Overcutting at Roof Level at the Winsford Rock Salt Mine

James H. Newman and Dennis H. Scotney[1]
ICI Mond Division, Salt & Lime Group
Cheshire, England
[1]Robert L. Priestley Ltd
London, England

ABSTRACT

The rock salt strata at the Winsford Mine of Imperial Chemical Industries (ICI) is of a typical bedded structure with a shallow dip between major geological folds. Mining takes place at about 180 meters below surface and is of a conventional room and pillar type. Rooms are up to 20 meters wide and 7.6 meters high with pillars 24 meters square. Rooms are undercut, drilled and blasted, pulling about 4.5 meters per round.

Roof scaling after blasting to achieve the required standard of safety is labour intensive, itself dangerous and has to be repeated several times. However, in an old section mined in the 1930s, a roof that had been precut still stands today, apparently as sound as the day it was formed.

R. L. Priestley in conjunction with ICI, Goodman & Fletcher Sutcliffe Wild have developed a mobile gantry to support a modified Goodman 2500 universal cutter equipped with a 4.88-meters long (16 ft.) jib which can precut at roof level from the floor, some 7.6 meters below. No subsequent roof scaling or treatment is required.

Operation of the prototype machine since June 1981 has been remarkably trouble free and the paper elaborates on the overcutting technique with details of the machine.

INTRODUCTION

The Winsford Mine is situated in Mid Cheshire some 40 km southeast of Liverpool in the UK. The rock salt occurs as a bedded deposit in a basin of Triassic Age and when complete lies in an upper and a lower series with maximum thicknesses of 400 m and 300 m, respectively, separated by a mudstone also 300 m thick. Winsford lies in the northwest of the basin where between 100 and 300 m of the lower series only suboutcrops to collapsed mudstone covered with pervious glacial drift.

In this area the two principal exploitable beds of rock salt are 25 to 30 m thick overall in each of which 7.6 m is of the necessary purity. The two beds are separated vertically by about 90 m of alternating bands of mudstone and impure rock salt. They are generally flat lying with variable dips up to 3°, but the mining area is interrupted by a series of parallel monoclinal folds with vertical displacements of up to 85 m. Until the early 1970s all mining had taken place in the bottom 5 to 7.6 m of the lowest salt bed. Since then mining has been concentrated in the middle 7.6 m of the higher bed of the series where a monocline fold has brought it down to a level that made it accessible by twin inclined drifts from the older workings. All workings to date lie between 130 m and 200 m below the surface.

The rock salt being mined is massive without bedding planes, marker beds or jointing; nevertheless, it suffers creep under the ambient stresses present.

MINING METHOD AND HISTORY

Mining is by the classical square patterned, room and pillar methods. Present day rooms are 20 m wide and 7.6 m high separated by pillars 24 m square. Rooms are undercut, drilled and blasted, giving up to 1,500 tonnes per pull. Broken rock is loaded by LHDs with 11 cubic-metre buckets and delivered to Stamler Feeder Breakers. The product is conveyed to an underground crushing plant and the final product of −10 mm in size is hoisted to the surface.

The essential roof control after blasting is the matter featured in this paper. To appreciate the logic of developing an overcutting technique it is necessary to understand some of the history of the Winsford Rock Salt Mine.

The original shafts at Winsford Rock Salt Mine were sunk in the 1840s. The mine operated on a small scale until 1892 when it was closed and production concentrated on the Adelaide Mine at Northwich. The Adelaide Mine was lost due to flooding in 1928 and the Winsford Mine was re-opened and has remained productive ever since.

After 1928 output was small and rarely reached 50,000 tonnes per year, the main market being animal licks for both home and export. In 1960, to meet the new road de-icing market the first major expansion scheme was commissioned, raising the capacity to some 350,000 tonnes per year. Successive measures were taken to further increase capacity until 1974 when a new product winding shaft, underground crushing and screening facilities and additional mining equipment enabled demands of up to 1.8 metric tonnes per year to be met.

In the earlier years the operation was very labour intensive, the advance of workings slow, and it was possible to maintain a high standard of roof scaling so that there was no incidence of major injuries caused by falling rocks from the roof. It was natural and desirable that this standard should be maintained. As methods were modernised production increased and new workings were created more quickly.

