LONGITUDINAL DYNAMICS OF A LONG TRAIN DURING THE DUMPING OPERATION

C. G. WILLIAMS

1 INTRODUCTION

The location of iron ore deposits in W.A.'s Pilbara region large distances from suitable coastal export facilities had led to extensive use of railways for ore transport. Unloading the unit trains running on these railways is a problem that has been tackled differently by all four major miners, though the majority use rotary dumpers. Mt. Newman Mining Company has two rotary ore car dumpers in operation - one a two car device, the other capable of dumping three ore cars simultaneously.

Positioning (or indexing) unit trains for dumping can be done in a variety of ways as well, Mt. Newman's choice for both dumpers being the winch driven positioning arm. The exacting task of this machinery is to index ore trains of about 17,000 tonnes' gross weight at a rate of ten per day. It is not surprising, therefore, that the indexing operation has led to a great deal of research work, both in computer modelling and field testing. The rewards include greatly reducing the fatigue damage to ore car drawgear and draft gears, extending the operational life of positioning equipment, optimising the dumping cycle, and minimising production stoppages.

As has been stated in other related papers, a programme of research into longitudinal train dynamics was started by the Company in early 1974. We aimed at simulating by computer model the longitudinal forces in our trains, both on main track and during indexing for dumping. (Test data from our first dumper was used to develop the initial model.) Then, by testing in the field, we were able to validate our computer models, and use them extensively to optimise all train operation. This paper covers research applied to the indexing part of our dumping cycle.

2 MT. NEWMAN MINING COMPANY'S TRAINS AND ROTARY CAR DUMPERS

The Company's trains usually comprise 138 ore cars, each of 25 tonnes' tare weight and nominally 120 tonnes gross, pulled by three 2700 KW diesel electric locomotives. Each ore car has one rotary and one fixed type "E" coupling. Conventional pneumatic braking is used.

Figs. 1 & 2 show the layouts of both No. 1 and No. 2 Rotary Dumpers. Both use electrically driven car positioners, with dumping and positioning (indexing) cycles operating automatically, fully interlocked and protected.

