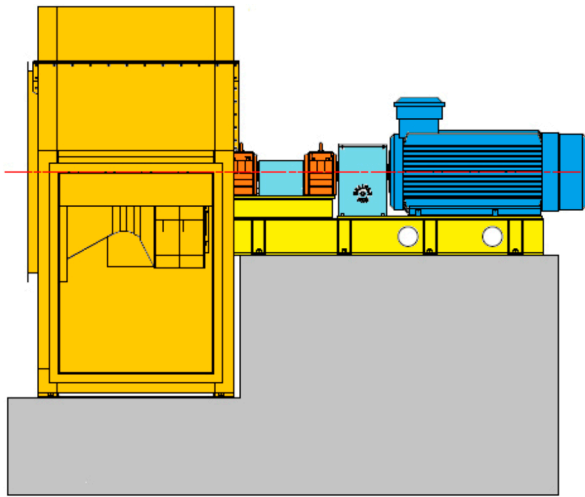


# INVESTIGATING FAN VIBRATION ISSUES

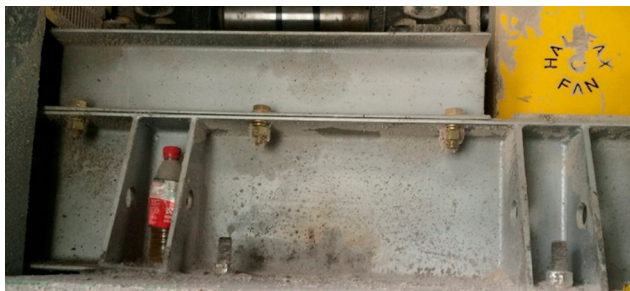
Dr John Irons, James Swinton  
and Jessie Jia, Halifax Fan,  
review the issue of fan  
vibration and the solutions  
available to fertilizer plants.

**M**ost rotating machines are highly robust structures. It is not uncommon to have a cast structure mounted on a foundation block or on a base-frame connected to a foundation block. This is associated with the high power density that the machine is putting into a fluid (e.g. pumps, compressors) or the high power density that the machine is taking out of a fluid (e.g. turbines). In the case of fans – which are used in fertilizer plants to move air and

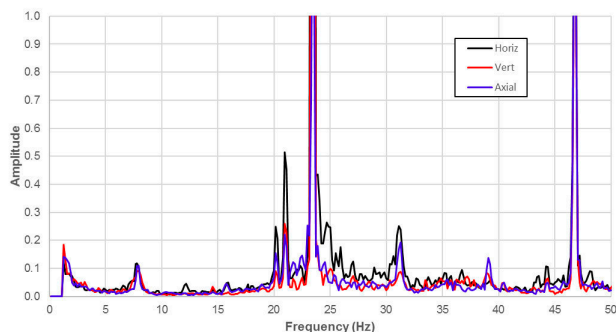
process gas, assist in cooling and drying the product and to collect dust generated from production – the power density tends to be much lower. This in turn means that these fans are predominantly large fabricated machines, with casing and bearing supports made of welded plates. In addition to this, fans are often exposed to the fertilizer product, which can stick to or erode the impeller, creating balance issues. Fans are therefore a reasonably flexible type of rotating machine.



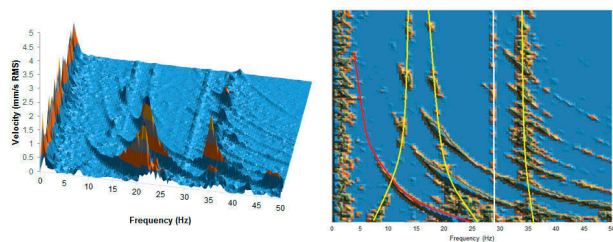
**Figure 1.** Fan layout.



**Figure 2.** Condition of foundation bolts.



**Figure 3.** Vibration spectrum at running speed.



**Figure 4.** Waterfall plots of fan running down: isometric view (left); plan view (right).

**Table 1. Relative movements at bearings**

	Relative movement (%)	
	In-board bearing	Out-board bearing
Concrete pedestal/floor	11.4	21.3
Concrete/frame	31.9	11.4
Frame and bearing	56.7	68.3

Another major difference between fans and other rotating machinery is that the design of the former tends to comprise of an impeller and shaft supported on bearings driven by a motor. Thus, fans do not usually require complex bearing lubrication units, knock out vessels etc. Fans also tend to have a wide range of functions e.g. pressure, volume and temperature. For bespoke fan manufacturers such as Halifax Fan, this means that a fan designer will start from a basic design and continue on to develop the fan in full, rather than a singular component.

