element Analysis of the original fan and to design a replacement which would be suitable for variable speed operation.

The analysis of the original impeller showed it had acceptable structural integrity for constant speed operation. This had been demonstrated by its actual service life to date (over 20 years of start/stops).

However, an area of relatively high stress at the root of the centreplate cutaway was noted, as shown in the following plots. This was consistent with the location of the cracks found during inspection.



The estimated fatigue life for the fan, following conversion to variable speed operation was calculated to be only a few months. This hence confirmed that this fan was not suitable for variable speed operation.

The analysis was repeated for a new impeller design, This incorporated several modifications, including changes to weld specifications and to the cutaway dimensions and location.

Changes were also introduced to minimise the impeller inertia, thus allowing it to run on the existing supports and with the previously used motor.

The results confirmed the following for the new design:-

- Static Stress Levels were acceptable
- A fatigue life could be achieved to comply with the customer's variable speed operating requirements. This data was presented to the customer in the form of a Miner's summation, detailing combinations of start/stops and various speed change cycles.
- The impeller natural frequency analysis complied with design rules.
- The rotordynamics gave acceptable results over the full running speed range and complied with critical speed assessment criteria.