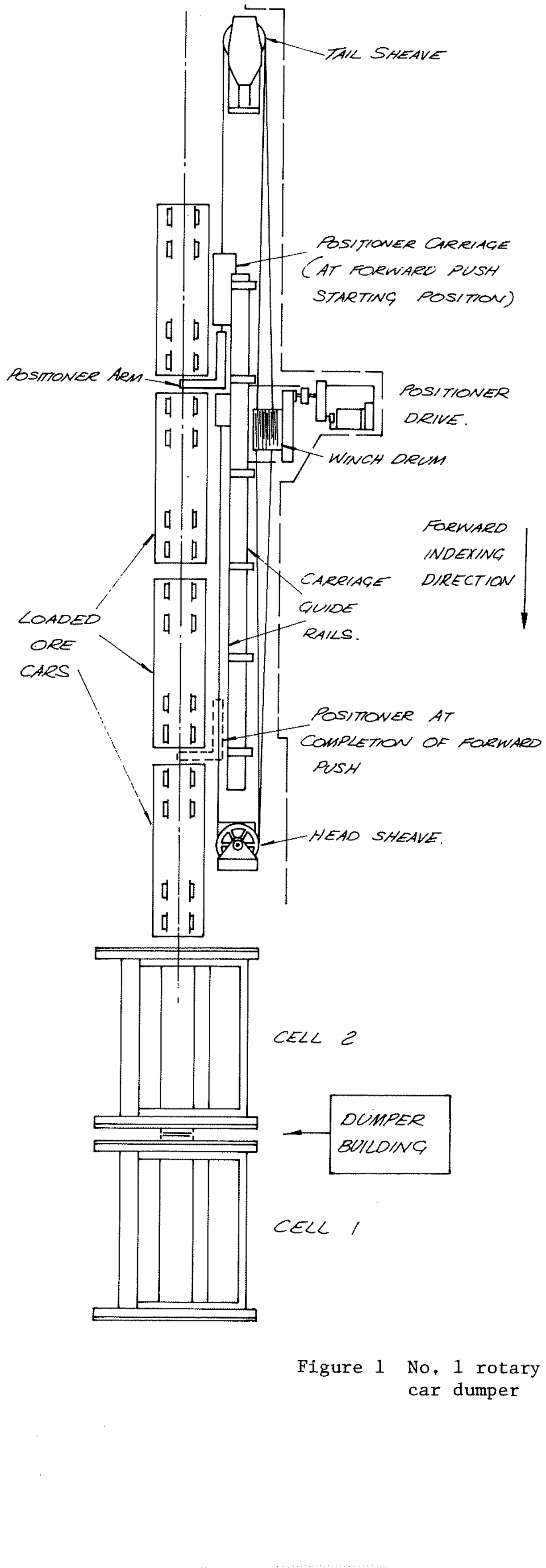
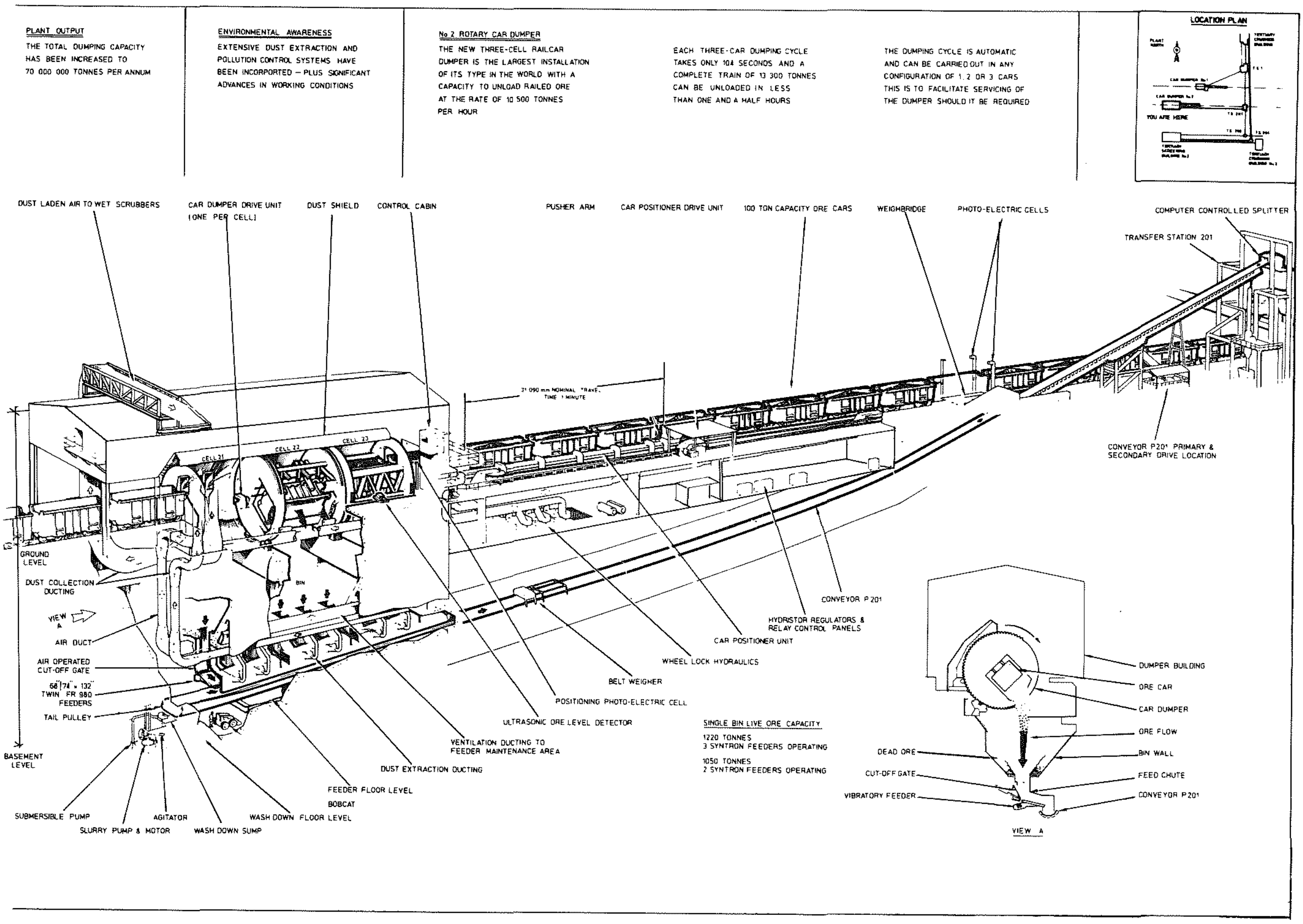


Figure 1 No. 1 rotary car dumper



PLANT OUTPUT
THE TOTAL DUMPING CAPACITY
HAS BEEN INCREASED TO
70 000 000 TONNES PER ANNUM

ENVIRONMENTAL AWARENESS
EXTENSIVE DUST EXTRACTION AND
POLLUTION CONTROL SYSTEMS HAVE
BEEN INCORPORATED – PLUS SIGNIFICANT
ADVANCES IN WORKING CONDITIONS

No 2 ROTARY CAR DUMPER
THE NEW THREE-CELL RAILCAR
DUMPER IS THE LARGEST INSTALLATION
OF ITS TYPE IN THE WORLD WITH A
CAPACITY TO UNLOAD RAILED ORE
AT THE RATE OF 10 500 TONNES
PER HOUR

EACH THREE-CAR DUMPING CYCLE
TAKES ONLY 104 SECONDS AND A
COMPLETE TRAIN OF 13 300 TONNES
CAN BE UNLOADED IN LESS
THAN ONE AND A HALF HOURS

THE DUMPING CYCLE IS AUTOMATIC
AND CAN BE CARRIED OUT IN ANY
CONFIGURATION OF 1, 2 OR 3 CARS
THIS IS TO FACILITATE SERVICING OF
THE DUMPER SHOULD IT BE REQUIRED

SINGLE BIN LIVE ORE CAPACITY
1220 TONNES
3 SYNTRON FEEDERS OPERATING
1050 TONNES
2 SYNTRON FEEDERS OPERATING

Figure 2 No. 2 rotary car dumper

3 THE ROTARY DUMPER CYCLE (Refer to Figs. 3(a),(b),(c),(d) & (e)

(a) Prior to the start of dumping, one locomotive spots the train so the first two (or three) cars are in the dumper cells. Hydraulically operated rail head level wheel locks hold both bogies of the first car and the leading bogie of the second car immediately outside the dumper. The positioner arm is raised, with the carriage ready to return at speed to the forward push starting position.

