Stope-face conveyors for gold mines

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SYNOPSIS

The results of trials with three stope-face cleaning systems are described. Two of these systems were based on armoured chain conveyors, and the third on a reciprocating-flight conveyor. The operational elements of each system are discussed with reference to their effectiveness, and many problems are highlighted. It is concluded that the reciprocating-flight conveyor is superior, and has the potential for being developed into a system yielding a labour productivity of more than 30 m² per worker per month and a face advance of 15 m per month working one shift a day.

SAMEVATTING

Die resultate van proewe met drie afbouplek-frontskoonmaakstelsels word beskryf. Twee van hierdie stelsels was op gepantserde kettingvervoerbande gebaseer en die derde op 'n heen-en-weerbewegende vlugvervoerband. Die bedryfselemente van elke stelsel word bespreek met verwysing na hul doeltreffendheid en talle probleme word uitgelig. Die gevolgtrekking word gemaak dat die heen-en-weerbewegende vlugvervoerband die beste is en ontwikkel kan word tot 'n stelsel wat 'n arbeidsproduktiwiteit van meer as 30 m² per werker per maand en 'n frontvooruitdrywing van 15 m per maand sal gee as daar een skof per dag gewerk word.

Introduction

The Chamber of Mines, in collaboration with manufacturers of mining machinery, has been engaged in developing a stope-face cleaning system for gold mines. The system comprises a rugged face conveyor to which is attached a blast barricade, a means of loading the conveyor, a means of moving the conveyor, and hydraulic roof supports.

In this system, a conveyor, typically 40 m long, is positioned at a small distance from the face and parallel to it. The blast barricade is arranged behind the conveyor so that the blasted rock is confined to the space above and in front of the conveyor. The rock on the conveyor is removed from the stope face by the conveyor and is discharged into a scraper gully. The rock lying in front of the conveyor is loaded onto the conveyor by operation of the loading mechanism and simultaneous advancing of the conveyor until it reaches the face. Once the face has been cleaned, the face is drilled, the roof support is advanced, and the barricade is re-erected in readiness for the next blast. The system is intended to complete a full mining cycle in a single shift and to achieve a substantially improved labour productivity together with a rapid rate of face advance.

These investigations into conveyors started in 1966. Robust, armoured-chain conveyors of the type used in collieries were considered most adaptable to gold-mining conditions. In a series of experiments in collaboration with Westfalia Lünen Gewerkschafteisenhütte in 1970, it was shown that there was a potential for a substantially improved labour productivity and rate of mining, but that the life of the armoured chain conveyor would be short because of the extremely high rate of wear in the conveyance of quartzite. In a trial at the Blyvooruitzicht Gold Mining Company, a labour productivity of 27 m² per worker per month and a rate of face advance of 8,5 m per month were achieved by use of a two-shift cycle with blasting on alternate days. The wear life of the conveyor was estimated to be 27 000 t. It was concluded that the system could be improved to give a productivity in excess of 30 m² per worker per month and a rate of face advance of 15 m per month with single-shift mining, and that the wear life could be improved to 36 000 t.

Spurred by the labour crisis in 1974, work was resumed, and new, complete face-cleaning systems were commissioned from Westfalia Lünen Gewerkschafteisenhütte and Dowty Meco Limited. Co-incidentally, during 1974, a completely new concept for a face conveyor was evolved in collaboration with Anderson Mavor (S.A.) (Pty) Limited. This new reciprocating-flight conveyor appeared to have many advantages over armoured chain conveyors, and a complete mining system was therefore also commissioned from Anderson Mavor. Consequently, during 1975 and 1976, trials were conducted simultaneously with the three different systems of face cleaning.

The development and design of the three face-cleaning systems have already been described[1, 2]. The purpose of this paper is to report on the results of the trials. The intention here is not to give specific technical details but rather to give the general conclusions and to draw attention to the problems that were identified during the course of the trials and that were not discussed in the previous papers.

The Westfalia Lünen System

The Westfalia Lünen system (Fig. 1) consisted of a 40 m long armoured chain conveyor with a loading plough attached to the face side of the conveyor. The design was based on the experience gained in the earlier experiments with a Westfalia Lünen conveyor, and particular attention was given to the components that had suffered severe wear.

The conveyor and loading plough were driven by hydraulic motors. The speed of the conveyor chain was 0,1 m/s, and of the plough 0,2 m/s. The driving force applied to the conveyor chains was 400 kN nominally, and that applied to the plough chain was 250 kN. The barricade consisted of a spring-mounted steel spill-plate hinged to the conveyor in such a way that it could

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be folded back to facilitate drilling. A steel grating was attached to the spill-plate. The grating was covered with conveyor belting and so arranged that it could slide upwards to seal against the hangingwall. The slidable portion of the barricade was meant to be lifted and held in place by the hydraulic roof-support props. The conveyor and plough were advanced towards the face by 10 pusher-rams, each capable of generating a force of 60 kN each and being staked against a single hydraulic prop.

