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EXPERIENCE IN THE USE OF VIBRATION HEALTH MONITORING TECHNIQUES ON CENTRIFUGAL FANS

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INTRODUCTION

Allied Breweries' new plant at Mistley will produce 22,000 tonne of malt per year; 25% of the company's malt production, and went into operation in March 1977.

After steeping for 48 hours, a batch of barley is transferred to one of two aluminium floored concrete boxes where it is germinated and subsequently kilned. During the 72 hour germination, moist air is circulated through the grain bed by an air conditioning fan. Then follows a 24 hour kilning period and this time hot air is circulated through the grain by a 373 kW kiln fan. Although each box has its own air conditioning fan, they share the kiln fan because of the staggered nature of the production programme. A major failure of one of the fan bearings, in particular the kiln fan, would cause a serious disruption in production.

The majority of commercially available monitoring equipment requires preset vibration levels for warning and/or shutdown purposes. However, all the fans are "one-off" units (ref.1) with the result that no case history data existed to allow realistic alarm limits to be chosen. To fill this gap, a series of vibration measurements was made between June 1977 and January 1978.

FAN LAYOUT

The kiln fan shaft is supported by roller bearings at each end. It is driven via a flexibly coupled layshaft by a vee belt drive from an electric motor. The air conditioning fans have vee belt drive at one end and have no layshaft.

ANALYSIS METHODS

The data from accelerometers stud-mounted to the top of each bearing cap was analysed to give the overall RMS levels of both velocity and acceleration. It is well-known that the various bearing elements (races, cage, rollers) have characteristic frequencies which can be used as an aid to identifying the nature of failures and acceleration spectra were produced to examine this. Early work on the use of kurtosis (ref.2) has suggested that it is a good predictor of failure, particularly as it would appear to be substantially independent of bearing load, size and speed. For a finite length sample, an estimate of the kurtosis can be obtained from the expression

$$\beta_2 = \frac{\frac{1}{T}\int_0^T \left[x(t) - \bar{x}\right]^4 dt}{\sigma^4} \qquad (1)$$

where β_2 = kurtosis, $\bar{x}$ = mean value of signal $x(t)$ over sample length T, σ = standard deviation.

For most vibration signals the mean value is zero and equation (1) reduces to

$$\beta_2 = \frac{\frac{1}{T}\int_0^T [x(t)]^4 \, dt}{x^4_{rms}} \qquad (2)$$

With an eye on the practical implementation of the method on site, the latter equation has been adopted and acceleration used as the measured signal.

Crest factor is the ratio of peak to RMS levels for a signal and, like kurtosis, is dimensionless. In the early stages of damage the essentially discrete shock loading that is present could be expected to produce a rise in crest factor and, hence, a warning of failure. Again, acceleration was used as the measured signal.

RESULTS

Because of the plant's tight production schedule, it was not possible to examine the condition of the bearings at the time that each set of vibration measurements was made. The first opportunity to do this arose during the plant's first annual maintenance during April 1978.

The interpretation of the results at the time was based on the premise that the bearings were in good condition at the start. More will be said of this later.

1) Kiln Fan Bearings

Two bearings were found to be of particular interest; the fan bearing at the free end of its shaft (No.1) and the layshaft bearing at the drive pulley end (No.4). Data for the other layshaft bearing (No.3) is included for comparison. Table 1 shows the RMS velocity and acceleration, kurtosis and crest factor for measurements in June and October 1977 and January 1978.

With the exception of the RMS acceleration, the figures for bearing 4 show a progressive increase with time. The RMS velocity level in January of 10.2 mm/s is classed as 'just acceptable' by BS 4675. The high kurtosis is also indicative of incipient failure. In contrast however the RMS acceleration fell in value. The apparent anomaly can be explained from the acceleration spectra (fig.1). While the general acceleration level for January is significantly lower than in the previous tests, the low frequency (< 100 Hz) content has increased, thus accounting for the rise in the RMS velocity which is dominated by these low frequencies.

When the bearing was removed for examination in April 1978, significant surface damage was found on the outer race. Due to the propagation of sub-surface fatigue cracks, spalling had occurred on two patches of 2-4 cm^2 spaced a roller pitch apart. One and two roller pitches further on, more surface damage was present, although no metal had broken away. The spacing suggests strongly fretting induced fatigue.

The acceleration spectra (fig.1) have a pattern consisting of a set of uniformly spaced peaks suggesting strongly an association with one of the characteristic frequencies of the bearing elements. The spacing agrees closely with the frequency (63-64 Hz) of the rollers striking an isolated defect on the outer race.

With bearing number 1, an inconclusive picture emerges. Although the RMS velocity level at 6.6 mm/s in January is only 'just acceptable', it is no more than 12% above the June level; at which time the bearing was assumed to be in good condition. Kurtosis in January at 4.2 showed a rise over the earlier tests and might have indicated the very early stages of damage. However, it was not at a level to suggest imminent failure. When examined in April, bearing 1 was found to have a badly deteriorated inner race. There was spalling on both halves of the race over an area totalling about 10 cm^2.