(b) During dumping of the first three cars, the positioner carriage returns and spots itself at the forward push starting position. This usually takes about 30 seconds, being the time taken to dump and return two (or three) cars.

(c) The arm is lowered between coupled cars, and creeps forward to a seated position against the pusher pad (the load bearing structure immediately above each car's striker casting). It then holds the train, which allows the wheel locks to release.

(d) The forward push of the indexing cycle starts and the arm and its carriage follow the velocity profile as shown in Fig. 4.

(e) As the train is brought to rest by the arm at the end of the forward push, the wheel locks are applied, correcting minor mis-spotting if necessary. The arm is raised only when interlocks have confirmed that the train is correctly spotted and held stationary by the wheel locks. The dumping cycle starts and the whole process continues.

4 PRODUCTION REQUIREMENTS OF THE ROTARY DUMPERS

Our No. 1 and No. 2 Ore Handling Plants naturally depend on the operation of No. 1 and No. 2 Dumpers. The two car dumper (No. 1) was upgraded soon after installation to allow maximum production to increase from 5,700 TPH to 7,500 TPH. The Company's three car dumper (No. 2) was designed and built to have a maximum throughput of 10,500 tonnes per hour. When the rest of the Ore Handling Plant requires those amounts, we know from experience it is continuously available, but accompanied by the highest probability of damage to equipment. Lower dumping rates are currently used due to the level of production and shipping required. Whatever rate is needed from either or both car dumpers, we know it is possible to tune the indexing portion of the cycle to prolong the life of ore car drawgear and draft gears, and minimise wear and tear on positioning machinery. (West, Williams and Kerr 1978, make clear the benefits to train operation and production obtained from the former.) By computer simulation (backed by field testing), we have been able to balance our production requirements with realistic life of ore car and positioning equipment.

5 THE FORWARD PUSH VELOCITY PROFILE AND RESULTING TRAIN BEHAVIOUR

The initial positioner velocity profile used with No. 1 Car Dumper was a modified version of a proven profile. The designers then supplied a new profile for the upgrading, after we had sponsored their use of computer simulation. We repeated this exercise when they designed our No. 2 dumper. Both profiles are similar to that shown in Fig. 4.