The face-cleaning system was tested in a stope in the Ventersdorp Contact Reef at the Elsburg Gold Mining Company Limited, where the conveyor was used in an up-dip mining situation operating in the strike direction and discharging into a dip-gully. The reef dipped at 10° and, as a result, the conveyor was tilted backwards at 10°. The reef and the rock adjoining the reef were very hard and highly quartzitic. The lava overlying the narrow stratum of quartzite above the reef formed the hangingwall, but did not cause any particularly serious problems. The conveyor was advanced right up to the face with the intention that the plough would scrape the face and so reduce the need for barring, and was left in that position during drilling and blasting. The face advance per blast was nominally 0,6 m, and the stoping width was nominally 1,4 m.

The objectives of the trial were to evaluate the improvements that had been made to the conveyor, plough, and barricade, particularly with regard to wear, and to investigate the potential for improving labour productivity. However, immediately after the commencement of the trial, it was apparent that the driving force was inadequate to start the conveyor under full load, and more powerful motors with better static torque characteristics were fitted. These motors generated a driving force of 580 kN and enabled the conveyor to start under most circumstances. The conveyor and plough operated satisfactorily until 2500 t had been conveyed, at which stage chain failures started to occur and became progressively more frequent. These failures hampered mining operations very severely. In addition, the conveyor's bulk made drilling extremely difficult. These problems prevented systematic mining and precluded a meaningful assessment of labour productivity. The trial was terminated when sufficient results had been obtained to make a technical assessment of the performance of the equipment.

Conveyor

The initial start-up problem with the conveyor was unexpected since this problem had not occurred at all with the less powerful equipment used in the earlier trials. The problem was attributed to a combination of three factors that differed from those in the earlier trials: the conveyor was much more heavily laden because it was much closer to the face during blasting, the stoping width was greater, and it was tilted backwards in the direction of the dip.

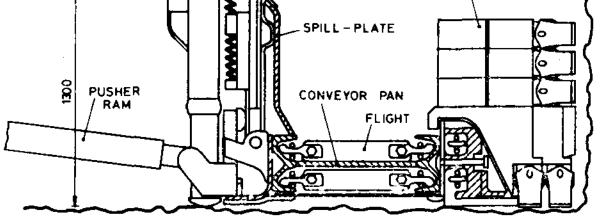

Fig. 1—The Westfalia-Lünen system in position before blasting

From the earlier trials it had been deduced that rock fragments trapped between the conveyor pans and the chain and flights were primarily responsible for the chain's resistance to movement. Thus, it was believed that the mass of the rock on the conveyor and the dip were not important factors in determining the force necessary to drive the chain.

From observations in this trial it is believed that the predominant factor in determining the resistance to initial start-up arises from the necessity to generate a flow boundary between the moving rock on the conveyor and the stationary rock in front of the conveyor when there is a deep pile of rock on and in front of the conveyor. The creation of a flow boundary requires that all the large fragments lying across the boundary should be re-orientated. Because the larger fragments in the rock pile tend to key all the fragments together, the re-orientation of the large fragments that lie across the flow boundary disturbs the whole rock pile and meets with considerable resistance.

The existence of a well-defined flow boundary was obvious once the conveyor had been started. The conveyor could be restarted with a force no greater than that necessary to keep it moving. The big fragments that were forced upwards to the top of the pile during the formation of the flow boundary tended to catch and roll back wherever they touched the hangingwall, joints in the spill-plates, or large fragments in the stationary rock pile. In the earlier trials, the formation of a flow boundary was less significant because the rock pile was relatively much shallower.

Conveying horizontally in the strike direction without the assistance of gravity may have added to the initial starting difficulties, but this must have been a second-order effect since no difficulty was encountered when the conveyor was restarted. Operating the conveyor horizontally increased the extent to which fine fragments were carried into the bottom race of the conveyor. Force measurements on the conveyor showed that the presence of only a small quantity of fine fragments in the bottom race could drastically reduce the force available to move the rock on top of the conveyor. Whenever fines were allowed to accumulate in the bottom race, starting difficulties were encountered.

The proximity of the conveyor to the face, together with the high stoping width, probably added to the initial starting difficulties because rocks could be blasted right into the top backside chain race. In addition, the backward inclination of the conveyor increased the tendency for fragments to be trapped in the top and bottom backside chain races. These factors caused not only increased resistance to movement of the chain, but also an uneven force distribution between the backside and faceside chains. Nearly all the chain failures occurred in the backside chain. The high force needed for the initial starting of the conveyor simply overloaded the chains. The minimum breaking load specified for the 22 mm class C chain is 610 kN. Measurements at the delivery end of the conveyor proved that the motors could generate a driving force of 580 kN. Thus, the backside chain, having greater resistance to movement than the faceside chain, could have been subjected to almost the full driving force at times. Different mechanisms of chain failure were identified. The first failures were attributed to bending fatigue of the vertical links, the cracks being initiated at corrosion pits on the inside surface of the shank of the link. The bending of the links when passing through the sprockets was aggravated by the hard quartzitic fragments that were trapped between the chain and the sprockets. The later failures were attributed to strain-age embrittlement at the crowns of the links and cracking propagated by fatigue loading. Undoubtedly, correct lubrication of the chain could improve the chain life by preventing corrosion and by mitigating the severity of inter-link rubbing, thereby reducing work hardening.