There is usually not enough time to carry out a finite element analysis (FEA) of the fan support structure, so fan manufacturers will rely on design rules to ensure that there are no support structure issues. Rules for plate thickness, based on fan speed and power, are in place, however they often have to be adjusted depending on end-user requirements, such as space constraints, weight constraints and the extent of concrete foundations.

Fan installations are often carried out by local civil engineering companies that have limited familiarity with rotating machinery. This can result in issues related to the connection of the fan to the concrete or steel structure and alignment problems. The fan manufacturer, if involved in the installation, is typically called in near the end of the process to perform a check. This may or may not lead to installation issues being identified.

Given this background, fans often experience vibration problems following installation. Resolving these problems is typically fairly straightforward, with solutions ranging from the discovery of installation issues to identification of additional bracing. However, not all vibration problems can be easily recognised and resolved. Consequently, a fan manufacturer must use a combination of site testing techniques, rotordynamics and FEA to arrive at a solution.

### Case study

The following case study examines process fans that were installed on a pier cast into a floor that had vibration problems, preventing the fans from reaching full speed. The fans were installed in Chongqing, China (Figure 1).

### Outline of problem

The fans had an overhung rotor, with the bearing unit on a pedestal supported by a baseframe, which also supported the motor. The purpose of this design was to allow the rotating assembly to be installed onsite in one lift. The impellers were wide backward inclined. Due to the ongoing wet process at the site, adhesion of particles to the impeller was occurring.

Although the fans have a design speed of 1650 rpm, it was found that the fans had experienced high vibration at 1500 rpm, with up to 25 mm/s being reported. The first approach was to try and address the high vibration with balancing, which led to a temporary reduction in the vibration level.

At the start of the site investigation it was found that the end-user had welded additional supports to the bearing unit pedestal, and that the condition of the impeller end baseframe foundation bolts was of concern. In the case of one fan a foundation bolt had been broken. For the other fan one of the foundation bolts was not being used (Figure 2). Instead, a plate had been welded on to the baseframe and a new bolt used, forming a poor foundation connection.

In short, the fans had both installation and vibration problems. Although it could have been insisted that the installation problems were solved first, it was decided to carry out an investigation to

ascertain the influence of the installation problems and the design on the vibration issues.

### Finding natural frequencies

An examination of the impeller indicated that it was collecting some dust but not a lot. This confirmed that the impeller type selection was appropriate and also pointed to the most likely problem: that the fan was running close to a natural frequency. There are various techniques for identifying natural frequencies and it is best to use more than one to obtain confirmation of the fan's dynamic behaviour.

The rotor natural frequencies of fans are best observed by striking the impeller in the horizontal and vertical direction. For this particular fan the results were a horizontal peak at 15.5 Hz and a vertical peak at 16.5 Hz; well below running speed. However the impeller is overhung so there will be a reverse whirl natural frequency that reduces with higher speed and a forward whirl natural frequency that increases with higher speed. The speed-affected natural frequencies are due to a gyroscopic effect, the force that stops a spinning top from falling over.

Fans have an aerodynamic turbulence which excites natural frequencies. These natural frequencies are seen as small peaks in the spectrum, either by using a high gain spectrum or by using a long amplitude plot. In the case of these particular fans the running speed is the peak at 24 Hz and a peak was seen close to it at 25 Hz (Figure 3). A problem with only using this method of natural frequency identification is that another machine running near by can also produce small peaks in the spectrum. Other methods should therefore also be used.

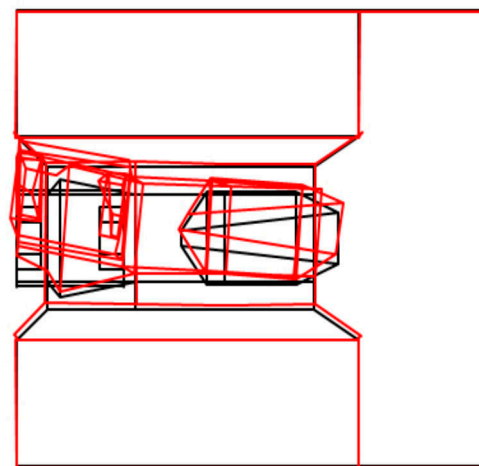
Natural frequencies can also be identified as the fan runs down or runs up. The natural frequencies are seen as peaks in the multiples of running speed as the fan speed changes. This plot is three-dimensional and known as a waterfall plot (Figure 4 left). The plan view shows the peaks more clearly and allows them to be plotted out. In the plan view shown in Figure 4 (right) the natural frequencies are depicted as yellow lines, the running speed as a red line and another fan running is shown as a white line. The plot confirms that the peak seen at approximately 25 Hz was the fan forward whirl natural frequency. The peak at approximately 8 Hz was the fan reverse whirl natural frequency.