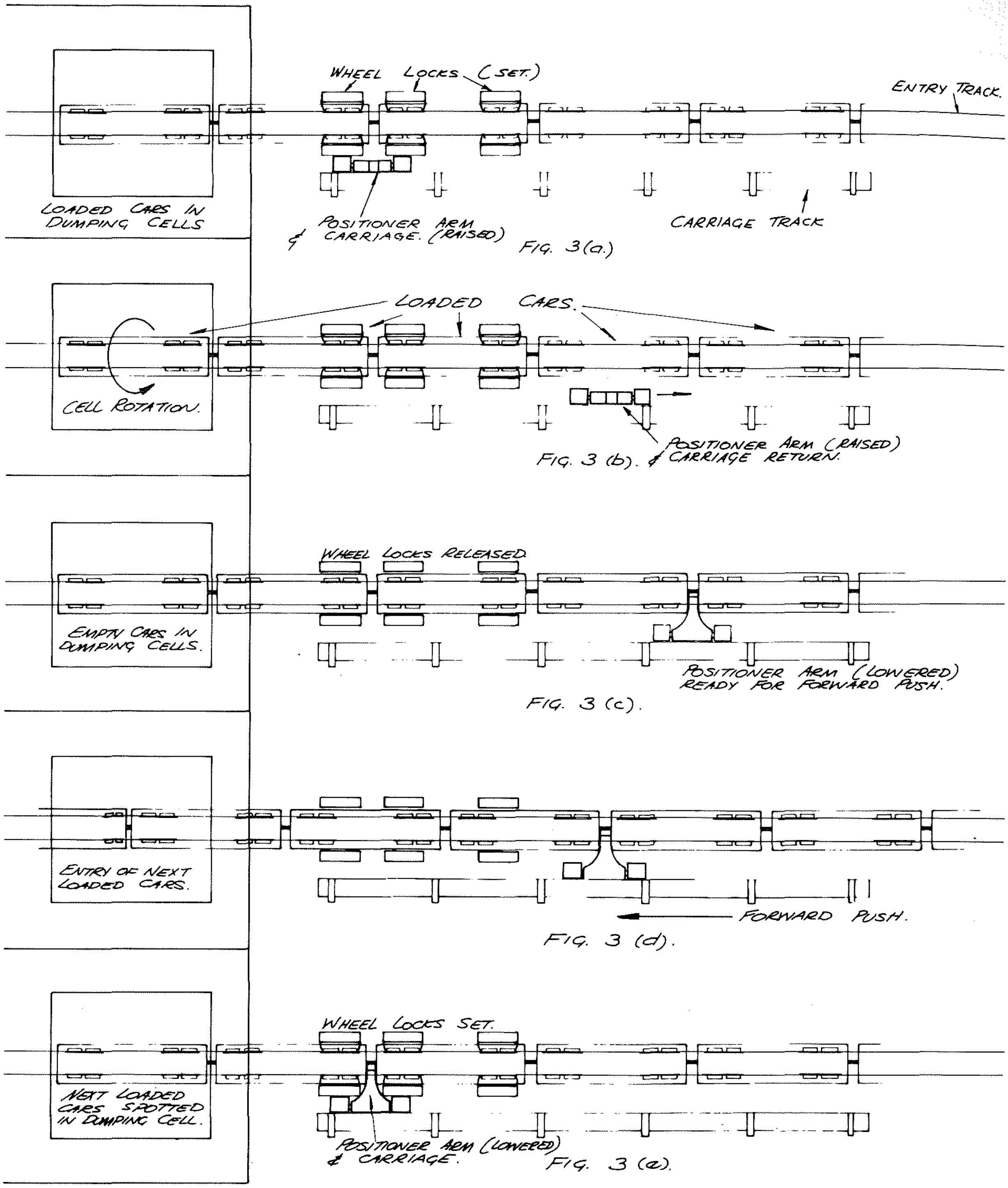


Figure 3(a),(b),(c),(d) & (e) Rotary dumper cycle

5 (cont.)

From (A) to (B) there is a "creep" section during which the arm moves forward slowly to "seat" against the leading car's pusher pad. This takes place to ensure that the train is held by the arm when the wheel locks are released.

(B) to (C) is the acceleration of the arm, (C) to (D) the plateau speed, and then (D) to (E) the initial deceleration of the arm. (E) to (F) is a creep section designed to spot the cars correctly, and (F) to (G) is the final deceleration phase which halts the train. Any minor mis-spotting of the train is then corrected by the wheel locks.

Normally, the initial condition of the front of the train is bunched. Drag braking is not applied till the train is spotted correctly, so the remainder of the train is usually slightly bunched also.

Now, if we consider the ramp up (acceleration) phase of the velocity profile (B to C), it is apparent that as the arm accelerates it will do likewise to a small block of cars. Drawgear slack and draft gear travel cause cars to be picked up in turn as the arm accelerates. About 10 to 15 cars will be moving by the end of the ramp up phase, in a stretched condition.

From (C) to (D) the positioner, travelling at plateau velocity, "jerk" accelerates the rest of the train serially. The coupler forces resulting

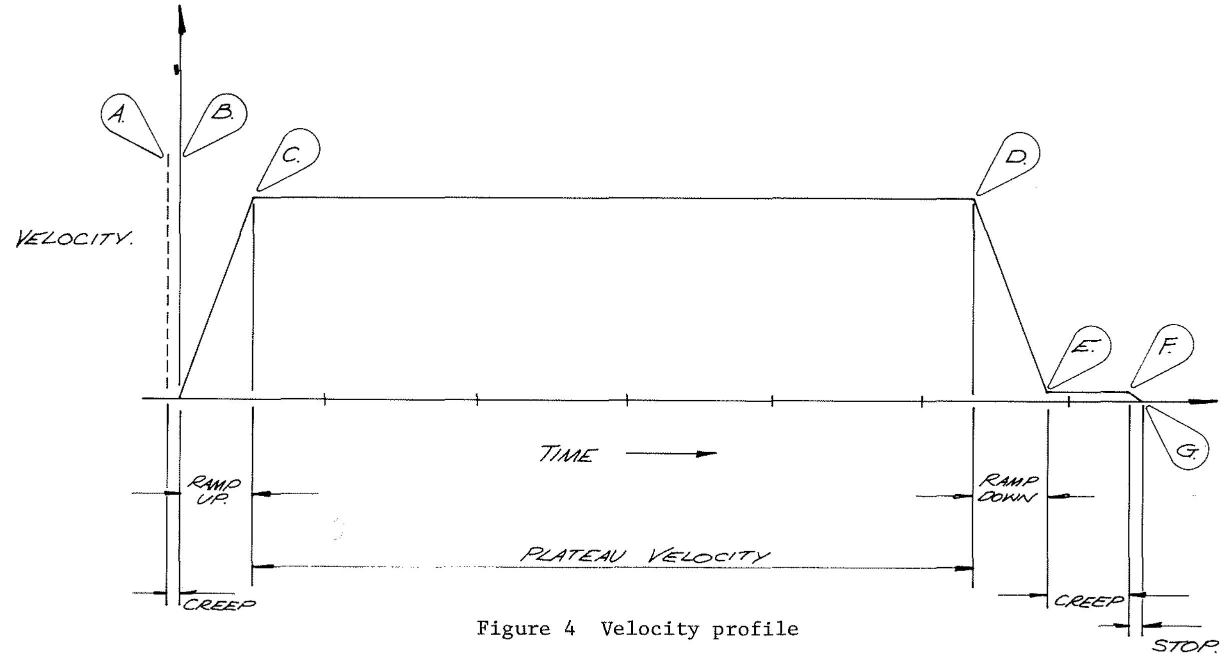


Figure 4 Velocity profile

5 (cont.)

from this action are the highest produced during the passage of the extension wave along the train. At some point (C) and (D), the complete train will have been accelerated to plateau velocity, and the release of energy stored in draft gears during acceleration causes the extension wave to become a compression wave. This travels back towards the dumper, attenuated gradually till the train reaches equilibrium at plateau velocity.

