CHARACTERISTICS AND CONTROL OF LOW FREQUENCY NOISE FROM LARGE RECIPROCATING SCREENS

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1. INTRODUCTION

Reciprocating screens are used commonly within the mineral and other extractive industries for sizing, classifying and cleaning extracted mineral ores. Such screens are comprised of a large deckplate, either perforated, to allow mineral to be sized, or wedge wire to allow cleaning liquid to be drained. The screens reciprocate at low frequencies, typically 500 to 1200 rpm and hence are responsible for the generation of low frequency noise and vibration. Where such screens are in operation close to residential areas, propagated low frequency noise can interact with the structural elements of nearby buildings, resulting in induced element vibration. Despite the prevalence of industrial screens, there is very little published literature on associated low frequency noise and vibration signatures.

2. SCREEN MECHANISMS

A typical screen for sizing extracted mineral ore is shown in Figure 1. There are several different types of screen action, but each results in the screen moving mineral across it from the feed end to the discharge end. For 'jigging' screens the screen motion is in the plane of the screen deck; for 'vibrating' screens the screen deck moves at some 45 degrees to its plane. Audible noise from such screens, measured as dB(A) levels, is well documented (1,2,3). Noise results from (a) the impact of mineral on steel feed and discharge chutes, (b) the impact of mineral on the steel deck plate and (c) the impact of mineral upon itself. Noise control treatments for (a) and (b) above include the use of cushioning materials on chutes, at impact points (rubber and polyurethane products) and the use of resilient or sound-deadened steel deckplates, as shown in the figure.

However, in addition to the generation of noise in the audible frequency range, the screen action results in the generation of low frequency noise and vibration. In the coal mining industry a typical vibratory screen deck is some 6m long by 3m wide, reciprocating at 900 rpm with a 'stroke' of approximately 10 mm. Consequently, despite the perforated nature of the screen deck the screen action results in a forced vibration, not unlike that of a large loudspeaker diaphragm.

Particular problems arise if the screen reciprocation frequency corresponds with resonant frequencies of the building in which it is housed, known within the mining industry as a coal preparation plant. However, for most large coal preparation plants the initial principal building resonances are in the range upwards of 25 Hz and are therefore not excited by the screens. Nevertheless, the forced vibratory action can still result in high noise and vibration levels, whether or not the screens are housed within buildings.

A further complication within the older designs of coal preparation plant was that the screens were located high up in the building, to avoid subsequent lifting of the sized products prior to undergoing other treatments. Often they were located some 10m to 20m above ground level. Consequently, because of induced structural vibration re-radiating as low frequency airborne noise from the large plant walls, later building designs incorporated solid concrete flooring beneath the screen mounts, rather than the more typical skeletal steel structure (Figure 2). Since any problematic vibration in skeletal steel structures resulted from the forced vibration of the screens, remedial action was extremely complex and costly.

3. SPECIFIC NOISE COMPLAINTS

The screen noise problem addressed specifically within this paper was one which occurred at a new 'open' screen installation, where the screens were mounted close to ground level and were not enclosed in a plant building. A schematic of the site is shown in Figure 3.

At the commissioning stage for the plant, complaints were received from residents living to the North, at approximately 300m distance, directly in line with the coal flow from screen 4 (Figure 3). The complaints were of low frequency vibration of house, porch and garage windows.

In order to assess the complaints and to diagnose the cause of any problem, noise measurements were taken near to the complainants' properties and adjacent to the screen installation. These latter measurements were at some 20-30m from most of the screens but were effectively still in the 'near field' because of the frequencies involved (Microphone position 1 in Figure 3). Subsequently vibration measurements were undertaken both on the screens and on particular house building elements.

4. INSTRUMENTATION

Recordings were made on magnetic tape using Nagra IV-SJ tape recorders operating at a speed of 1.5 inches per second (3.8cm per second). Transducers and calibrators were of Bruel & Kjaer manufacture : type 4145 microphones, type 4368 accelerometers, type 2619 pre-amplifiers, type 4220 pistonphone and type 4291 accelerometer calibrator.

