DRAGLINE FIELD TESTING

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ABSTRACT

Draglines are the most expensive pieces of equipment used in coal mines at a cost of $50 M to $100M each. Improving their productivity will produce major benefits to the coal mining industry. The dynamic behaviour of the dragline structure has a significant effect on the fatigue life of the main components of a dragline and related maintenance costs. This paper describes the field tests conducted on the dragline DRE23 at the Peak Down coal mine, Queensland, Australia. Sixteen accelerometers were installed on the dragline boom and mast. Three different excitation methods were used in the test: 5.4-kg impact hammer, dragline bucket impulse and ambient excitations produced during normal operation. The aim of the modal testing was set to explore the six global modes for the dragline boom structure. The results showed that the impact hammer excitation was not adequate to excite any of the global modes. The excitation produced by bucket impulse was powerful but was difficult to control. The output-only identification using the response to the ambient excitation was promising but it was difficult to identify all targeted global modes.

INTRODUCTION

Draglines are used in surface coal mines to remove the overburden before mining the coal. Overburden depths up to 60 m are typically excavated by using draglines. Overburden removal is usually the critical process in the mine and the dragline is the key piece of machinery. Any improvement in the productivity of a dragline would directly result in more coal being exposed at a higher rate, and hence more coal that could be mined and shipped out. Conversely, a major breakdown on the dragline may cause the whole mining process to stop in single-pit mine sites.

Most failure on draglines occurs through fatigue. Dynamic characteristics of a dragline structure have a significant effect on the fatigue life of its major components. In particular, an improved understanding of the dynamic coupling between the structures and the rest of the machine is important to prevent catastrophic failures, as has happened recently in an Australian coal mine.

A series of tests were carried out on a dragline. The primary objective of these tests was to characterise the loads acting on the dragline during normal operation and the resultant stresses on critical components. As part of the testing program it was decided to investigate the feasibility of using different techniques to determine the modal properties of the dragline boom in the field. This paper describes these modal tests and some preliminary analysis of the test data.

Fig. 1 shows the operation of a dragline in a coal mine. During the digging operation, the motion of the bucket is controlled using the drag and hoist ropes. After the bucket is filled, it is hoisted to the dump height and swung to the dump position by swinging the house and the boom. Hoisting and swing operations occur concurrently. One full cycle is achieved after the bucket swings back to the digging position.

Fig.1 Dragline working in Peak Downs coal mine.

The tests were part of a project concerned with the relation between the bucket size and the machine component reliabilities. The objective of the modal component of the field tests was to identify the first few natural frequencies of the dragline boom-mast structure. Sixteen accelerometers were installed on the dragline boom and the mast. Three different excitation sources were used in the test: a 5.4-kg impact hammer, the dragline bucket itself, and the normal dig-swing-dump operation.

LOCATIONS OF THE ACCELEROMETERS

A finite element model was constructed to calculate the modal parameters of the dragline. The predicted frequencies for the first ten modes were less than five Hertz. Most importantly, these modes were very closely spaced presenting a serious challenge to modal analysis of this kind of machine. The first ten predicted natural frequencies of the dragline boom, mast and A-frame are listed in Table 1 and the first two modal shapes are plotted in Fig. 2.

Table 1 First ten modes of the dragline DRE23.

Mode No	*Freq. (Hz)*	*Component*
1	0.981	Boom
2	0.998	Boom
3	1.72	Boom & mast
4	2.169	Boom & mast
5	2.208	Boom & mast
6	2.281	Boom & mast
7	2.445	Boom & mast
8	2.548	Boom, mast & A-frame
9	3.17	Mast
10	3.43	Boom