The ramp-down from (D) to (E) produced the expected run-in at the arm, which travels towards the rear of the train as a compression wave. Drag braking limits its travel, as the rear of the train is prevented from running in completely. The creep section (E) to (F) produces very little train action, as does the final deceleration (F) to (G).

This is a very brief and simplified description of the complex behaviour of a train being indexed. Computer aided solution of the mathematical model provides the most complete picture.

6 END OF TRAIN DRAG BRAKING

To assist in control of the longitudinal dynamics of our long unit trains during dumping, we use a "compressor car" set to retard the motion of the end of the train. This restricts the extent of the run-in occuring at the completion of the push forward. We found it necessary to develop drag braking early in the operation of No. 1 Dumper. Our efforts to optimise dumping rates led to excessive run-in forces, causing increased ore car drawgear and draft gear damage. Problems with ore cars pushed over set wheel locks and damage to cars in cells during rotation were also experienced.

The "compressor car" sets each consist of a converted ore car carrying an air compressor and regulating equipment, and another car ballasted to act as an index car. The compressor keeps charged the train brake line of the train being dumped, and supplies air at a pre-determined pressure to the car set brake cylinders independently. The index car is required for two reasons. Firstly, the necessary retarding force can only be supplied by two sets of car brakes. Secondly, it allows the last loaded car in the train to be dumped, as the indexing arm only pushes to a distance one car length from the dumper.

By setting the drag brake pressure to a value which allows the rear portion of the train to just enter the run-in phase at the completion of the push forward, compressive forces are minimised. The force necessary to 'lift' the train at the start of the next push is also minimised by ensuring that the majority of the train is bunched and not stretched.

As the train length on the 'upstream' side of the dumper is reduced, the end of train drag braking must be reduced. This is done in step fashion by using one reduction and a final release at pre-determined points. These points relate to the number of cars left to dump, and initially were found by trial and error using applied positioner force and train noise as criteria.

7 PARAMETERS INFLUENCING TRAIN BEHAVIOUR DURING INDEXING

The behaviour of the train is affected in varying degrees by many parameters:-

7.1 Ore Cars

7.1.1 Drawgear free travel (slack)

7.1.2 Draft gear travel

7.1.3 Car weight

7.1.4 Car rolling resistance

7.2 Positioner

7.2.1 Velocity profile

7.2.2 Maximum push force

7.3 Entry Track Gradient

7.4 Drag Braking

7.4.1 Retarding force

7.4.2 Reduction and release timing

7.5 Train Length

7 (cont.)

It is impossible here to describe in detail the effects all these have on the behaviour of the train. It is possible to briefly discuss the effects of the most important.

7.6 Ore Car Drawgear Free Travel (Slack)

Excessive drawgear slack between cars leads to high impact loads. This is due to the absence of control by draft gear action of inter-car relative velocities. Higher impact loads mean higher levels of fatigue as well as increased uncontrolled train action.

Since the maximum indexing velocity is usually below 2 kmh^{-1}, the influence of slack on train behaviour during indexing is far less than on main track. (A programme aimed at minimising drawgear slack has been initiated and will improve track operation.) In the future, we may run longer trains (up to 280 cars) and this would increase the effect of slack during indexing.

7.7 Draft Gear Travel

Long travel draft gears installed in significant numbers in our fleet would lead to another undesirable effect. This is the change in train length occurring during the acceleration and deceleration phases of indexing. Exaggerating, we could have a situation where, although the front of the train has been spotted and is stationary, the rear is only just accelerating. Clearly the motion produced by the speed of the extension wave must be a trade off between peak coupler forces and satisfactory train indexing time.

7.8 Positioner Velocity Profile - Plateau Velocity

The most important part of the velocity profile is the magnitude of the plateau velocity. Since the positioner acceleration ramp only accelerates the first ten or so cars (serially) before plateau speed, cars behind this block will be 'jerked' to plateau speed. The higher this speed, the higher the peak coupler forces.

7.9 Positioner - Maximum Push Force

Connected to the magnitude of the plateau velocity is the maximum push force the positioner is capable of. Should the initial condition of the train be stretched, the arm will need to accelerate a very large block of cars in 'jerk' fashion (after it has accelerated the first block of cars in its acceleration ramp phase). This is instead of 'jerk' accelerating cars in serial fashion as is normal with a bunched train.

Therefore, if electrical settings allow push forces above that normally required, no indication of malfunctions in drag braking (causing a stretched condition) will be evident. We (most importantly) will inflict far more fatigue damage than is necessary or desirable.

7.10 Entry Track Gradient

Both car dumpers have entry tracks which incorporate a slight downgrade. This is intended to compensate partially for car rolling resistance. The optimum gradient is dependent on drawgear slack, positioner plateau speed and ramp down (deceleration), and ore car rolling resistance. Obviously, entry track gradient is not easily altered from that used at the time of construction.

7.11 Drag Braking

Drag braking is perhaps the most important influence on train behaviour, and has consequently gained most attention in our work.

The degree of retardation applied (brake cylinder pressure) directly controls the extent of run in at the completion of the push forward, and hence the condition of the train at the start of each push. A slightly bunched state is the most desirable, but with a minimum of stored compressive energy. As mentioned previously, a stretched condition (caused by excessive retardation) is most unsatisfactory. Fig. 5 shows the plot of the coupler force adjacent the positioner arm during an uncontrolled run-in (produced by complete drag brake failure). The mis-spot which occurs can result in loaded cars jumping set wheel locks.