Tape recordings were analysed on a Scientific Atlanta SD380 Signal Analyser. A tape recorder playback speed transposition to 15 ips enabled a linear frequency response down to 2.5Hz.

All recording and analysis equipment was of precision grade, conforming to the requirements of BS 5969, Type 1.

5. INITIAL SITE MEASUREMENTS

Noise measurements taken near to the complainants' houses had the character shown in Figure 4. The four principal tones corresponded to the reciprocation rates of the four individual screens, at 13.2 Hz, 13.4 Hz, 15.0 Hz and 16.8 Hz. The other tone at 9.5 Hz was from a separate screen which had been in operation for some time and which had not resulted in any complaints. At the time of these measurements, there was no visible vibration of any building elements and residents stated that the 'noise' was not a problem as it had been when the plant was initially operated.

In order to indicate the severity of any potential problem, however, the noise levels were compared to criteria presented in Hubbard's study(4), Figure 5. The graph indicates that induced vibration of house windows may be possible at the levels and frequencies measured. However, despite the usefulness of Hubbard's curves as a general guide, it should be pointed out that (a) Hubbard's data was derived principally from aircraft noise measurements and (b) since it was principally aircraft data, presumably from near airports, it is possible that the house building standards were not as high as at the present site. Nevertheless, the curves indicate that the levels were, at least, close to those which may cause annoyance.

A Japanese survey of low frequency noise problems(5) indicates that levels slightly higher than Hubbards may not induce window vibration. The paper suggests that levels up to 65 dB should be acceptable, but that 'moderate' rattling can be expected at levels of 80 to 90 dB.

At this stage it was concluded that excessively high noise levels may have arisen at the start up of the plant, due to unusual loading or operational procedures.

After some six weeks of operation, further noise complaints were received, from the original complainants and from others located at 500m to the West of the installation, in line with screen 2 discard belt (Figure 3). Noise measurements were repeated; the principal findings were;

(a) Noise levels from all the four screens had increased, by at least 4dB,

(b) The noise level from screen 3 had increased the most and was now some 14dB above the level from screen 1, a nominally identical screen. The new screen 3 level near the complainants' properties was 79dB, well within the region for exciting window vibration (Figure 5).

6. SITE INVESTIGATION

A programme of work was initiated to investigate the reason for the general increase in noise level from all the screens and to determine the substantial increase in the level from screen 3.

Firstly the operation of the screens was checked in conjunction with the screen manufacturers. All were operating satisfactorily at the same speeds as during the previous testing and with the same stroke, although minor structural problems were being encountered with screen 1. From the operation of the screens, there appeared to be no reason for the general increase in noise levels.

6.1 Increased Levels From the 4 Screens.

Coal loading was considered to have some effect on generated noise levels, since, when fully loaded with coal, the screen decks had effectively 'lost' their open area. Measurements proved that a coal loading of 70-80 tonnes per hour increased tone levels over the no-load tests by approximately 3 dB. At the higher design tonnages of 260 tonnes per hour differences of 4 to 6 dB were encountered. Furthermore, constant use of the screen resulted in some blocking of the open area in the wedge wire deck, thus effectively decreasing the open area. Although a marginal effect, this could account for steadily increasing levels from the screens.

Wind speed and direction were also considered to have an influence on measured noise levels at 300m, although this effect was also considered to be minimal at the frequencies involved. Nevertheless the Environmental Noise Model (ENM) was used to assess the effect of wind speed and direction, calculated at 31.5 Hz and interpreted for the frequencies of interest. Predictions showed that differences in level of some 2/3 dB could occur at the properties.

6.2 Study of Screen 3.

An earth bund, located between the plant and the complainants' properties, had a different effect on the noise from screens 1 and 3, because the screens were at different positions relative to the bund and were also at slightly different heights. The effect was considered to be minimal at the frequencies involved, but predictions were undertaken using the barrier model in the ENM software to assess the effect.

Predictions were coupled with changes in wind speed and direction to show potential differences between screens 1 and 3 of 4 to 5 dB.

A further difference between screens 1 and 3 was the underpan arrangement beneath each screen. (The underpans essentially comprise an enclosed collection hopper for the cleaning water which drains through the screen deck). Furthermore, during screen deck cleaning tests the fluid reservoir beneath screen 3 was seen to vary and this appeared to affect the far field noise levels. This observation led to predictions of the fundamental noise generation from screens being undertaken.