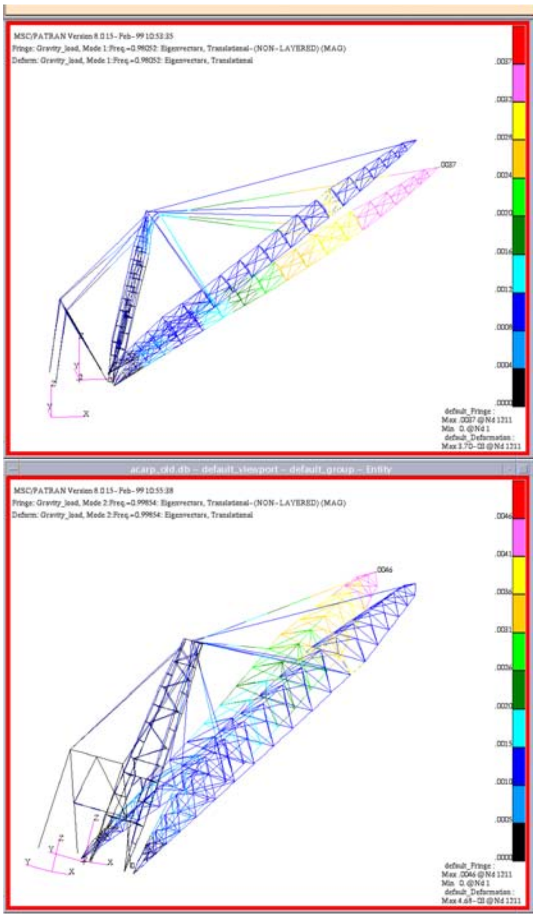

Fig. 2 First and second modal shapes of DRE23.

An optimum set of sensor locations was identified based on the results of finite element calculation. The optimum locations of the sixteen accelerometers were identified from a two stage process. In the first stage a Guyan Reduction exercise was applied to the Dragline FE model – this allowed the ranking of the best master degrees of freedom according to the Guyan Reduction process. The second stage involved the selection of 16 of the highest ranking master dofs. In choosing these 16 dofs the Modal Assurance Criteria (MAC)[1] was used to assess how uniquely identifiable the first 10 FE modes were according to their representation by the 16 selected dofs. In making the final selection of the 16 dofs, consideration was also given to the practicality of instrumenting certain regions of the dragline. Figure 3 shows the 16 accelerometer locations used for the dragline modal tests. Among these sixteen accelerometers, eight are strain gauge based (TML type) accelerometers (AB_1 to AB_5, AB_8, AB_9 & AB_11) and the other eight are the piezoelectric type (PCB type) accelerometers.

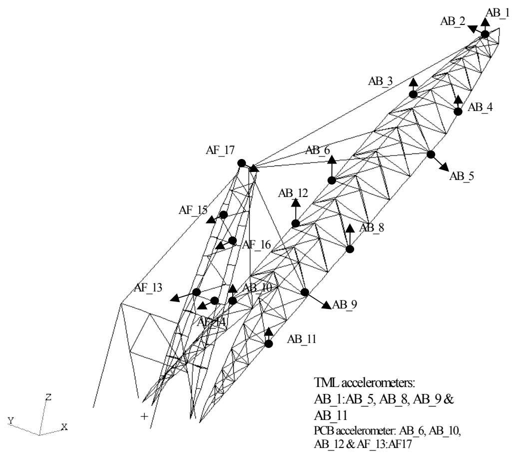

Fig. 3 Locations of the sixteen accelerometers.

MODAL IMPACT RESPONSE TESTS WITH IMPACT HAMMER

A 5.4-kg impact hammer was used to hit the boom tip (near the location of AB_1) and the middle of the boom (near the location of AB_5 and AB_8, see Fig. 3 for the locations of the accelerometers) in both vertical and horizontal directions. The output of the impact hammer and the response of each accelerometer were recorded. Fig. 4 shows a plot of the outputs of the impact hammer and the accelerometers AB_1 and AB_2 when the hammer was hit at the location near the accelerometer AB_1 vertically. Fig. 5 shows the output of the hammer and the accelerometers AB_1, AB_2 and AB_5 when the hammer hit near the accelerometer AB_5 horizontally.