Apart from the initial starting difficulties and the later chain failures, the conveyor worked very well. The conveying rate was very impressive; the conveyor would discharge 50 t within 20 to 30 minutes, which is equivalent to a conveying rate of about 100 t/h.

Loading

The loading plough worked very well and was capable of loading at a rate of up to 150 t/h provided the rock pile in front of the conveyor was sufficiently deep. In addition, it was fairly effective in barring the face. About 10 per cent of the broken rock was not picked up by the plough and passed under the conveyor as it was advanced. It is felt that this inability to pick up the rock left behind was mainly due to other deficiencies in the system. First, the footwall was extremely rough owing to the exceedingly difficult drilling conditions. Second, the design of the pan joints was such that the conveyor and plough guide tended to straighten out in a vertical direction when the plough or conveyor chains were taut, with the result that the equipment tended to bridge over troughs in the footwall and the plough could not keep in contact with the footwall. The 250 kN driving force was sufficient to get the plough past virtually all obstructions. Few chain failures occurred here, and those that did occurred in the slack chain adjacent to the plough. The fractured links showed evidence of strain-age embrittlement, and it is thought that the slack chain was subjected to inertial overloads as the plough suddenly moved past an obstruction.

Barricades

The spill-plate portion of the barricade, which consisted of the spring-mounted steel plate, was very robust and effective. However, the screen portion, which consisted of a steel grating covered with conveyor belting, proved quite inadequate. The conveyor-belting laminations separated under the impact of the blast, and the steel grating became distorted. Consequently, the screen would not slide in and out of its guides as had been intended. Furthermore, the range of movement was insufficient for the variations in the stoping width. The screen could not be securely supported where the width was great, and was often knocked out by the blast.

Since the face was being advanced up-dip and the barricade was 1,7 m from the face, the rock blasted against the barricade often piled up as high as the hangingwall. A considerable amount of rock, about 10 per cent of that blasted, escaped past the distorted and ill-fitting screens.

A further disadvantage of the barricade arrangement was that it imposed a rigid sequence of operations on the mining cycle. The screens could be lowered only after the conveyor had discharged its initial load, and they had to be lowered before the conveyor could be advanced. The entire barricade had to be tilted backwards to permit drilling, and the spill-plate could not be re-erected until drilling was complete. The support could be advanced only after the spill-plate had been erected, and the screen could not be set against the hangingwall until the support had been moved.

Advancing

The pusher-rams provided sufficient force to advance the body of the conveyor, but additional rams had to be provided to assist with moving the very large drive ends. The rams were manned individually, and co-ordinating the operators presented problems. The props for staking the pusher-rams were sometimes pushed out by the rams. This severely disrupted the advancing process, but was overcome by providing a continuous pressure supply to each staker-prop during the advance.

The simple advancing arrangement had not been designed to pull the conveyor back from the face. Had this been done, it is very likely that the problems with starting and drilling would not have been so severe.

There was almost no tendency for the conveyor to move lengthways, and the little movement that did occur could be controlled by setting the pusher-rams at a slight angle to the conveyor. No anchor station had been provided since no particular problem was expected with the conveyor operating horizontally.

Drilling

Drilling was done by hand. It had been visualized that, in the relatively wide stoping width, the drill operators could sit on the conveyor or on the spill-plate after it had been hinged back. However, drilling proved to be extremely difficult. The problem stemmed from the inability to drill the bottom holes in the proper direction because of the height of the conveyor and plough guide-rail and their proximity to the face. This resulted in a very rough footwall. The roughness of the footwall compounded the problem since the conveyor sat on protrusions and the plough left rock behind. Thus, there was less space above the conveyor than had been visualized, which proved to be most uncomfortable and awkward for the operators. Also, there was no suitable place to sprag the thrust leg. As a result, drilling was very slow and inaccurate.

Attempts were made to use drill-rigs to overcome the inaccuracy of drilling, but it was still not possible to drill the bottom holes in the correct direction.

