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Hydraulics, Lubrication and Maintenance Management

1/8/00

Cable Safe System

For

Shuttle Cars

A.C.A.R.P

Project C9004

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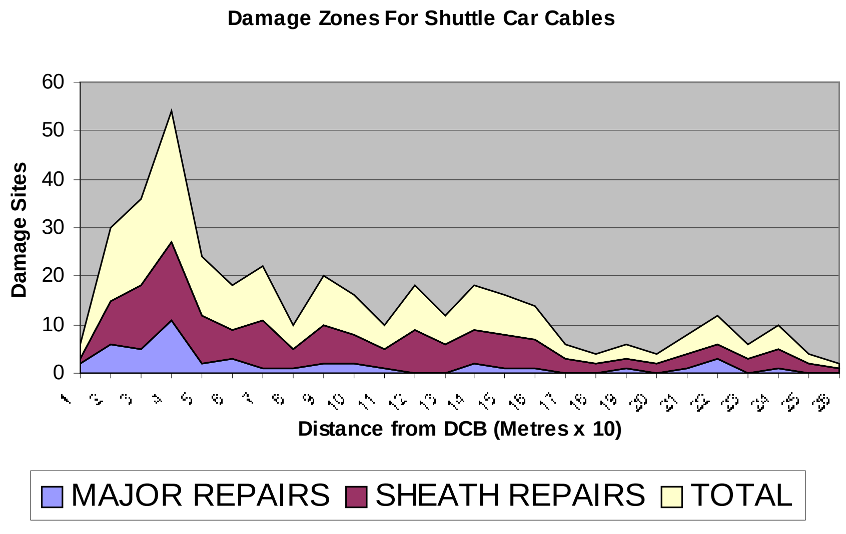
SUMMARY

The objective of the project is to improve safety and to reduce the costs associated with failures of trailing cables, through the application of a new product that may be retrofitted to existing fleets. This product: (1) increases the minimum tension to reduce failures resulting from the formation of 'loops' in the cable and failures from the car crushing its own cable, and (2) decreases the maximum tension to reduce failures from tension overload.

Cable tension decreases as the cable reel fills and is therefore at a minimum at the anchor. It also decreases as the vehicle accelerates towards the anchor and, with several build standards, this is compounded at the boot end by the actuation of the conveyor cylinder. Thus cable failures due to 'loops', and from the car crushing its own cable, will predominately occur near the anchor and probably during the pay-out process that immediately follows reeling-in under low tension.

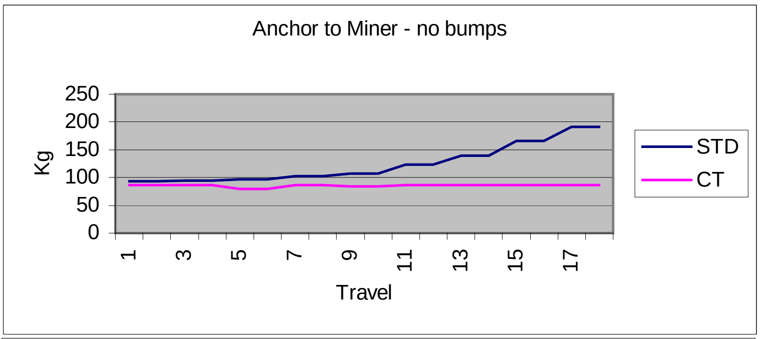
Low tension may also occur due to losses at the Archimedes and guide rollers, since these losses subtract from the torque available to the reel. These losses is particularly high when the car is cornering, as demonstrated during earlier underground tests at Myuna.