7. PREDICTIONS

The three principal generation mechanisms for low frequency noise were considered to be:-

(i) Direct airborne noise arising from the action of the screen and radiated from the top of the screen deckplate.

(ii) Direct airborne noise from beneath the screen, which was "confined" by the drainage hoppers but which could be radiated from a small open area just below the screen.

(iii) Vibration of the screen side panels, feed and discharge chutes etc. re-radiating as noise.

Work was carried out to estimate the radiated sound power from these sources and to rank them.

7.1 Radiation from Vibrating Plate Areas.
The sound power radiated from a vibrating surface can be estimated from:-

$$W = \sigma \rho c A \overline{v^2} \quad \ldots\ldots (1)$$

where;

W = radiated sound power from the surface (watts)

σ = radiation ratio

ρc = characteristic impedance (=415 PA.S/M)

A = area of plate (m^2)

$\overline{v^2}$ = mean square velocity averaged over the plate area. ($m^2 s^{-2}$)

Equation (1) was applied to the important plate areas on the inlet chute, discharge chute, underpans and screen sides of the clean coal screen (screen 3), with σ set to unity, to indicate the maximum possible contribution from this source. Vibration measurements were made in the centre of approximately 40 vibrating panels (each typically 1.5m^2 area).

Assuming omnidirectional radiation over a plane, the sound pressure level, at the screen frequency, was calculated at a distance of 300 metres from the screen. The resultant sound pressure levels for the various elements of the screen were;-

Inlet Chute	68 dB
Discharge Chute	53 dB
Underpans	50 dB
Screen sides	60 dB

At the screen 3 frequency the radiation ratio is much less than unity, and the sound pressure levels significantly less than shown above. The levels were not recalculated, however, since it was found that the levels given above did not contribute to the overall sound pressure level at 300 metres.

7.2 Radiation from the Screen Deck.
Equation (1) was used to estimate the sound power radiation from the screen deck of the clean coal screen. For the screen deck, a value of σ was calculated, using the method given in (6). σ was set at 0.01.

Assuming omnidirectional radiation over a plane, the sound pressure level was calculated at a distance of 300 metres from the screen to be;-

$L_{300} = 67$ dB

7.3 Pressurisation of Air Volume beneath Screen Deck.
A modified version of the simple theory given in (7) for a piston in an enclosed volume was used to model the behaviour of the air volume partially enclosed beneath the screen deck.

The r.m.s. acoustic pressure within the enclosure is given by;-

$P_{r.m.s.} = P0(A-S)\ D_0\gamma/\sqrt{2}V$ ....(2)

where;

P0 = atmospheric pressure (N/m^2)
A = area of screen deck (m^2)
S = open area of enclosure (m^2)
D_0 = vertical amplitude of screen deck (m)
γ = ratio of specific heats for air
V = volume of enclosure (m^3)

Equation (2) was used to estimate the reverberant sound pressure level within the enclosure. Assuming omnidirectional radiation over a plane, the sound pressure level at a distance of 300 metres was calculated from this reverberant level, using;-

$L_{300} = L_R + 10\log(S) - 20\log(300) - 14$ ....(3)

Where;

L_R = reverberant level
S = open area of enclosure (m^2)

It was found that $L_{300} = 77$ dB

8. COMPARISON OF MEASURED AND PREDICTED LEVELS

The predicted levels given above indicated that the three noise sources could be ranked, with the enclosed volume source being the principal one. Nevertheless a number of assumptions had to be made in each of these calculations and it was desirable to confirm the predicted contributions where possible.

In order to provide some indication of the contribution from the vibrating panels a number of the panels providing the maximum radiated levels were removed. Sufficient were removed to reduce the noise level by 6 dB, had this been the principal noise source. However, no noise reduction was measured.