Wear

During the course of this trial, 5700 t of rock was conveyed. The distribution of wear along the conveyor was similar to that in the earlier experiments in that the wear increased uniformly from the tail end to the discharge end. The distribution of wear across the conveyor, however, was quite different (Fig. 2). In the earlier trial at Blyvooruitzicht, the wear had been mainly on the deckplates of the pans, with deep grooves on the sides of the deckplates near the chains. The wear on the deckplates in this trial at Elsburg was very uniform across the deckplate width and greatly reduced. From this it would appear that the careful design of the flights, flight connectors, and deckplate material had been successful. However, in the Elsburg trial, the wear at the sides of the pans that form the chain races was much worse than in the Blyvooruitzicht trials. The material used in the sides of the pans was the same in both trials. The difference in wear is believed to be due to the highly corrosive environment at Elsburg. At Blyvooruitzicht it had been observed that corrosion greatly accelerated the abrasive wear. Analyses of the service water at Elsburg showed that it was predominantly an acid water, often attaining a pH value of 3,5, whilst the dissolved solids in the water created an extremely oxidizing and conductive medium compared with the water at Blyvooruitzicht. This was relatively neutral (6,5 pH) and had a lower content of dissolved solids. In addition, the conveyor at Elsburg was exposed to corrosion for a much longer time than that at Blyvooruitzicht. Undoubtedly, the acceleration of abrasion due to corrosion must have been worse at Elsburg.

The wear in the top chain races was much worse than in the bottom races, and that in the backside chain races was much worse than in the faceside races. Obviously, heavier wear occurred on the topside because there was more rock on the topside than on the bottomside, and heavier wear occurred on the backside than on the faceside because of the attitude of the conveyor. The actual rate of wear in the top backside of the pans would have limited the life of the pans to about 20 000t. However, if the quality of the mine service water were controlled, if different materials were used for the sides of the pans, and if the conveyor were not tilted backwards, the expected pan life of 36 000 t might be achieved.

Too small a quantity of rock was conveyed for the life of the other components of the system to be assessed.

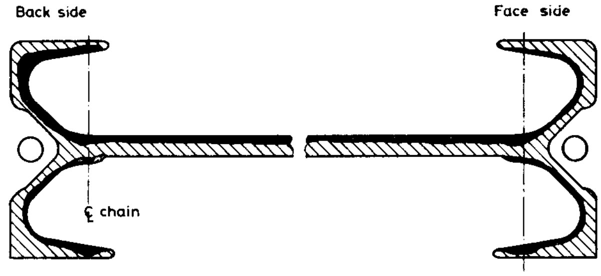

Fig. 2—The wear pattern on the Westfalia-Lünen pans, the position and extent of metal loss being shown by the solid shading

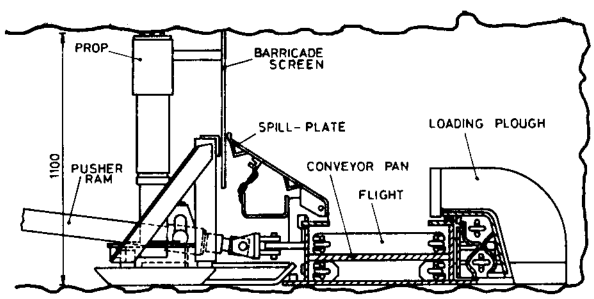

Fig. 3—The Dowty-Meco system in the pre-blast position before the introduction of the drill rigs

The Dowty Meco System

The Dowty Meco system (Fig. 3) comprised a custom-built armoured chain conveyor 40 m long, with a loading plough attached to the faceside of the conveyor, a blast barricade, and simple chocks incorporating hydraulic props and pusher-rams. The conveyor and plough were built to the same general specifications as the Westfalia Lünen conveyor and plough, namely, a conveyor-chain speed of 0,1 m/s, a plough speed of 0,2 m/s, driven by hydraulic motors with a conveyor-chain driving force of 400 kN and a plough-chain driving force of 200 kN. The barricade consisted of a spill-plate attached to the back of the conveyor and an 8 mm thick steel screen attached to the hydraulic props in the chocks behind the conveyor. The spill-plate was hinged forward over the conveyor to facilitate drilling. The hydraulic props in the chocks served as roof support, as support for the barricade screen, and for staking the pusher-rams. The pusher-rams were mounted in trunnions on the chocks and were used to push the conveyor forward while the props were set, and to pull the chocks and props forward when the props were released.

The rock-handling system was tested at the Vaal Reefs Exploration and Mining Company in a flat stope with a nominal width of 1 m. The rock surrounding the Vaal Reef was an argillaceous quartzite, fine fragments of which tended to be very sticky when wet.

It was intended initially in the trial that the mechanical components of the system should be developed, and subsequently that the system's performance with regard to mining rates, labour productivity, and wear should be evaluated. However, at the start of the trial, it was immediately apparent that the drives for both the plough and the conveyor did not generate the specified driving forces. After modifications had been made to correct this deficiency and other problems, the plough and conveyor functioned adequately. Drilling then emerged as a serious problem. Drill rigs were introduced, and it became necessary to pull the conveyor back from the face after cleaning to make space for drilling. Thereafter, numerous problems with the barricades, and advancing and chock-staking arrangements were identified. Circumstances prevailing at the mine did not permit time for further modifications, and the trial was stopped at that stage.