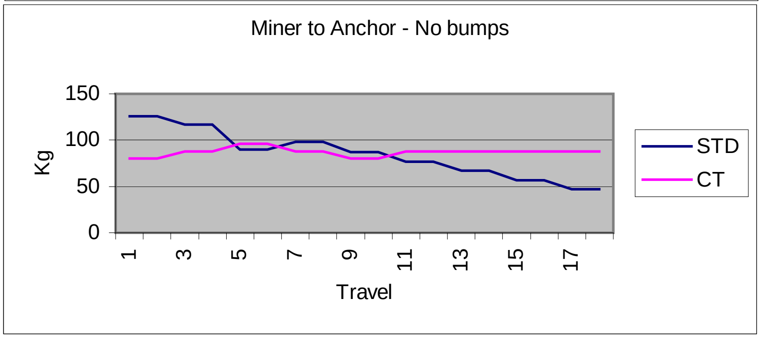
Highest tension occurs during pay-out with a near empty reel and since this is where the bend radius is minimum, the condition for the cable is severe. Resulting elongation travels along the cable to the loose end causing 'knuckling' at the anchor. A damage zone study, performed by Rutherford Cables, shows the highest incidence of failures to be within 50m of the plug (DCB). The remaining failures correspond to 'pillar' spacing and may be due to cornering problems, where the cable is pulled across the front of the car, or to 'bumps' at the intersections.



The design achieved the constant tension objective and should provide relief to the cable problem. One component of the design is already proven through underground use at Appin, Myuna and Southland mines.

The CT (constant tension) design provides 90-kg tension for both the reel-in and pay-out modes. It reduces tension during pay-out, with a near empty reel, by a factor of 2 and increases tension during reel-in, with a full reel, by a factor of 1.8.





Tests at Appin mine, midway through the project, indicated that extreme transient loads occurred when ‘bumps’ in the road are encountered and that these were higher than targeted by the project and by the devices developed. While tensions in excess of 400 kg frequently occurred, some tests produced loads in excess of 1000 kg. The recommended maximum tension is 150 kg for 25mm cables and 210 kg for 35mm cables.

Industry representatives, invited to review the project, recommended an expansion to the ‘bump’ studies and this decision postponed the completion of development and underground testing of the CT system. These representatives also concluded that the ‘Appin’ test track may not be representative and proposed a different ‘bump’ test (refer appendix).

The new test track produced less violent ‘pitching’ of the vehicle and generally the shock loads to the cable were less than 400kg. A key finding, from the additional ‘bump’ tests, was that the shocks to the cable were not directly related to the proximity of the bump to the anchor but were related to the amount of cable on the reel at the time.

A new anchor device improved the protection against shock for bumps in close proximity, but this had a reducing benefit as the distance between the bump and anchor increased.

The decision to vary the project was validated since the additional study determined other causes of failure, providing direction for further study and a need to consider interim operational restrictions.

Given the assessment that the ‘Appin’ tests were extreme, this study has provided solutions to the majority of problems concerning cables and has identified means of dealing with the remainder. However, some engineers have questioned the assessment made regarding ‘bumps’ and further input is now sought.

A brief summary of indicated actions is as follows:

1. **Vehicle brakes:**
   Use a 700-psi brake valve, particularly for cables with a length over 200m.

2. **Boom operation**:
   a) Upgrade those cars that apply back-pressure to the hydraulic motor while lowering.
   b) Avoid placing the anchor beyond the boot. The anchor should be placed at approximately 20m in front of the boot so that boom raising commences after passing the anchor.
   c) To remove the above restriction, the hydraulic system will need to be modified to enable boom raising without a loss of tension.

3. **Roads:**
   a) Rough roads are to be avoided where possible and particularly in close proximity to the anchor where the reel is full.
   b) Use low tram in bumpy areas.
   c) Extend 'bump' tests to include a fully laden car.
   d) Confirm that the 'Appin' tests were excessive and that the 'Myuna' tests were representative. Continue the development of the CT system

4. **Vehicle acceleration:**
   a) Determine the maximum pressure that may be used with the Cable-Safe component of the CT system and apply the product throughout the industry.
   b) Continue the development of the CT system.

5. **Driver visibility:** Consider vehicle modifications to improve the driver's ability to see the cable.

6. **Cornering:**
   a) Cornering, with the cable pulled across the front of the car, may result in a lower cable tension than back-spooling. Tests are recommended.
   b) Continue the development of the CT system.

7. **Cable laying**:
   a) To improve cable wrapping, a gear ratio should be selected to match the reel width and cable diameter.
   b) Further study is required to improve the cable-laying device.
   c) Continue the development of the CT system.