The natural frequency investigation gave consistent results for the three methods used and confirmed that there was a natural frequency issue.

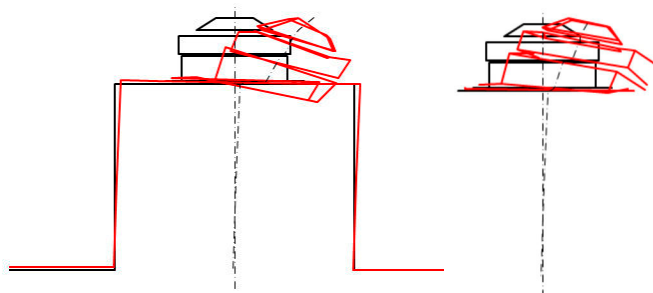
### Identifying support structure dynamic behaviour

Identifying a natural frequency problem is the first stage in a site investigation of a vibration issue. The next stage is to establish how the structure is moving. The two options for identifying how the structure is moving are slow motion filming methods and a vibration survey. The method chosen for this investigation was the latter, which involves using a single axis accelerometer on one location as the reference and moving another accelerometer around the structure. For each position the transfer function in the three directions is obtained, giving relative amplitude and phase. In this example the survey had 84 points.

The operating deflected shape is the movement of the fan at running speed. The plan view indicated that the main movement was a horizontal movement of the fan in-board bearing with parallelogramming and twisting of the frame



**Figure 5.** Vibration survey of fan plan view. Black = undeflected; red = fan; blue = steel support structure.



**Figure 6.** Vibration survey fan bearings view. Left = in-board; right = out-board.

(Figure 5). These two effects are typical of what is seen when a frame is not fully supported.

The deflection of the bearings plotted with respect to a centreline gives the relative horizontal/vertical movement. With a sufficient number of points the movement across interfaces can be seen. The property that is of interest is the relative movement at the shaft centreline (Figure 6). This is obtained by projecting the deflected lines up to the shaft centreline. Table 1 shows the relative movements measured.

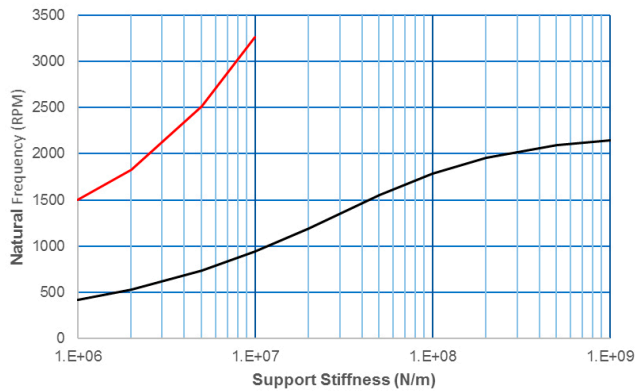
The results indicated that there was an issue with the foundation bolts local to both the in-board and out-board bearings. In addition, the bolts connecting the pedestal to the baseframe needed tightening.

The results confirmed, as expected, that moving the foundation bolts near the fan in-board bearing back had a significant negative effect on the support stiffness. This is primarily associated with the lack of vertical stiffness on the additional plate.

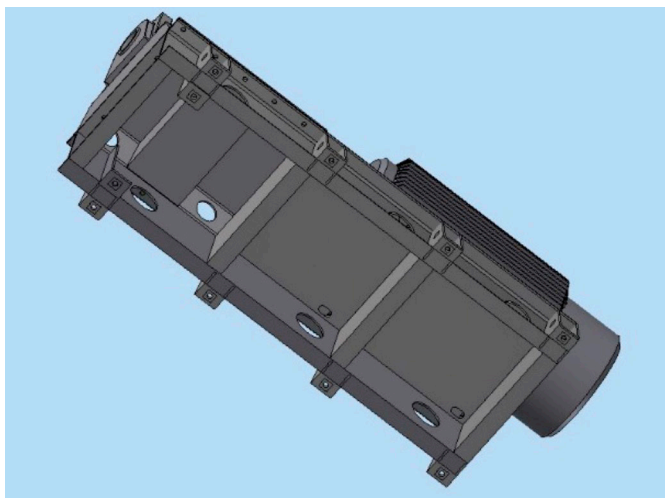
The fan balance results at 1450 rpm indicated that 15 g reduced the vibration from 94 mm/s to 2.4 mm/s. From the expected damping and proximity of the natural frequency a dynamic magnifier of 13.5 was estimated. This gave a fan in-board bearing support stiffness of 40 MN/m, which gives 50 MN/m for the bearing support stiffness and 200 MN/m for the concrete floor/pedestal stiffness.