Conveyor

Following the modifications to the drives to give a true 400 kN driving force, it was found that the conveyor would start satisfactorily but would run for only a few metres and would then stall. The stalling was due to fragments of rock sticking to the chains and flights and becoming entrapped in the drive sprockets. The application of strong water sprays to wash fragments from the chains and alterations to the shape of the chain race helped overcome this problem. However, it was found that large quantities of fragments still adhered to the back of the flights and would be carried round the sprocket into the bottom chain race. As the fragments accumulated in the bottom race, they would offer steadily increasing resistance to the movement of the chains. Alterations to the shape of the back of the flights greatly reduced this problem, but precautions to clear the bottom chain race before each blast were always necessary. The problems of fragments being carried into the drive sprockets and round into the bottom chain race were much greater in this trial, and were undoubtedly aggravated by the sticky nature of the argillaceous quartzite.

A phenomenon of great importance to conveyor design was observed in this trial: after initial start-up of the conveyor, the force required to drive the chain increased steadily as the chain moved; the force continued to increase until the chain had travelled about half the length of the conveyor, when it decreased rapidly as the chain moved further. This force increased to almost 400 kN, which was the limit of the driving force, despite the fact that the load on the conveyor decreased as the chain moved. It is thought that this phenomenon is caused by more and more fragments becoming entrapped between the chain flights and chain races as the chain moves, until a stage is reached where the proportion of chain that has been unloaded results in a net decrease in the force required to move the chain. This explanation is consistent with the observations in the early trials of the Westfalia Lünen conveyors, where it was found that entrapped fragments caused the chain tension to be distributed exponentially along a fully laden conveyor.

In the early stages of the experiment, when drilling was done by hand, it was frequently found that the rock pile occupied the whole of the stoping width above the conveyor, and the conveyor would not start because rocks were fouling the hanging.

After the introduction of drill rigs, and the consequent need to pull the conveyor back, this problem disappeared. After the modification, this conveyor functioned well provided that the bottom chain race was cleared regularly.

Loading

Many modifications had to be made to the shape and drive mechanism of the loading plough to make it function satisfactorily. Initially, the shape of the plough was such that it moved through the rock pile in front of the conveyor like a mole and had little loading effect. This problem was overcome by the provision of sharper leading edges with more acutely inclined surfaces, which moved the broken rock more positively onto the conveyor. Also, the plough did not quite reach down to the footwall so that it tended to climb over broken rock as the conveyor was advanced. The provision of sharp tines, which projected below the conveyor, solved this problem. The Dowty Meco conveyor suffered from the same design fault at the pan joints as the Westfalia Lünen conveyor in that they both tended to bridge over depressions in the footwall when the conveyor or plough chains were taut. This made it impossible for the ploughs to clean the bottom of depressions.

During the course of the modifications to the drive mechanism of the plough, it became apparent that a force of 200 kN was necessary to drive it through the rock pile and across projections in the footwall.

Drilling

In this trial, with the narrower stoping width, hand drilling was even more difficult than at Elsburg. In an attempt to improve this, a drill rig of the type developed by Vaal Reefs was fitted to the conveyor. The height of the conveyor led to problems in the drilling of the bottom holes where the conveyor was close to the face, and the conveyor had to be pulled back approximately 1 m to allow the rig to fit in. Despite this action, the height of the conveyor was such that it was difficult to drill holes that diverged sufficiently to maintain the stope width. It was concluded that this type of conveyor could not be used in stopes of less than 1,1 m and that rig drilling was a necessity.

Advancing

The chocks and advancing arrangement on the Dowty Meco system formed the biggest departure from previous experience, and many new problems were encountered. The chocks had very large bases with two widely spaced props acting on each base. This resulted in two serious problems. First, since the footwall was not perfectly flat, the base plates would tilt as the props were set, which made it difficult to control the position of the chock and frequently required re-setting of the props. Second, the large base resulted in a low staking stress at an indeterminate point. Thus, the chocks were pushed out easily when the pusher-rams were activated.

A chock was located behind each conveyor pan and connected to the pan by a trunnion-mounted pusher-ram. The pans were 1,5 m long; thus, there were 25 chocks and pusher-rams attached to the conveyor. Each pusher-ram had a stroke of 1 m and was capable of generating a force of 100 kN. The combined pusher-ram forces were more than adequate to move the conveyor and plough and did, in fact, cause a number of problems. For instance, the plough could be pushed so hard against the rock pile in front of the conveyor that it could not move, and, if one ram reached the limit of its stroke before the others, or if it were left in a locked neutral position, the force generated by the other rams would tear the attachment points of the locked ram apart.

The need to pull the conveyor back to permit drilling meant that the conveyor had to be pushed much further forward during the loading operation. With only a 1 m pusher-ram stroke available, it was necessary to interrupt the loading after the conveyor had been advanced by an amount equivalent to the face advance per blast, and then to move all the chocks forward to permit the loading plough to reach the face. This interruption could have been avoided had time permitted the modification of the pusher-rams to accept extension tubes to increase their stroke.