RECOMMENDATIONS

The following recommendations consider the situation at the cable only and may not be practical from a mining viewpoint:

1. Vehicle Brakes: Violent braking, during reeling-in with a near full reel, causes stress to the cable. According to an 'Appin' test, cable stress may be reduced to an acceptable limit by limiting the maximum brake pressure to 700-psi.

2. **Operation of boom (conveyor cylinder):** Most systems apply full back-pressure to the cable reel motor when the boom is raised and there are also systems that apply back-pressure while the boom is lowered. Back-pressure reduces the efficiency of the system to a degree depending on the design of the drive unit.

For a anchor-beyond-boot situation, the reduced cable tension while raising the boom is then immediately followed by an increased tension during lowering. This is possibly the worst scenario for cables as it may cause 'over-wrapping' and should be avoided where possible.

Where the anchor is before the boot, raising the boom increases cable tension during the pay-out mode and lowering the boom reduces tension for the reel-in mode. The reduced tension during lowering is further eroded by the need to back-spool and a critical situation may develop. Many cars have been modified, to avoid back-pressure while lowering, but some may remain with this problem and these should use low tram until upgraded.

For standard cars, operating with a nominal 900-psi, it is important to limit the back spooling to about 20m so that the boom is raised only after the car has passed the anchor.

3. Condition of roadway: A smooth roadway is highly desirable to reduce the maximum stress on the cable when the reel is near empty and thereby permit an increase to the minimum tension, when the reel is near full. An added benefit is that smooth roadways will reduce the incidence of other component failures and will considerable improve driver comfort.

Whereas bumps in the road, regardless of when they are encountered, may cause excess cable stress, those encountered while the cable is being reeled-in under lowest tension may cause slackness in the cable and to the formation of loops. On this basis, bumps near the anchor are likely to be the most damaging and particularly those between the boot and anchor.

Where violent bumps cannot be avoided, operators should be encouraged to use low tram speed.

Tests of the CT system indicate a need to increase the tension when the reel is near empty. The pressure differential used for tests of about 500-psi needs to be increased to an estimated 650-psi to overcome losses due to the tighter bend radius. Other tests indicate a need for closer control of pressure differential, suggesting the need to position the relief valve at the motor and other detail changes.

With the exception of a braking test at Appin, all tests were performed with an empty car and testing is now required with a fully laden car.

4. **Vehicle acceleration:** The almost immediate change in speed causes slackness in the cable, particularly when the reel is near full, and places a demand on the system to accelerate the reel. Whereas the tension falls too low at the standard 900-psi, the minimum tension at 1400-psi appears acceptable.

The Cable-Safe valve currently operating at Appin, Myuna and Southland permits an increase in reel-in tension without an increase to the maximum tension. These applications however, are currently reducing stress to a minimum and tests up to 1400-psi are now recommended to increase the minimum tension,.

5. Driver control: With the test vehicle, a minimum catenary of 9m provided some visibility and this corresponds to a pressure range from 900-psi with an empty reel to 1400-psi with a full reel. However, during acceleration tests, the operator did not feel completely comfortable until the pressure was increased to 1800-psi.

A slight modification to the body of the vehicle, combined with the increased tension provided by CT system, will improve the driver's view of the cable with a resulting ability to reduce cable problems.

6. Cornering: Earlier tests at Myuna, indicated that the torque required to drive the Archimedes could reach about 50% of the total torque available and this is suspected to occur during cornering with the cable being pulled across the front of the car. Thus, this situation may result in a lower tension than during back-spooling and further tests are recommended.

7. Cable Laying: It is clear, from observations, that the problem of untidy reeling is only partly due to uneven cable tension and a study to improve the cable laying device is recommended.

TEST RESULTS

Notes:

a) Tests were inhibited, at both Appin and Myuna, by a difficulty in reading cable tension at a distance greater than the catenary produced. Accordingly most tests were performed with the strain gauge at the anchor.

b) At Myuna, cable supply difficulties limited the total cable length to 185m, giving 165m on the reel. Tests with a 200m cable would demonstrate the increased problem of low tension and an increased necessity for the CT system.

c) It was not practical to load the conveyor for 'boom' tests and a relief valve was introduced to the 'boom' circuit to simulate the load.