7.12 Drag Braking - Reduction and Release Timing

As well as the magnitude of retardation, the time at which any decrease is made has an important influence on train behaviour. Too much or too little can result in an unsatisfactory starting condition, and too early or too late a similar problem.

8 SIMULATION

The computer models used to assist reaearch into longitudinal train dynamics have been described adequately by others (Booth, Blair & Steven 1978, Fitzgerald, Kerr, Thompson 1978, West, Williams & Kerr 1978). Applying computer modelling to the indexing part of the dumping cycle has been accomplished by first getting realistic input data. By experience and observation, suitable changes in the parameters described above were then made, aimed at optimising the cycle.

To date, we have used the computer model to simulate the effects of using a lower drag braking pressure, using modified positioner acceleration ramps, lower positioner plateau velocities, and modified entry track gradients. An example of the output produced by simulation is shown in Fig. 6.

Input for the model must be realistic and accurate, if we are to have faith in its output. Field testing is the only correct way to achieve this.

9 FIELD TESTING

9.1 Input Data Acquisition

Since early 1975, testing instrumented trains in both our rotary dumpers has yielded valuable data. More than 25 trains have been monitored as they were indexed for dumping in Dumpers 1 & 2. In a production oriented environment such as the Nelson Point site at Port Hedland, this is an appreciably large task, because test trains must fit into a tight schedule.

Using rakes of up to ten instrumented cars, which are then cut into normal length trains, tests have been carried out by recording various signals from hardwired instrumentation on the test ore cars. An air conditioned instrumentation van is driven alongside the entry track as the train is indexed, so tape recorders in it can be used to continuously monitor all signals.

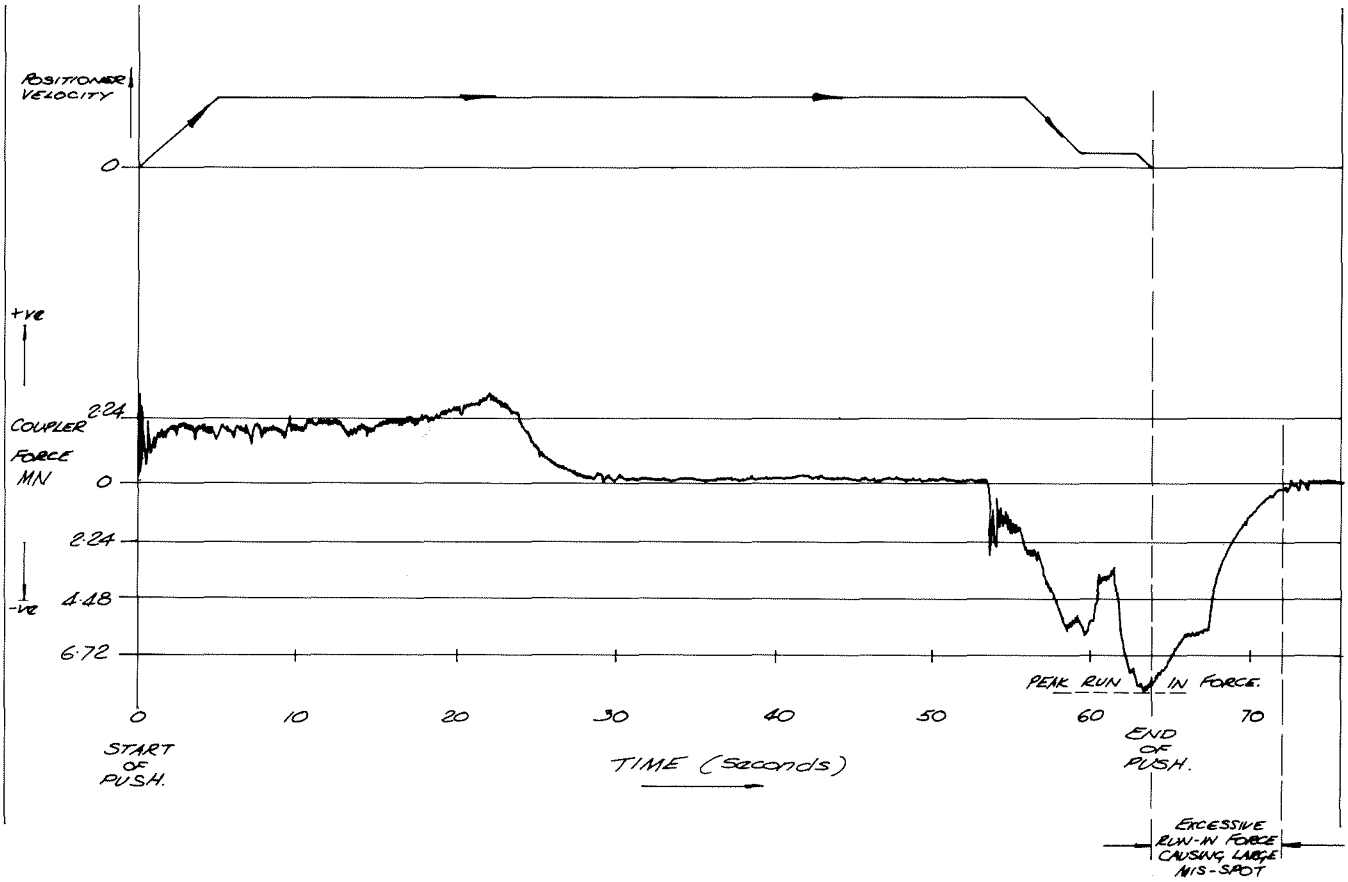


Figure 5 Drag brake malfunction allowing very high compressive forces (coupler force adjacent positioner arm)

9.1 (cont.)