ROOF CONTROL

Prior to 1970, treatment of the roof after blasting was as follows:

Primary Scaling. The shotfiring team using pinch bars made a safe way up the heap of broken rock to examine the visible part of the face for misfires.

Secondary Scaling. A team of three men standing on the heap of broken rock hand scaled the exposed roof, face and sidewalls as far as they could reach to make it as safe as possible for the loading out operation (Figure 1).

Tertiary Scaling. After loading out, the same team using an elevated platform would hand scale the whole area checking back over the previous 3 or 4 blasts. The incidence of creep, moisture attacks in the summer months and a fresh blast would open up cracks that were originally tight and safe.

Follow-up Scaling. Where a roadway had a significant

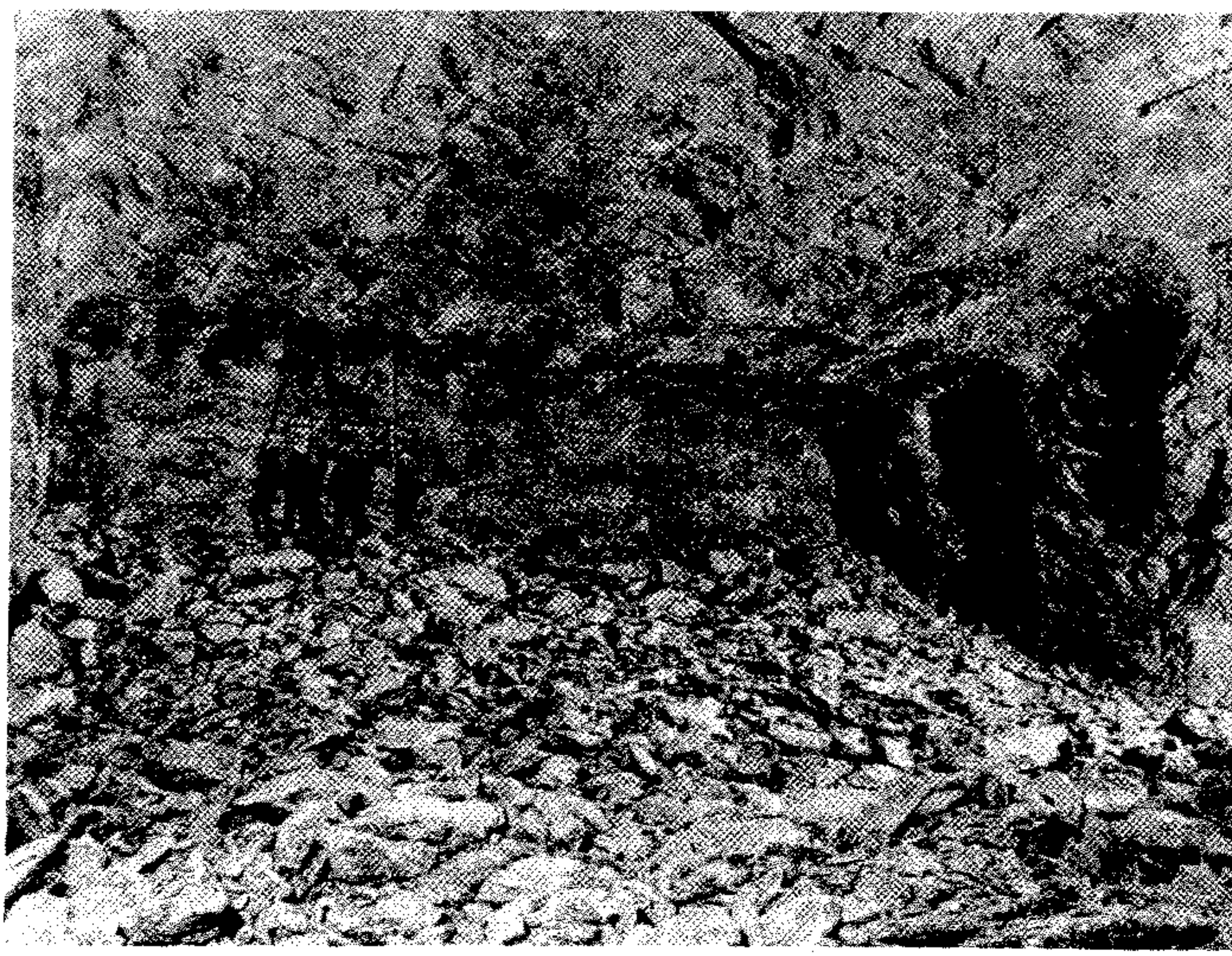


Figure 1. Secondary scaling.

life as a travel way it had to be hand scaled at intervals to remove potentially dangerous loose rocks caused by continuing creep and atmospheric attack.