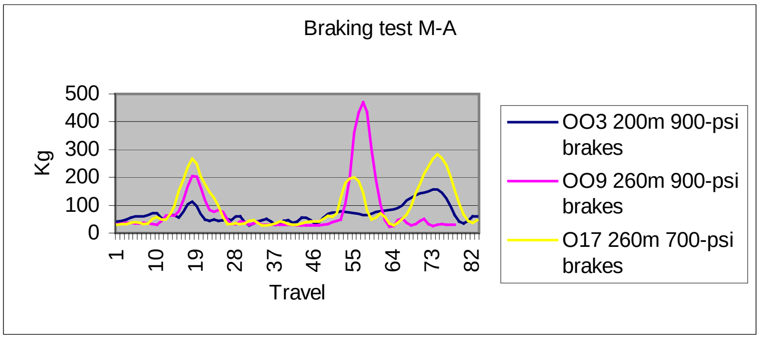
d) Whereas over 120 tests were performed and Myuna and about the same at Appin, only the most significant are included in this section. Those not included are available on CD. Tests were recorded at 1000 samples/sec and the graphs produced for this report are smoothed to 20 samples/sec.

e) In the following charts, 'M' is miner, 'A' is anchor and 'B' is boot so that M-A would indicate travelling from the miner to anchor whereas B-A-M would indicate travelling from the boot, past the anchor and towards the miner. STD is a standard car with a KIS system and CT is the constant tension system.

f) All tests were with an empty car and some tests should be repeated with a fully laden car.

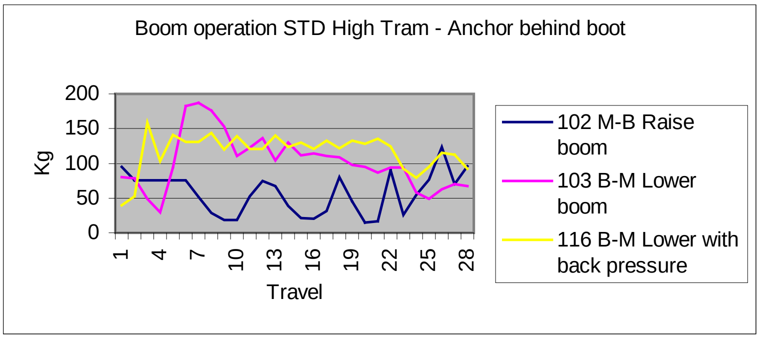
1. VEHICLE BRAKING (Appin tests – 003, 009 and 017)

High shock loads occurred with a 260m cable at a brake pressure of 900-psi. These became acceptable when the brake pressure was limited to 700-psi. Either pressure is acceptable for a 200m cable but 700-psi is preferred.



2. OPERATION OF BOOM (Myuna tests – 101, 103, 107-110, 115 and 117)

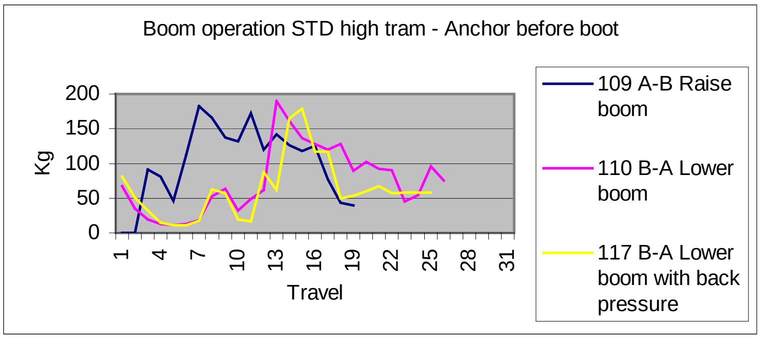
With the anchor behind the boot, a low reel-in tension occurs as the boom is raised. This is followed by high tension as the boom is then lowered while travelling away from the boot. This occurs in both low and high tram and is likely to lead to cable failure.