The concrete floor and pier could not be altered. However the results showed that most of the movement was coming from the frame moving on the concrete and the frame.

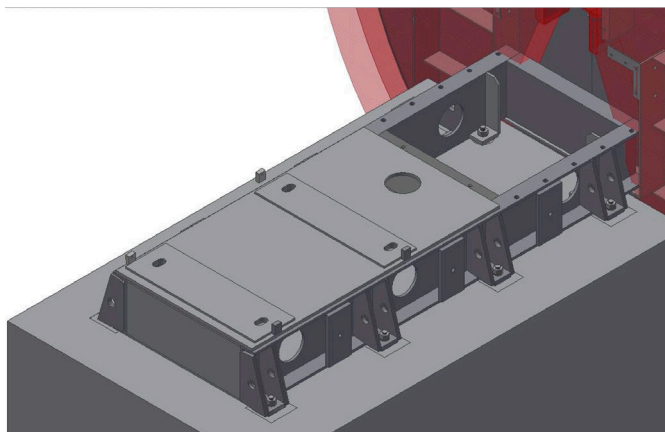
### Rotordynamics analysis



**Figure 7.** Rotordynamics model results for varying support stiffness.



**Figure 8.** View of modified bearing support.



**Figure 9.** New foundation bolts being fitted.

**Table 2. Effect of varying steel supports**

Steel stiffness (MN/m)				First natural frequency (rpm)	
In-board bearing		Out-board bearing		at 1500 rpm	at 1650 rpm
Horizontal	Vertical	Horizontal	Vertical		
50	200	200	400	1592	
200	400	200	400	1696	1845
400	800	400	800		1932

3D FEA cannot easily take into account gyroscopic effects. This means that a rotordynamics model – either a lumped mass model in a finite element programme or a model in specialist rotordynamics software – must be created. A rotordynamics model was created with the bearing stiffness estimated using a standard formula. This model indicated that the support stiffness had a very low value of 45 MN/m (Figure 7). This was close to the site investigation value determined.

The vibration survey indicated that the concrete floor/pedestal stiffnesses was much higher than the pedestal stiffness of the fan in-board bearing, but much closer for the fan out-board bearing. Based on this, values of horizontal stiffness = 200 MN/m and vertical stiffness = 500 MN/m were used for the concrete floor/pedestal. Table 2 shows the results that were obtained from varying the stiffness of the bearing steel supports.

The results indicate that for both bearing supports the stiffness had to be increased to approximately 400 MN/m.

### Finite element analysis

As the support stiffness is being determined, only the pedestal and baseframe need to be modelled with loads applied at each bearing to determine the stiffness. The bolted connections have to be modelled with only localised connections at the bolts. If not, the connections can be modelled too stiffly and give misleading results (Figure 8).

The objective of the FEA was to increase the support structure stiffness, and to do so with minimal site work. To reduce the amount of site work the number of additional foundation bolts was minimised and the bearing housing pedestal was replaced.

Only two additional bolts were used, both to increase the stiffness below the in-board bearing and to increase the reliability of the baseframe/foundation connection below the in-board bearing (Figure 9).

The pedestal was changed from a frame type to a box type. In addition to this internal stiffeners were added to the pedestal. Stiffening of the pedestal also increased the stiffness of the baseframe by preventing out of plane distortion. The end result was that the required stiffness of 400 MN/m was slightly exceeded.

The changes were implemented on the two fans and resulted in a maximum vibration level below 3 mm/s root mean square (RMS). This confirmed that the changes had been successful. Subsequent to this other fans have been supplied to the same facility with the same configuration and design. These have also operated successfully.

### Summary

Fans are used in a wide variety of applications and for a range of duties within the fertilizer industry. They are designed

using established rules and in the majority of cases run successfully without any vibration issues. However problems do arise from time to time and must be dealt with effectively. This usually means combining testing and analysis of the problem to establish a positive solution. Although there may also be installation problems, these should not be focused on to the detriment of identifying and solving other issues. This means working with the customer and end-user to develop a solution. Through such collaboration, an approach can be derived that usually leads to a successfully implemented solution. **WF**