Sound intensity techniques could not be used to separately identify noise contributions from the screen deck and the underpan volume. However, the 'enclosed' air volume beneath the screen deck could be varied in a controlled manner, by varying the quantity of fluid in the reservoir. In the predictions of Section 7.3 an enclosed volume of $42m^3$ was used and this resulted in a predicted level close to that measured. Testing was undertaken with no coal across the screen and with the air volume progressively changed between $30m^3$ and $50m^3$. Measurements showed that by changing from the maximum to the minimum air volume, noise levels decreased by 9 dB. The result was opposite to the predicted trend, thereby indicating that a more refined model is required for more detailed predictions.

Neverless, the conclusion from this result was that the entrained air volume beneath screen 3 influenced radiated noise levels. Together with the predicted indication that this was the principal noise source, remedial noise measures were concentrated on reducing the influence of this source.

9. NOISE CONTROL SOLUTION

Using equations (1) and (2) above, the effect of increasing the open area, S, beneath the screen 3 deck was investigated. It was predicted that to achieve a reduction of 10 dB at 300 metres, the open area had to be increased to 90% of the area of the screen deck. (i.e. $18m^2$). Subsequently the top sections of the underpans were cut and removed, providing a total open area around the bottom of the screen of $17.6m^2$. The results are shown in Figure 6. (Weeks 4/5)

This action resulted in the cessation of virtually all the noise nuisance complaints.

Finally, since screen 1 had now become the principal noise contributor, a similar procedure of opening up the area beneath that screen deck was implemented. This removed any residual complaints; the result is shown in Figure 7. (Weeks 10/12).

A feature of Figures 6 and 7 is the different characteristic of each screen at the two locations, Position A, 300m to the North of the installation and Position B, 500m to the West. Position A is at 90 degrees to the line of action of screen 3 and Position B is at 90 degrees to the line of action of screen 1. For screen 3 prior to the modifications, the noise level at 'A' is some 12 to 14 dB higher than at B and subsequently shows a much bigger reduction - a 'mean' of 18 dB compared to 10 db. The inverse is true for screen 1, a reduction of 18 dB at B compared to 10 dB at Position A. The results indicate strong directional characteristics associated with the low frequency noise from these screens.

10. CONCLUSIONS

i) Low frequency tone levels from reciprocating screens, measured at residential properties, vary over periods of time, dependent upon mineral loading and weather condition. Therefore a key requirement in determining baseline data and the effects of remedial measures is to obtain sufficient data over periods of weeks.

ii) Nuisance criteria, derived empirically in the US by Hubbard, may overestimate the low frequency noise levels which induce house element vibration.

iii) The highest levels of airborne low frequency noise from reciprocating screens were shown to emanate from the 'enclosed' underpan volume beneath the screens. Where screens are located close to nearby residences (up to 500m), substantial venting of this enclosure may be required in order to prevent low frequency noise nuisance.

iv) The sound radiated from the screens appears to have a directional character. Noise levels can be minimised by orientating the screen layout such that its line of action is in line with any noise sensitive locations.

11. REFERENCES

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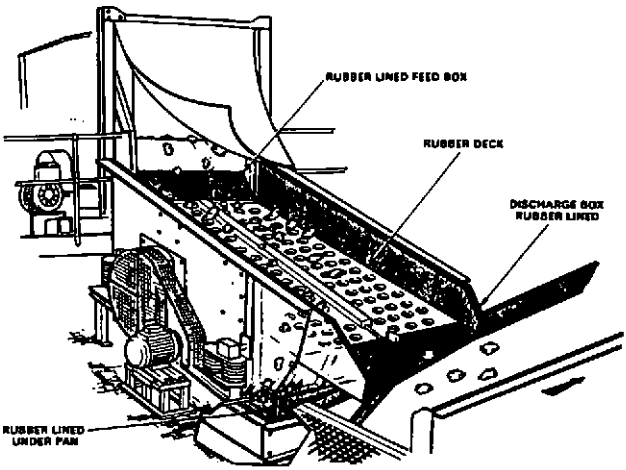