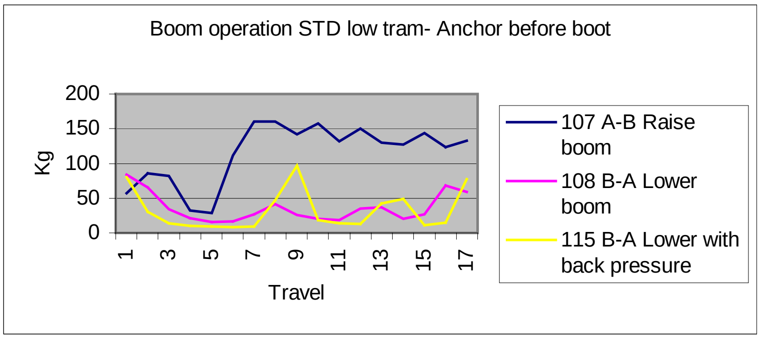


With the anchor placed before the boot, the boom is raised during the pay-out mode and the increased losses increase the tension.

Reeling in while back-spooling results in low tension, particularly with systems that apply back-pressure to the hydraulic unit.

The CT system will solve these problems but confirmation tests were not performed



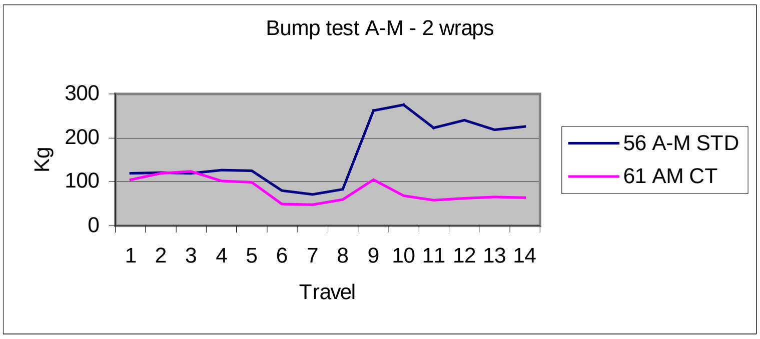


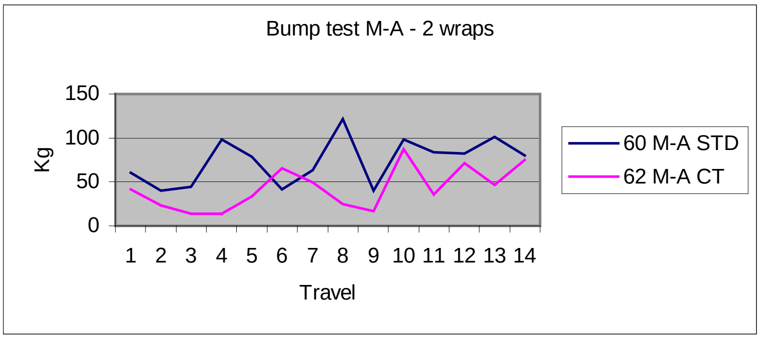
3. CONDITION OF ROADWAY (Myuna tests – 56 and 60-62)

The 'Appin' tests were considered to be excessive and the results, summarized in the appendix, have not been included in this summary.

There was little difference in the shock loads between the CT and standard system when tested with a near full reel. The graphs, for a near empty reel, show a 300% gain for the CT system to bring the load within manufacturers recommendations

The pressure setting for the CT system will need to be marginally increased to avoid the low tension during reel-in. This will slightly reduce the gain achieved.



