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FLOW STABILITY IN A LARGE INDUSTRIAL FLUIDISED BED PLANT

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ABSTRACT

During commissioning of a large air-fluidised furnace, high amplitude oscillations in pressure and flow were observed, which ultimately damaged the plant. Spectral analysis of the data recorded during start-up showed that bubble motions in different horizontal portions of the bed were correlated with each other, and with the total air flow. This was interpreted as wave-like bed motion, driven by plenum pressure variations. These in turn were reinforced by the fan, but only within a critical range of plenum volume, which determines the delay in the plenum pressure response.

Active feedback control was shown to be a simple method of changing the delay, and thereby of damping the oscillation.

INTRODUCTION

During commissioning of a large (7 m dia.) air-fluidised furnace designed for soda recovery from spent paper-pulping liquor, a large amplitude periodic flow oscillation at approximately 1 Hz was observed. The pressure surging that accompanied this oscillation was apparent in all variables recorded throughout the plant. In particular, the oscillating pressure difference across the 'dome' (a refractory distributor plate, which both supports the ~100 tonne bed material and distributes air through it) ultimately led to its damage. The task presented to CSIRO was to study the surge behaviour with the goal of finding a cure. Existing instrumentation of the plant enabled motor currents, damper positions, and 16 pressures in the system to be recorded. Many other variables were accessible through the control room. A schematic arrangement of the two-bed continuous furnace, and the way in which pumping duty is shared between the high pressure forced-draft single-stage centrifugal fan, and low pressure induced draft fan, is shown in Fig. 1.

INVESTIGATION PROCEDURE

It was apparent at the outset that the surge phenomenon, being ultimately destructive, would involve substantial amounts of energy being diverted from the steady flow (~ 1MW) to feed the oscillation. Fortunately, the full surge did not occur during the investigation. The pre-surge behaviour is of greater interest because it is not immediately obvious how unstable flow may be initiated. The investigation proceeded by testing various hypothetical types of pre-surge behaviour.

The most straightforward of these hypotheses was the periodic stall and recovery of an overloaded fan. In order to investigate this possibility, a 3/4 radius flowmeter was installed in the long inlet duct, 5 diameters from the inlet, and calibrated in accordance with BS 848. In addition, hot wire sensors were located 3 diameters from the inlet, in the first bend downstream of the inlet, and in the volute of the forced draft fan in the plane of the rotor.

FAN STALL

Without material in the fluidised beds, the pressure loading of the forced-draft fan was adjusted using butterfly valves at the furnace inlet. Figure 2 shows the *in situ* pressure flow law of the fan in terms of static pressure rise across the fan-silencer combination, and the 3/4 radius flowmeter output. These results show that the fan is not stalled at the normal operating point, and there is no possibility of static instability. A check with

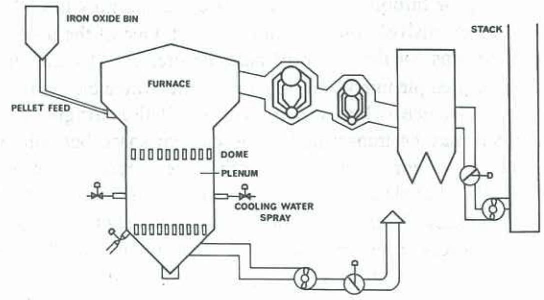

Figure 1 Schematic of a SODA recovery plant.