Control of the props during their advance was a serious problem. They tended to slew sideways and catch on neighbouring chocks while being advanced and could not always be positively located against the conveyor on the completion of the advance. To enable chocks to function successfully, it is important that a means be provided to guide the chock during its motion and to positively locate it against the conveyor.

The most troublesome problems with the chocks and advancing equipment were associated with the control valves and the hydraulic supply to the chocks and pusher-rams. The valves were inaccessible and not suitable for the gold-mining environment. The hoses were extremely vulnerable to damage. The 'block-push' control feature, although it did not function correctly, exhibited considerable potential for overcoming problems in co-ordinating the operation of all the pusher-rams.

An innovation that was extremely successful was a rubber supporting ring attached to the foot of each hydraulic prop and the base plate of the chock so that the ring held the prop erect when it was released. The props could then be reset with the minimum of manual effort.

Barricade

The barricade was resistant to blast damage and functioned adequately except that it was intolerant of variations in the stope width. If the stope width was too narrow and the conveyor was riding on a projection in the footwall, the spill-plate portion of the barricade could not be folded forward to permit drilling. If the stope width was too wide, the screen portion of the barricade would leave a gap above the spill plate.

Reciprocating-flight Conveyor System

The reciprocating-flight conveyor, developed in collaboration with Anderson-Mavor, was also 40 m long. The conveyor was loaded by simply being pushed into the rock pile. The single block-section conveyor chain was driven by hydraulic cylinders at each end of the conveyor, the cylinders being capable of generating a driving force of 500 kN in the chain. The stroke of the chain was 3 m, and it was driven at a rate of 35 seconds per cycle. The barricade consisted of high-strength steel plates 6 mm thick linked together with short

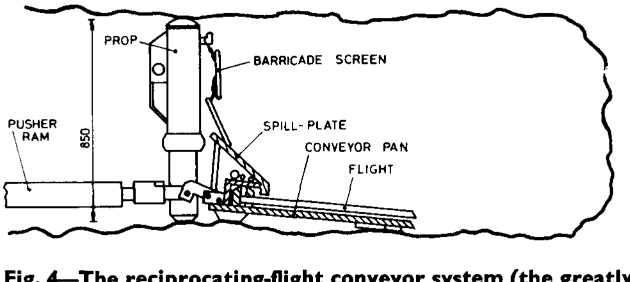

Fig. 4—The reciprocating-flight conveyor system (the greatly reduced bulk of equipment allows effective and accurate drilling)

chains so that they resembled a venetian blind. The plates were folded down in front of the conveyor spill-plate to permit advancing, and were manually lifted up before the blast and tied to the roof support props behind the conveyor. The conveyor was advanced by 13 pusher-rams each capable of generating a force of 140 kN. The pusher-rams thrust against two hydraulic props on a small base plate. The conveyor was pushed right against the face to load as much as possible of the rock and then pulled back for drilling.

This cleaning system (see Fig. 4) was tested at Grootvlei Proprietary Mines Limited in a stope on the Main Reef. The stoping width was nominally 1 m. The dip was about 3 ° so that no anchoring system was necessary. The footwall of the stope was formed by the contact between the Main Reef and the footwall shales, and was unusually smooth. The rock at the face was unfractured, glassy, and very hard, and required heavy charging to be broken effectively. This caused the broken rock to be finely fragmented, and to be thrown far from the face and piled high on top of the conveyor against the barricades. The depth of the rock pile at the back of the conveyor was typically 0,8 m, and that at the front edge was 0,4 m. Drilling was carried out by hand with a nominal advance of 0,75 m per blast.

The object of this trial was also to develop the equipment into a workable system and then to achieve a consistent blast every shift with good labour productivity. Excellent progress was made in the development, and eventually both these objects were realized. The trial continued until the available ground was mined out. The best result obtained was an advance of 13,1 m in a month (working a single shift a day) with a labour productivity of 27,7 m² per worker per month. Work studies indicated that, with further improvements to the system such as rig drilling, powered erection of the barricade, and more refined advancing and staking arrangements, a productivity in excess of 40 m² per worker per month could be attained.

Conveyor

The heavy load on the conveyor caused starting difficulties. As had been observed in the trial at Elsburg with the armoured chain conveyor, it was necessary to generate a flow boundary between the rock on the conveyor and the rock in front of the conveyor to enable the rock on the conveyor to move past the stationary rock (Fig. 5). However, it was found that a flow boundary could be generated relatively easily if the conveyor chain was caused to cycle with a very short stroke initially and then with a steadily increased length of stroke until a full stroke was achieved. The cycling of the conveyor with a short stroke caused some agitation of the rock pile and so enabled the flow boundary to be generated with relatively lower starting forces. After some experience had been gained, the full-stroke conveying situation could be reached within five to ten minutes of starting up.