The signals monitored include coupler force, intercar displacement, train brake pressure, positioner drive motor control relay status, positioner drive motor voltage and current, positioner haulage drum velocity (positioner velocity) and arm movement relative to positioner carriage. Drag brake pressure is recorded manually.

Using the records of coupler force and displacement, we have constructed realistic models of draft gears. Our computer simulation must use draft gears as they are known to perform in our service. A combination of positioner velocity, car displacement and coupler force has been used to gain realistic values of ore car rolling friction. Special tests using a purpose built instrumented coupler gave us the relationship between indicated drag braking pressure and retarding force for each of three car sets in use.

9.2 Simulation Validation

The simulations mentioned above would not have been possible had the input data been unavailable. Similarly, the predictions of the simulation would be of no use if validation of the computer model had not been done. Testing has permitted this, as well as checking the validity of certain simulation runs.

For example, our selection of the optimum drag braking pressure (to minimise fatigue damage, yet optimise train behaviour and production) had to be checked in practise. This has been done and shown to continue to be the correct choice in subsequent testing.

In another area, we are currently using the model to arrive at a plateau speed that minimises fatigue damage, but maintains acceptable production rates. Our testing enabled us to construct a quantitative relationship between plateau velocity and peak coupler forces. When we are sure of the final plateau velocity we want, a check test will be run. While this one test must be done, we have by-passed the need for repetitive trial and error testing necessary without our model.

10 MEASURABLE BENEFITS TO THE COMPANY'S INDEXING AND DUMPING OPERATIONS

It is important to remember computer simulations using mathematical models require many software man hours, testing man hours and much computer time. Bearing this in mind when making statements concerning the convenience of use and value of computer simulations, ensures that the benefits detailed below are held in proper perspective.

10.1 Fine Tuning of the Indexing Cycle

While it has been said that the designers of both the Company's dumpers used simulation and experience to produce their final cycle, we have extended this early work as the benefits of field testing and specialised modelling of our indexing system were not available to them.

We have been able to use this knowledge to modify the cycle (positioner plateau velocity, drag braking, etc.), which will result in increased life of positioning equipment and ore car drawgear and