VIBRATORY R.O.M. SCREEN FITTED WITH TRELLFLEX PANELS

FIGURE 1: MINERAL PROCESSING SCREEN

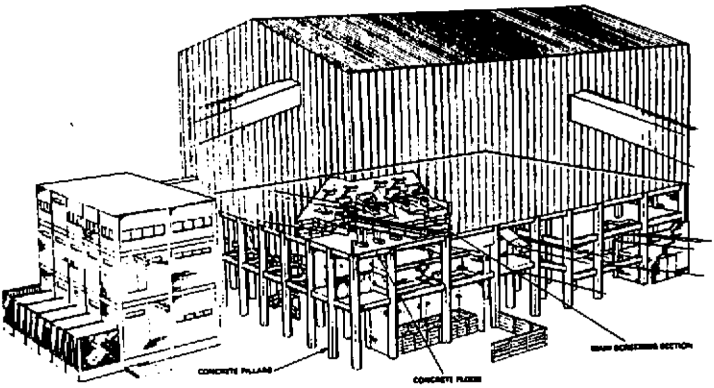
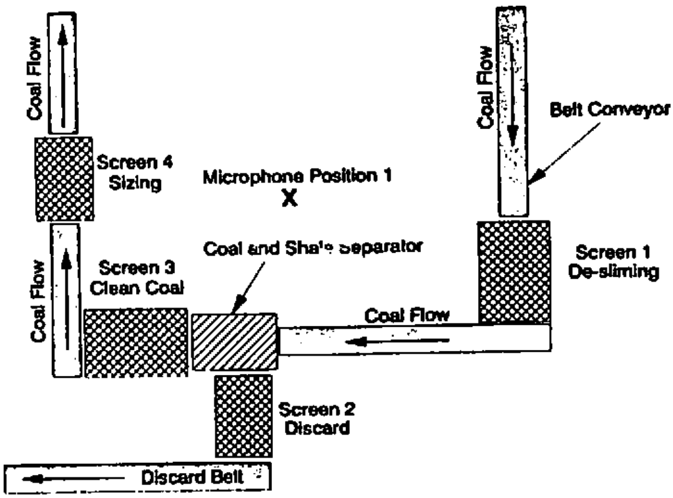


FIGURE 2: COAL PREPARATION PLANT WITH CONCRETE SUPPORT FOR SCREENS

Figure 3: Layout of Coal Preparation Plant



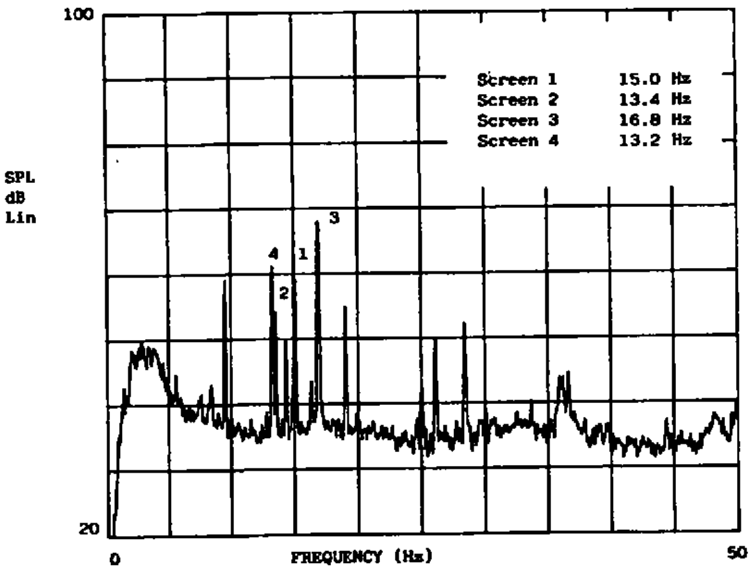
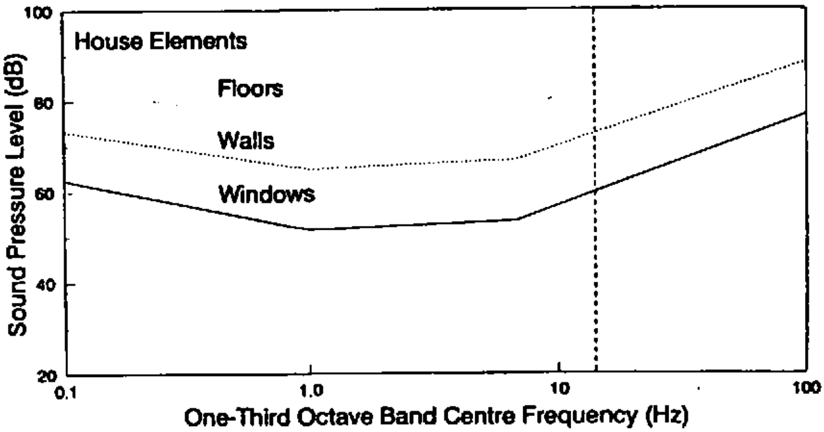