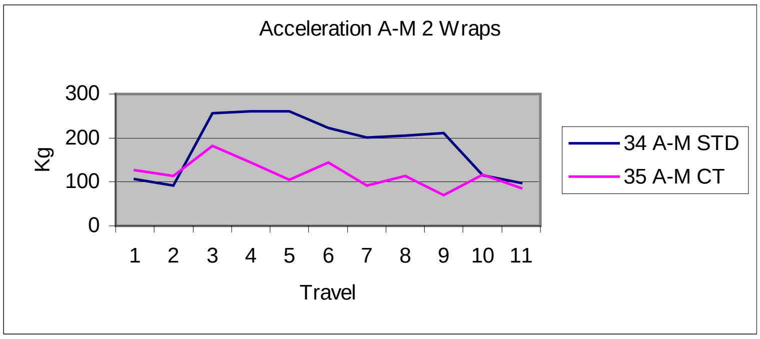


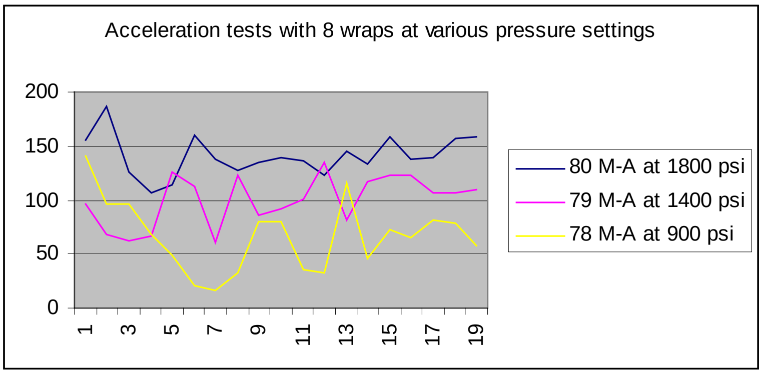
4. VEHICLE ACCELERATION (Myuna tests 34,35 and 78-83)

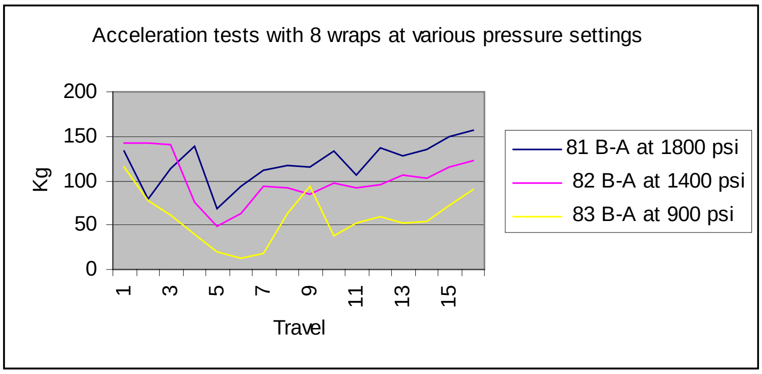
Acceleration tests with a near empty reel and towards the miner show a 30% shock reduction for the CT system, bringing the load to within manufacturers recommendations.

Acceleration tests with a near full reel and towards the anchor are more significant. These show that the minimum tension is unacceptable from the standard 900-psi system and is just acceptable with a 1400-psi system.

The operator was not completely comfortable, with the cable slack, until the pressure was increased to 1800-psi.

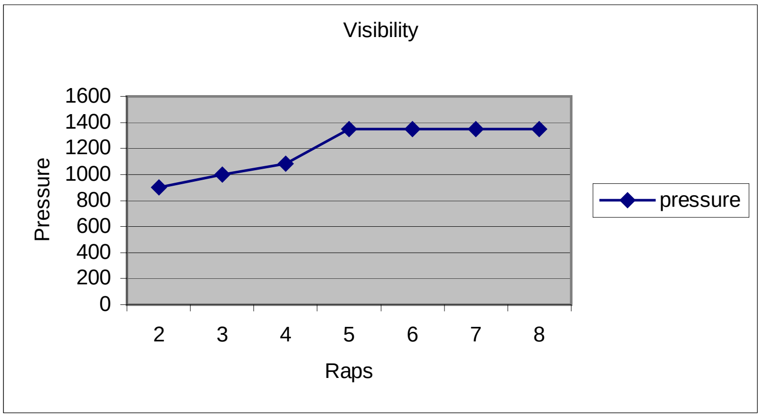






5. DRIVER VISIBILITY

The chart shows the pressure at which the cable became visible to the operator. The pressure needed varied from 900-psi with an empty reel to about 1400-psi with a full reel.



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Jerry Hessenberger – Major Overhauls Engineer for BHP Coal
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