In the early 1970s Gradall Scalers were obtained in an attempt to reduce the manual effort and improve productivity. These were diesel-driven, hydraulically-operated excavators specially converted and equipped with a scaling hook (Figure 2). More recently the purchase of electrically operated scaling machines has greatly improved the underground environment in which these machines work.

Unfortunately, the cracks in the roof caused by blasting all tend to be angled back from the face so that the most effective point of attack is from the face looking back into the open room. Nevertheless, the Gradall operation even when worked from the "wrong direction" removed larger quantities of scale than the hand operation, but it had to be a blanket coverage which still left some dangerous pieces hanging there. Therefore, the Gradall could not replace hand primary and secondary scaling because of reach and was only partially effective on the tertiary operation. It was most useful for "follow-up" scaling where it could be pointed in the "right direction."

OVERCUTTING

Back in the 1930s and 1940s a part of the old workings was exploited by mining a top slice about 2 m high leaving a bench below. The top slice was overcut and undercut to about 1.5 m in depth using Anderson Boyes machines (Figure 3). The result was a machined cut roof that has not had to be touched since and remains as safe today as when it was formed between 40 and 50 years ago (Figures 4 and 5). Such a method of operation cannot be done economically today and a search was instituted for a company that could design, engineer and manufacture at an economic price an overcutting device which could operate from the floor about 7.6 m below the cutting face. The idea, if pos-