FIGURE 4: NARROWBAND NOISE SPECTRUM NEAR COMPLAINANT'S PROPERTY

Figure 5: Sound pressure levels sufficient to cause perceptible vibrations of house structure elements over a range of frequencies



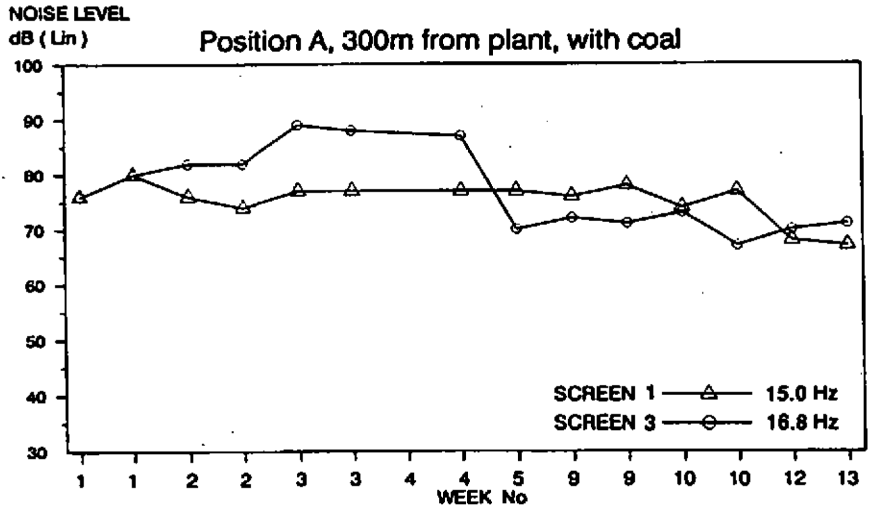


FIGURE 6: SCREEN TONE LEVELS SHOWING EFFECT OF REMEDIAL TREATMENT

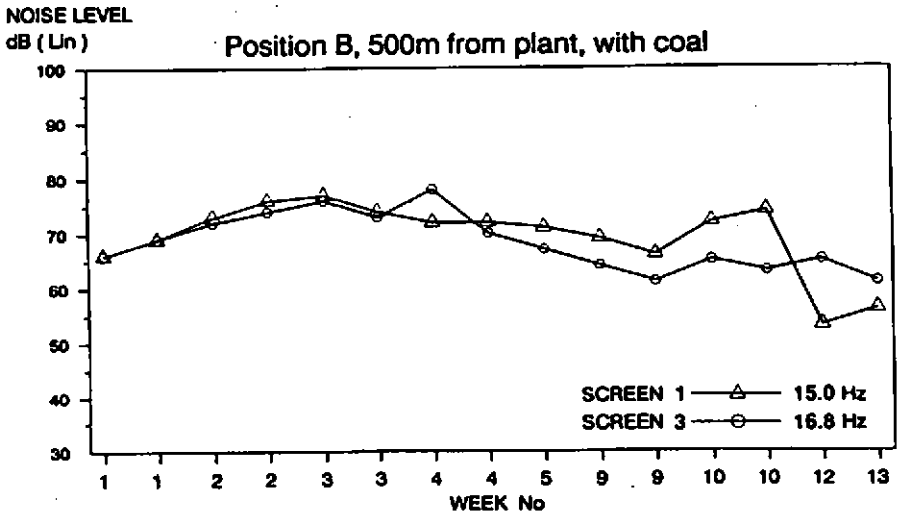


FIGURE 7: SCREEN TONE LEVELS SHOWING EFFECT OF REMEDIAL TREATMENT