At the start of the trial, the conveying rate of this conveyor was very much less than had been anticipated. After considerable experimentation with the height of flights and the spacing between flights, the correct conveying rate was achieved when the flights towards

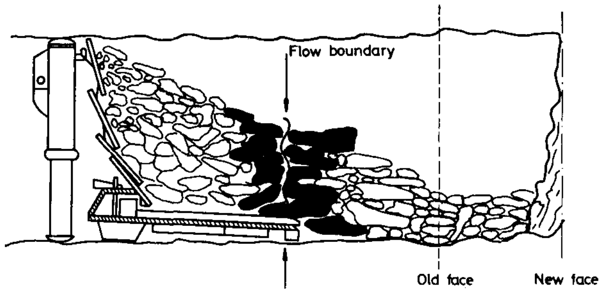

Fig. 5—The development of a flow boundary at the toe of the reciprocating-flight conveyor showing the alignment of the larger fragments of rock

the discharge end were higher and more closely spaced than those at the tail end. When the flight distribution is uniform, the conveyor has a tendency to choke under heavy load. The mechanism involved is obvious if one considers a flight distribution in which the more effective flights are at the tail end: clearly, the rock at the tail end would be conveyed more rapidly than at the delivery end, so eventually causing choking.

After the flight distribution had been modified, the initial heavy load on the conveyor was conveyed off at a rate of about 100 t per hour. The conveyor could not be kept as heavily laden during the advancing and loading process so that the average conveying rate, excluding delays, was about 60 t/h.

Loading

Loading the conveyor by pushing it into the rock pile was very effective provided that the front edge of the conveyor could be kept against the footwall at all times. To keep the front edge down while pushing forward, it was necessary to push the conveyor at a position above the plane of the pan deckplate, and, when pulling back, it was necessary to pull at a position below the plane of the pan deckplate. A special linkage between the pusher-ram and conveyor was designed to do this, and was effective in keeping the front edge of the conveyor on the footwall. However, the operators were reluctant to use the linkage correctly because the mass of the pusher-rams made changing the position of the pushers arduous.

Advancing

There was no difficulty at all in advancing over the smooth shale footwall except that the staker props were pushed out frequently. The shale tended to yield under the 400 kN load exerted by the two hydraulic props acting on the small baseplate. It was necessary to re-pressurize the props before and during the advance. An experiment with a rudimentary chock was carried out towards the end of the trial with encouraging results. In the experiment, two props, each with its own small base, were spaced widely apart behind the conveyor and connected to the pusher-ram at some distance behind the conveyor. This decreased the tendency of the footwall to yield, and divided the pusher-ram load evenly between the two staker props.

The pusher-rams had an inadequate stroke. Together with their extension tubes, they allowed an advance of 1,85 m. With the need to pull the conveyor back from the face to make space for drilling, it was found that the conveyor had to be advanced 2,05 m after a 0,75 m blast. Thus, it was necessary to advance and reset the staker props during the advance of the conveyor, which interrupted the cleaning cycle.

There was a slight tendency for the conveyor to migrate lengthways towards the discharge end because the advancing and loading of the conveyor always started at the tail end. The migration was controlled easily by mining the face slightly overhand so that the face formed an angle of about 85° with the gully.

Barricade

The venetian-blind barricade was very effective in containing the blast provided that it was located firmly against the hangingwall. Rubber strips attached to the edges of the topmost steel plates helped considerably in sealing off the blast. However, the barricade proved difficult to erect before the blast and equally difficult to lower afterwards. Several attempts were made to alleviate the problem by the use of portable jacks, but no completely effective method was found.

Drilling

No particular problems were encountered with the hand drilling provided the conveyor was pulled back sufficiently far from the face. To achieve a face advance of 0,75 m per blast, it was necessary to pull the conveyor back to provide at least 2,2 m between the spill plate of the conveyor and the face.

Wear

After some modifications, the conveyor proved reliable, and a good assessment could be made of the wear. It was found that the pattern of wear along the length of the conveyor conformed to that established previously during the tests with the armoured chain conveyors, in which the wear decreased linearly with distance from the discharge end. Heavy wear was confined to the region of the chain track (Fig. 6). This presented the possibility of using replaceable wear surfaces in the areas prone to wear. Simple modifications were made to the conveyor in which loosely-fitting replaceable wearplates were inserted under the chain. These proved highly successful. Judging from the wear that had occurred, and taking into consideration a redesigned chain track to increase the engagement between the front of the chain and the chain track, it was estimated that the life of the chain and replaceable wear parts could be in excess of

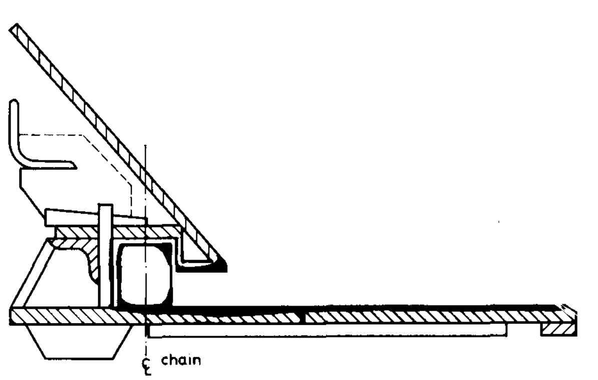

Fig. 6—The wear on the reciprocating-flight conveyor showing that the heavily worn areas are very localized

25 000 t conveyed. Also, judging from the wear pattern on the less wear-prone and irreplaceable parts of the pans, it was estimated that a life of more than 150 000 t could be achieved.