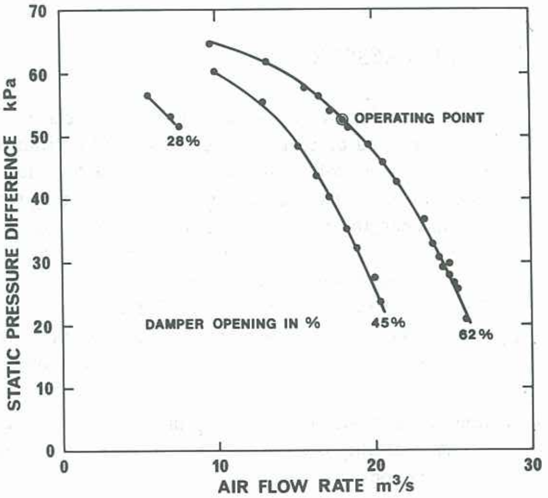

Figure 2 Performance curve of fan at 2970 rpm and atmospheric conditions.

the volute-mounted hot wire, which had a life of some two minutes, showed no evidence of a rotating stall.The margin between the mean pressure and the stall is large, so that stall cannot be involved in the initiation of pre-surge oscillation. It is possible, however, for high amplitude flow instabilities to involve periodic stalling in the final stages, and further increase energy input.

OTHER AEROACOUSTIC SOURCES

There are several locations in the airstream, other than fan blades, where periodic flow separation could occur. These are at the inlet cowl, at the furnace entrance, and at a nearby butterfly valve found to be loose on its shaft. In an experiment involving removal of the inlet cowl, no effect on the oscillation was observed. A model of the freely rotatable butterfly valve installed in a straight pipe could not be induced to oscillate, even by perturbing the pipe flow. Finally, a Helmholtz resonator model of the furnace at 1/100th scale, equipped with sharp transitions like the furnace inlet, could not be induced to oscillate. In the plant, removal of about 40% of the inlet ducting would have raised the Helmholtz frequency, whereas the oscillation was not affected. Elastic resonance of the distributor plate was not investigated, beyond an estimate of the resonance frequency, which was an order of magnitude too high.

FLUIDISED BEDS

Gas fluidised particulate beds commonly produce random pressure fluctuations which accompany the generation and bursting of bubbles. These pressure fluctuations have been studied extensively throughout the world. One of the proposed mechanisms for the origin of periodic pressure fluctuations is the so-called plenum resonance. In systems where the distributor plate resistance is low, the pressure oscillations originating in the bed may be transmitted to the plenum space beneath, and since the plenum is much smaller than the acoustic wavelength (at 1 Hz), bubble events may tend to be correlated across the bed diameter. Such correlations, between the signals of bubble event sensors in the main furnace, were found (Fig. 3). From this, it may be inferred that regular surface-wave motion is present, driven by plenum pressure variations. Surface wave activity, or sloshing, has been observed previously in fluidised beds of relatively low height/diameter ratio (Sun *et al.* 1988).

PLENUM PRESSURE VARIATION

A mathematical model of one-dimensional vertical motion in the fluidised bed predicts that self-sustained oscillations in pressure and flow will occur, provided that the charging time-constant for the plenum space is within a critical range for the bed. The charging time-constant is the product of the fan pressure/flow gradient and the compressibility of the plenum space. It determines the delay of pressure response to changes in flow out of the plenum chamber. If the delay in plenum pressure response is similar to that in the fluid bed, work is done by plenum pressure on the fluctuating bed motion.

Although the model is physically unverified as far as this particular instability is concerned, it does enable the following useful predictions to be made:

(a) The system has no steady state behaviour which is stable. The physical phenomenon that corresponds to this instability is probably the bubbling mode of behaviour, in which the contents of the fluidised bed are almost completely segregated into dense and dilute phases.

(b) Increasing the distributor plate resistance or the bed depth has a stabilising effect. This effect is well known but in this plant it cannot be applied because it would reduce the stall margin of the FD fan.

(c) Increased resistance upstream of the fan is destabilising.

(d) An increase of plenum chamber volume has a stabilising effect because it weakens the pressure swing in the plenum. This may be achieved artificially by active modulation of the upstream flow control damper. A substantial decrease of plenum volume may eventually stabilise by reducing the delay in pressure.