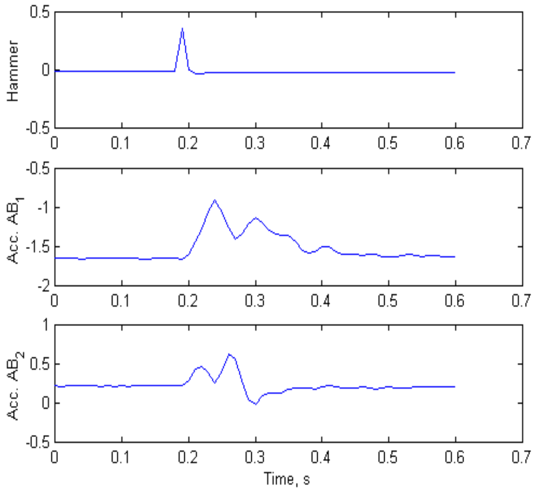

Fig.4 Outputs with the hammer hit near AB_1 vertically.

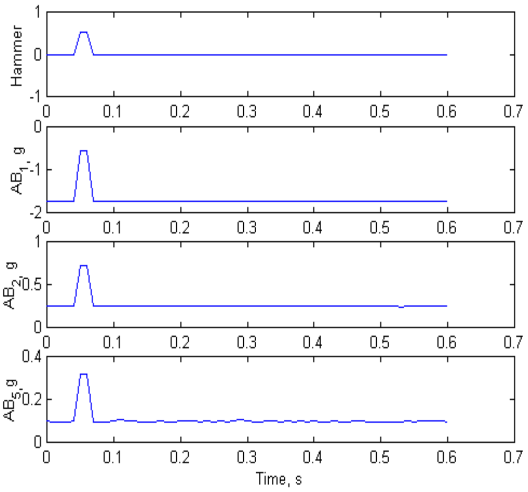

Fig.5 Outputs with the hammer hit near AB_5 horizontally.

As shown in the above figures, even at locations very close to the hammer impact the excitation was not enough during the hammer impact test. This indicates that with the type of accelerometers used on the dragline, the 5.4-kg hammer is not heavy enough to excite the dragline. Other methods such as the dragline bucket impulse and normal operation were used as exciting sources in the rest of our modal test.

MODAL RESPONSE TESTS WITH THE DRAGLINE BUCKET IMPLUSE

A short bucket lift-and-drop operation was used to excite the structure with the empty, half-full and full bucket. The time of lifting-and-dropping the bucket was controlled as short as possible in practice. The operations of these tests included:

- Start with the bucket lying on the ground under the boom point.
- Start the hoist but stop immediately before the bucket is lifted.

Figs. 6 and 7 show the outputs of accelerometers AB_1 to AB_5 with empty and full bucket impulse test, respectively. The signals from all PCB accelerometers were filtered with a user constructed 30 Hz low-pass filter and the signals from all TML accelerometers were filtered with 20 Hz low-pass filter of the dynamic strain gauge amplifier.

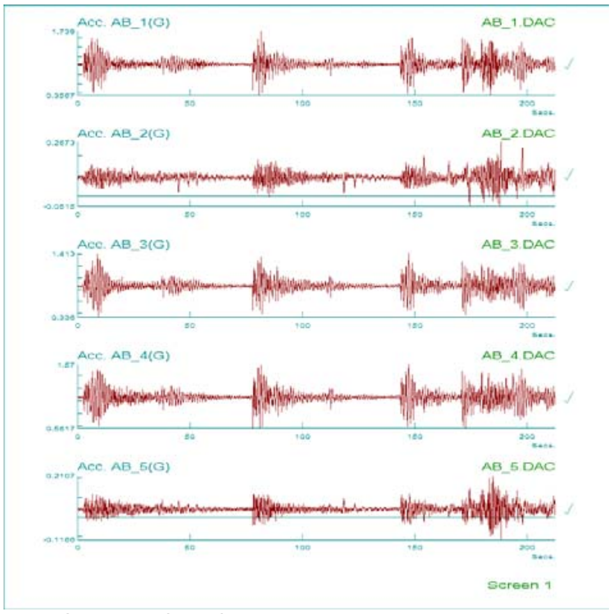

Fig. 6 Outputs of the four accelerometers with empty bucket impulse.