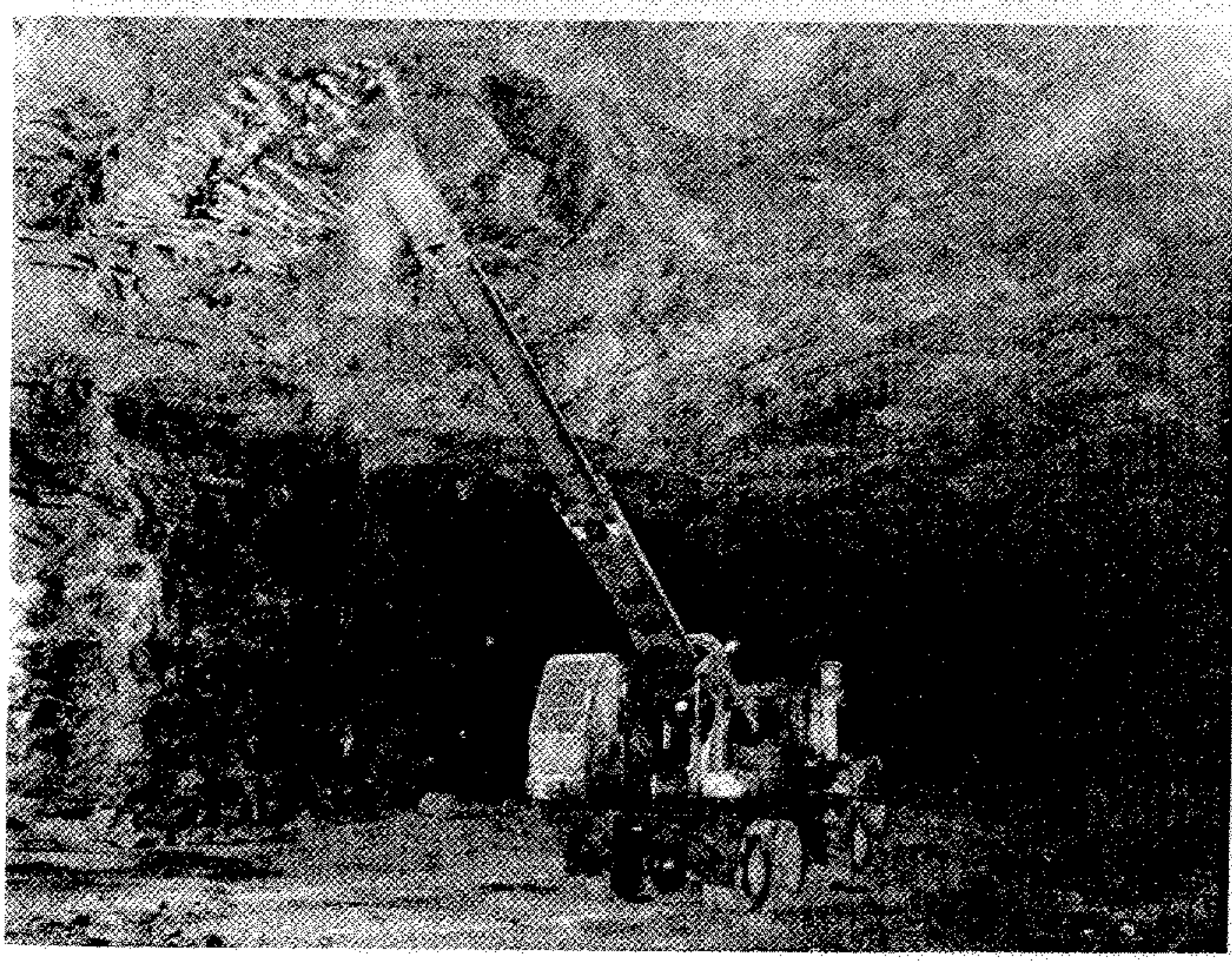


Figure 2. Scaling with Gradall Machine.