Data for bearing 3 is also included in the table. There are no large variations from test to test and in fact the values are not dramatically different from those for bearing 1. When bearing 3 was examined in April no visible signs of deterioration could be found.

2) Air Conditioning Fans

The two air conditioning fans were monitored only in October 1977 and January 1978. Of the total of 4 bearings, only one (the free-end bearing (No.2) of fan number 1) exhibited firm indications of adverse condition. Table 2 shows the values for this and the corresponding bearing from fan number 2. In January there was a large increase in RMS velocity to 24.1 mm/s taking it into the 'unacceptable' classification of BS 4675. Examination revealed that part of the cage retaining ring had broken and was rubbing on the adjacent housing.

DISCUSSION

The RMS velocity levels laid down in BS 4675 would appear to be a useful failure indicator for both fan types.

Kurtosis detected the outer race failure on bearing 4 but not the inner race failure of bearing 1 with any degree of certainty. It also proved insensitive to the fault on the air conditioning fan bearing. Although the crest factor results have not been discussed in detail, the same conclusions can be drawn. We believe however that crest factor is a less satisfactory parameter than the kurtosis.

Our conclusions are based on limited evidence from the plant although a more closely controlled study at Nottingham (ref.3) supports the results both qualitatively and quantitatively. The main problem was that values could not be correlated with the bearing condition because of the tight production schedule. The point at which visible deterioration of the races occurred remains conjecture but it is our belief that kiln fan bearing 4 (and probably 1 also) suffered significant damage at an early stage, possibly even before the first measurements in June. The fact that the pattern of uniformly spaced peaks indicative of some rotationally related disorder was present throughout the tests together with the evidence of fretting induced fatigue damage supports this. The large increase in kurtosis for bearing 4, the main factor suggesting the initiation of damage during the test period, can be accounted for by the reduction in RMS level. The history of the plant's construction also supports the assertion. Because of its size and location in the plant, the fan was installed before the floor above was built. As a result of this the unit was exposed to the weather for some weeks. Subsequent activity by the contractor's equipment would have introduced the element of ground borne vibration and such a history has been known to initiate fretting fatigue and it is our present belief that this occurred in this instance.

Bearing	Date	Acceleration g RMS	Velocity mm/s	Kurtosis	Crest Factor
1	Jun 77	0.7	5.9	3.4	3.4
1	Oct 77	1.5	3.8	3.4	3.6
1	Jan 78	0.5	6.6	4.2	3.9
3	Jun 77	0.5	4.7	4.2	3.6
3	Oct 77	0.9	5.3	3.8	4.1
3	Jan 78	0.3	4.9	3.6	4.2
4	Jun 77	1.4	2.9	3.5	3.5
4	Oct 77	1.1	8.6	4.3	4.2
4	Jan 78	0.3	10.2	18.9	8.3

Table 1 : Test results for kiln fan bearings

Fan	Date	Accel r RMS	Veloc mm/s	Kurt osis	Crest Factor
1	Oct 77	1.7	7.8	3.0	3.3
1	Jan 78	1.6	24.1	3.1	3.6
2	Oct 77	0.4	3.6	3.2	3.6
2	Jan 78	0.4	4.5	4.4	4.2

Table 2 : Test results for bearing 2 of the air conditioning fans

REFERENCES

(1) BS 4675 : 1971, A basis for comparative evaluation of vibration in machinery.

(2) D. DYER and R. M. STEWART 1977 ASME paper 77-DET-83. Detection of rolling element bearing damage by statistical vibration analysis.

(3) S. TURNER 1978 B.Sc. Thesis, Nottingham University, Early detection of failure in rolling contact bearings.

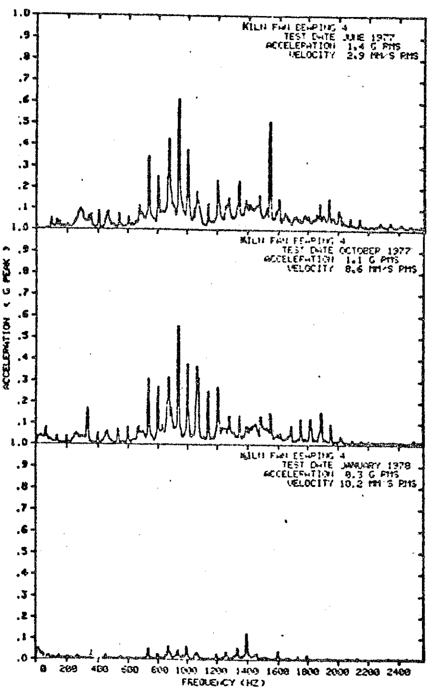

Fig.1 : Acceleration spectra for kiln fan bearing No.1