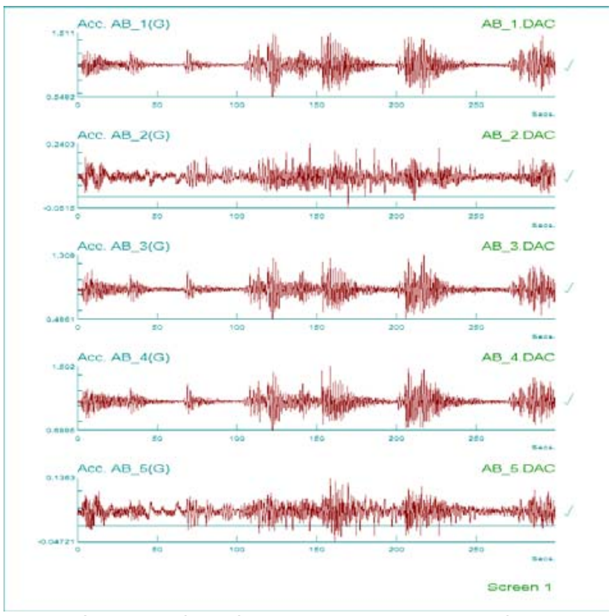

Fig. 7 Outputs of the four accelerometers with full bucket impulse.

MODAL RESPONSE TESTS WITH NORMAL OPERATIONS

The tests were carried out under normal dig-swing-dump operations. During the normal operations, the signals of all sixteen accelerometers were recorded continually. As in the case of the bucket impulse tests, the signals from all PCB accelerometers were filtered with 30 Hz low-pass filter and the signals from all TML accelerometers were filtered with 20 Hz low-pass filter.

Fig. 8 shows five minutes data of all accelerometers on the boom (AB_1 to AB_6, and AB_8 to AB_12) during the normal operation tests. Fig. 9 shows the same time record of all accelerometers on the mast (AF_13 to AF_17).

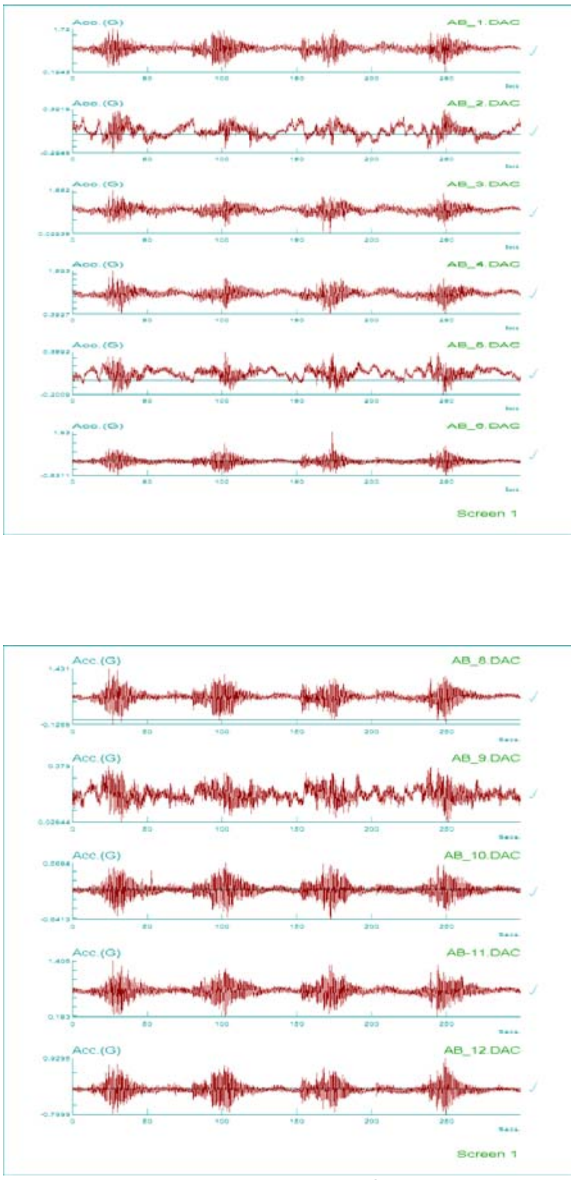

Fig. 8 Five minutes output of the accelerometers on the boom during normal operations.