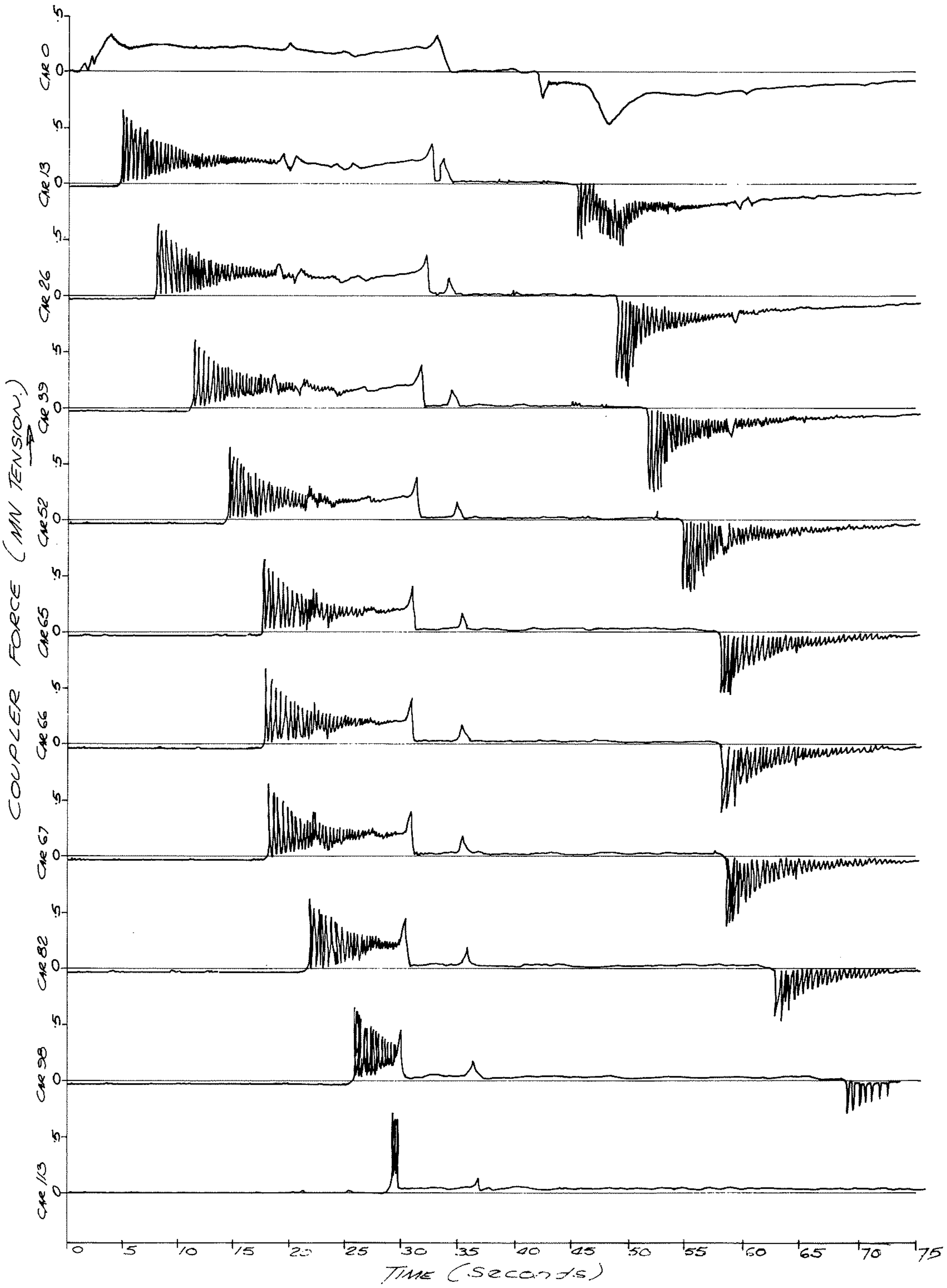


Figure 6 Coupler forces for various cars as predicted by simulation

10.1 (cont.)

draft gear.

10.2 Minimising Production Stoppages

A broken ore car knuckle (causing parting of a train being indexed) can result in a dumping delay of up to 45 minutes. At a rate of 10,500 TPH, it is obvious a costly loss in production can occur. By ensuring the minimum damage is inflicted on ore car drawgear (particularly coupler knuckles), the possibility of train partings during indexing is minimised. The first two or three months of operation of our No. 2 Dumper saw increased coupler forces quickly fatigue weak knuckles, resulting in frequent production stoppages. Double insurance against this problem is provided by lowering the plateau speed, as fatigue damage is reduced and the magnitude of peak coupler forces (which break knuckles) decreased.

10.3 Reduction of Fatigue Damage to Ore Cars

The maintenance of drawgear and draft gears in the Company's fleet of ore cars has been a high cost area. Our field testing has shown the fatigue damage inflicted on cars in a train during the Port to Mine return journey is at least equalled by the damage inflicted during indexing it for dumping. Our actions to reduce this damage by modifying parts of the indexing cycle will

10.3 (cont.)

certainly reduce costs in the future.

11 BENEFITS WHICH ARE NOT COST EVIDENT

Certain intangible benefits result from our research. Not the least is the expertise we are generating in the computer modelling field, instrumented train testing, and data acquisition and processing.

During testing in the dumper, the team meets the personnel responsible for maintaining and operating both rotary car dumpers. Often they have been able to increase the knowledge these people have of the intricacies of the indexing process, and as often, the reverse takes place.

Our testing of compressor cars led to recommendations on pressure regulation equipment concerning pressure setting ease and readability.

Finally, through this work it has been possible to highlight to all personnel the importance of correct operation of positioning and dumping installations. Figures relating production rates to ore car life are powerful reasons for the existence of stringent operating procedures.

12 FUTURE USE OF THE COMPUTER MODEL

This work requires regular review, as the model will require regular updating of input data. To retain validity and reliability, we must continue to test the model's predictions.

We plan a detailed study of drag braking in No. 1 Dumper (which operates at a plateau velocity 20% lower than No. 2 Dumper). When production requirements demand the running of longer trains, the model will aid us in planning indexing procedures.

The proposed automatic performance and condition checking of draft gears at the positioner arm will demand the model's assistance in the feasibility study stage. Operation of such a device will probably also use some facilities of the model.

Other areas of work related to this include draft gear evaluation and longitudinal dynamics of trains on track, and the information gained from use of the simulation in indexing aids model usage in these other areas.

13 CONCLUSIONS

13.1 A powerful, proven tool has been developed in the computer model simulating the behaviour of long unit trains during indexing for dumping.

13.2 Increased life of ore car drawgear and draft gear, and indexing equipment, while maintaining required production levels can be obtained through the use of the model.

13.3 It has finely tuned the indexing cycle initially produced by the designer, by using the model and input data gained from field testing. It now better matches the optimum arrangement.

13.4 Any changes to the indexing cycle found necessary in the future (due to increased production requirements, long trains, etc.) can be investigated quickly, and recommendations produced reflecting the effects on ore car and positioning equipment life.

13.5 The need for the development of the model (to explore and improve train handling during indexing) has generated faster and more efficient simulation techniques. Optimisation of other cycles and systems will benefit.

13.6 A suitable method is available to obtain the best system design for a unit train (or other) dumping operation.

14 REFERENCES

BOOTH, P.F., BLAIR, J.R. and STEVEN, D.H. (1978). A computer aided study of the longitudinal dynamics of long ore trains. Proc. Heavy Haul Railways Conference, Perth, 1978.

FITZGERALD, B.W., THOMPSON, I.R. and KERR, A.J. (1978). Application of computer simulation to railroads. Proc. Heavy Haul Railways Conference, Perth, 1978.

WEST, L.E., WILLIAMS, C.G. and KERR, A.J. (1978). A draft gear evaluation project applied to heavy unit train operations. Proc. Heavy Haul Railways Conference, Perth, 1978.