According to the mathematical model, the appropriate control scheme is to close the upstream damper in proportion to the rate of change of plenum pressure. This stabilising strategy has the advantage of not increasing the mean pressure duty of the fan, and it can be applied as an inexpensive retrofit.

The practicability of an active control system stabilising the pre-surge oscillation was demonstrated. The test was done when there was an oscillation with peaks at 0.625 Hz and 1.2 Hz in the distributor plate pressure drop. The dampers were actuated by a sine wave signal of frequency very close to 1.2 Hz. As the phase relationship between damper position and dome pressure difference gradually changed, the system variables became alternately more and then less stable. Figure 4 shows the stabilising effect of damper modulation on the distributor plate pressure drop. Modulation of the dampers at the lower frequency had no effect.

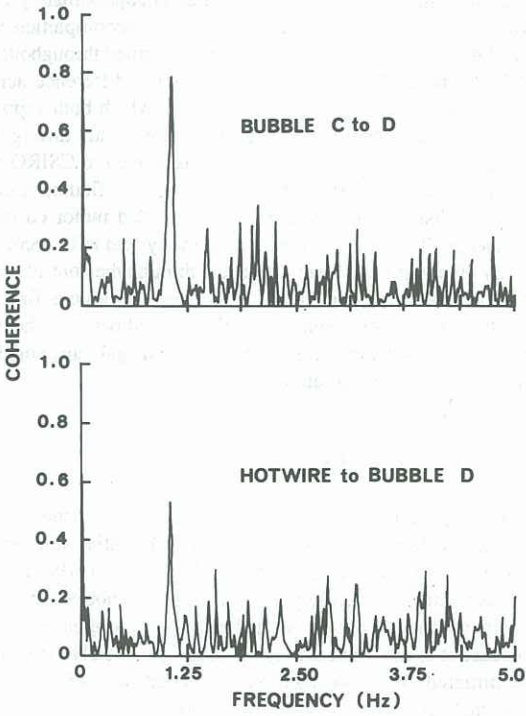

Figure 3 Coherence between bubble signals and the hot wire signals at the air inlet to the plant 10 hours after bed fluidised; bed depth = 1.04 m.

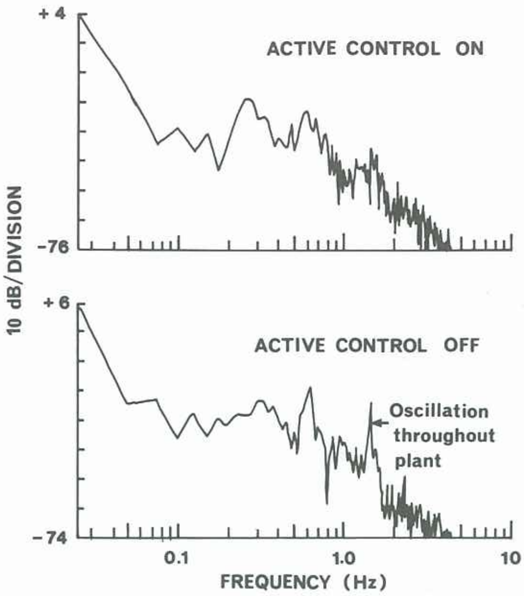

Figure 4 Spectra of dome ΔP with and without active feedback control.

CONCLUSIONS

It is possible for periodic fan stall to accompany the deep surge behaviour that damages the plant. However, it was not observed in the pre-surge oscillation.

Spectral analysis of data recorded during mild oscillations, eliminated fan stalling or other aeroacoustic factors in starting the oscillation. Bubble motions in different portions of the bed were partially coherent, and this was interpreted as the presence of one or more modes of regular sloshing motion in the bed. A mathematical model predicted that plenum pressure oscillations would be self-sustaining, within a critical range of plenum charging time constant. Active modulation of an existing flow control damper was demonstrated to be a simple technique for changing the charging time constant and thereby damping the pre-surge oscillation.

REFERENCES

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