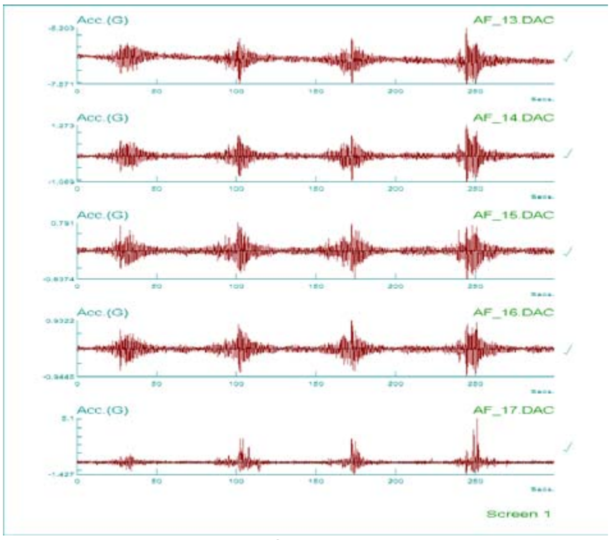

Fig. 9 Five minutes data of the accelerometers on the mast during normal operations.

MODAL IDENTIFICATION

The difficulty with the conventional FRF based modal analysis approach however is measuring the input excitation applied to the boom. Because of this problem a more promising approach to identifying the dragline's modal parameters is an identification algorithm based purely on the acceleration outputs [2,3]. A preliminary investigation of the method discussed by Abdelghani *et al* has been used to process accelerometer data acquired during the normal dig-dump operation of the dragline. The results of this analysis (which are still being conducted) are shown in Fig. 10 with Power Spectral Density (PSD) plots and the identified frequency stabilisation plot for the accelerometers of setup1 (AB1 AB3 AB4 AB6 AB8 AB12). The most likely undamped frequencies are those peaks in the PSD plots and they are summarised in Table 2.

Table 2: Undamped natural frequencies from Output only identification algorithm

Undamped natural frequency [Hz]	*Paired FE model frequency [Hz]*
0.878	0.981
2.1478	No conclusive pairing at this stage
2.540	No conclusive pairing at this stage
3.200	No conclusive pairing at this stage
3.63	No conclusive pairing at this stage
3.320	No conclusive pairing at this stage
4.6862	No conclusive pairing at this stage

The problem with the preliminary results shown in Table 2 however has been the difficulty pairing the identified mode shapes with the FE mode shapes – for example using the

MAC pairing metric. It was observed that with the exception of the first mode, the identified modes had MAC values of 0.5 or less and on many occasions multiple identified modes paired equally well with a single FE mode. Work is continuing on this problem.

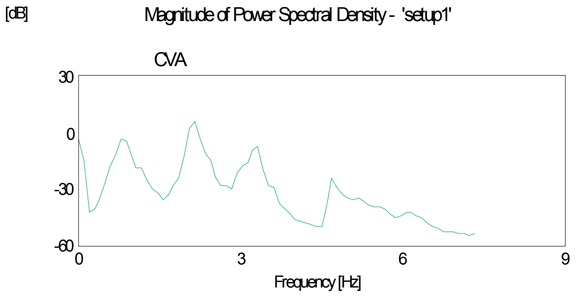

Figure 10 (a): Average Power Spectral Density of Setup1 accelerometers reading

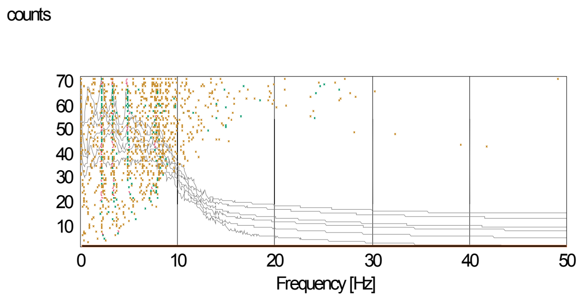

Figure 10(b): Stabilisation diagram of CVA method for setup1 accelerometers reading

CONCLUSIONS

The following conclusions are based on the preliminary analysis of the test data.

1. 5.4-kg impact hammer is not heavy enough to excite the dragline structure. The excitation with dragline bucket appears to have the potential to be an effective excitation tool in the modal testing of this kind of machines.
2. Output only modal identification method is probably the best method to identify the modal parameters of such machines.

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