On the driving ends, the drive ropes were most susceptible to wear. As the failure of a drive rope causes a severe delay, this component needs to be replaced on a routine basis before failure occurs. It is estimated that replacement would be necessary after conveying 5000 t. Wear on the other drive components was slight, indicating that they must be capable of much more than the 15 500 t actually conveyed in the trial.

Conclusions

A face-cleaning system using a reciprocating-flight conveyor consistently achieved a complete mining cycle in a single shift. It was shown to have the potential to mine at a rate of 15 m per month working one shift a day, and to attain a labour productivity of more than 30 m^2 per worker per month. The systems using armoured chain conveyors could also achieve a complete mining cycle in a single shift, but this occurred very infrequently and never on a consistent day-to-day basis.

Both the reciprocating-flight conveyor and the armoured-chain conveyor have the capacity to move rock at a rate of 100 t/h, but the former has some important advantages over the latter. The profile of the reciprocating-flight conveyor permits it to be loaded more easily, and does not interfere with drilling to the same extent, thus permitting it to be used in narrower stopes. The wear life of the reciprocating-flight conveyor is much better, and the armoured chain conveyor is more prone to operational difficulties because fine fragments tend to accumulate in the bottom race. In addition, it is more sensitive to the entrapment of fragments, and much longer delays arise when failures occur.

Three principles of great importance to the design of rockhandling systems were identified.

(1) Because a deep pile of rock at the front edge of a conveyor causes an initial start-up problem, a flow boundary should be generated between the rock on the conveyor and that in front of the conveyor so that the former can move past the latter. The formation of the flow boundary is strongly influenced by the size distribution of the rock fragments. Because of its low profile, the reciprocating-flight conveyor is more prone to this problem, but it can be circumvented by starting with short strokes.

(2) The force required to move a chain in a constant direction increases gradually as the chain moves owing to the increasing incidence of fragment entrapment. A reciprocating motion avoids this.

(3) It is advantageous to have a graded flight distribution along the length of a conveyor to reduce the incidence of choking. This is easily accomplished on a reciprocating-flight conveyor.

Both methods of loading were effective on their respective conveyors. Because the effectiveness of loading depends on the roughness of the footwall, it is extremely important that the front edge of the conveyor should be kept close to the footwall. This requirement is more stringent for the reciprocating-flight conveyor, and an improved design of linkage to the pusher-rams is necessary to ensure that the front edge stays down. The loading plough has the advantage that it decreases the need for manual barring of the face, but it is a complicated and expensive addition to the system.

Drilling over the conveyors proved completely unsatisfactory. Pulling of the conveyor back complicates the mining cycle by the addition of an extra operation, requires the advancing equipment to be more elaborate, and increases the span from the face to the first line of support behind the conveyor. On the other hand, it allows the broken rock to be spread more widely, and it thus alleviates the initial start-up problem and the incidence of rocks jamming between the conveyor and hangingwall. The use of drilling rigs is highly desirable to minimize the retraction of the conveyor and to improve the drilling accuracy.

Advancing is the element in the rock-handling system that is most in need of further development. Chocks have considerable potential for solving, or at least mitigating, many of the advancing problems, and at the same time providing possible solutions to the erection of barricades and the moving of hydraulic props. However, chocks complicate the operation because they require guidance while being moved and a means of locating them against the conveyor on the completion of the move.

The co-ordination problem could probably be overcome by the use of 'block push'. However, this would be more effective with the armoured chain conveyor using a plough for loading.

The main problems with the barricades were experienced in erection and lowering and in the provision of a sufficient range of adjustment to accommodate the variations in stope width. A means of raising and lowering the barricade under power would be of considerable benefit. The venetian-blind type of barricade has the most potential for accommodating variations in stope width, although the hinged spill-plate and screen is also promising. Steel plates are an excellent material for the construction of a barricade, and can be as thin as 6 mm provided they are flexible, made of high-strength steel, and mounted flexibly.

The wear pattern is similar on the two types of conveyor, and so is the amount of material worn away for a given quantity of rock conveyed. The difference between the conveyors is that replaceable wear surfaces can be included easily in the reciprocating-flight conveyor, which therefore has a wear life many times longer than that of the armoured chain conveyor.

Corrosion results in accelerated abrasion and is a major factor in decreasing the wear life of the pans and chains.

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