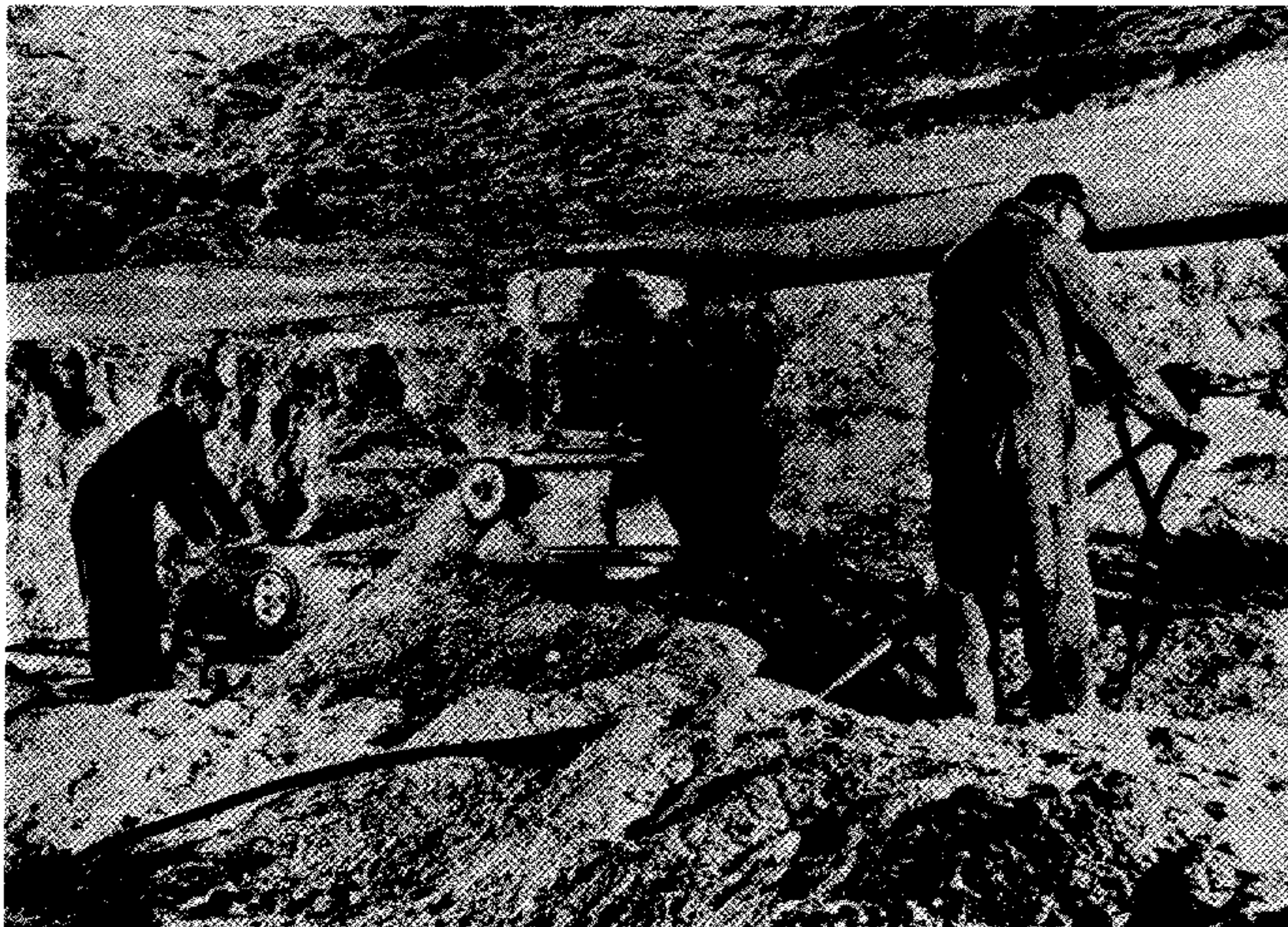


Figure 3. Overcutting in the 1930s.

sible, was to mount a universal cutter, well known in the salt mining industry, upside down on top of a mobile gantry. Because we were using Goodman '2500' Universal Cutters for our undercutting operation it was natural that they should be employed to modify as necessary their machine for the actual overcutting operation. The length of cutter bar employed was 16′ (488 m) to give a cut of approximately 15′ (4.57 m).

R. L. Priestley PLC became the main contractor for the project and many meetings were necessary to decide the mode of operation of an overcutter and the design of a robust gantry to carry it (Figure 6). Clearly one could not cut at roof level by crabbing the machine across the face as one undercuts at floor level.

It was considered that the best solution was to cut a series of overlapping arcs from fixed positions. The gantry was designed so that the cutter could be fixed hydraulically to the chassis in two positions 5.25 metres apart. By placing the gantry in two locations on either side of the room, the full 20-metre face could be cut using four arcs from four cutter positions. There are several ways to achieve the desired overcut; one example (Figures 7 a, b, c and d) is as follows:

The first arc covers a full semi-circle; the second after traversing the cutter to the other end of the gantry squares up the right-hand side of the face. The gantry is then moved to the other side of the room with the cutter in its right-hand location where the third and fourth arcs complete the face.

Two points to note are that the gantry has to be positioned close to the face and the length of bar determines the geometry of the pattern because it has to start parallel with the face. The whole gantry has to be orientated and tilted to obtain the correct plane of cut. If too much use is made of the orientation movements possible on the cutter itself it may try to cut a cone shape, thus putting considerable strain on the base mounting and bar itself. The cutter bar and its mounting plate should lie in the same plane as the intended cut.

It is comparatively easy to follow the line of the previous cut, but if it is necessary to change direction either down-

Figure 4. Area overcut in 1939.

hill or uphill, special measures have to be taken. Because stepped cuts in the roof are of no consequence, unlike the floor, it is simple to go downhill by levelling the gantry horizontally and overcutting at a lower level. This method is preferred in the instance where there is a choice of entry for a crosscut between two rooms at different levels. A change from an existing direction to cut uphill means that the whole gantry and cutter base plate should be angled for the desired rise to avoid the problem of cutting a cone and thus stressing the gantry mounts.

There is obviously a degree of skill in the overcutting operation, but no serious problems arose during the training period. It is possible to overcut a 20-metre-wide face in less than two hours.

EFFECTS ON OTHER OPERATIONS

First and foremost, the overcut replaces the top row of drill holes. Simply leaving out these holes and the explosive normally charged there resulted in very large slabs of rock from below the overcut lying on top of the heap. Satisfactory results were obtained by drilling the top row of holes about 0.6 m below the overcut and sequencing the blast as normal from the bottom upward.

A trial was also made of reversing the standard blasting pattern by inclining holes upward toward the overcut and firing from the top down. This was discontinued because blasting cracks slanted upward into the face near the roof and left dangerous pieces that were very difficult to remove safely.

Overcutting nevertheless saves some 15 percent of the drilling footage required and up to 10 percent of the explosives. No one in the face mining operation now has to work at roof level either for scaling or charging, and this is helpful because some diesel exhaust and blasting fumes tend to collect and be slow moving up there.

One other side benefit is that after monitoring some 12 overcut blasts compared with non overcut blasts, the peak particle velocity of the vibration measured on the surface directly above has been nearly halved.

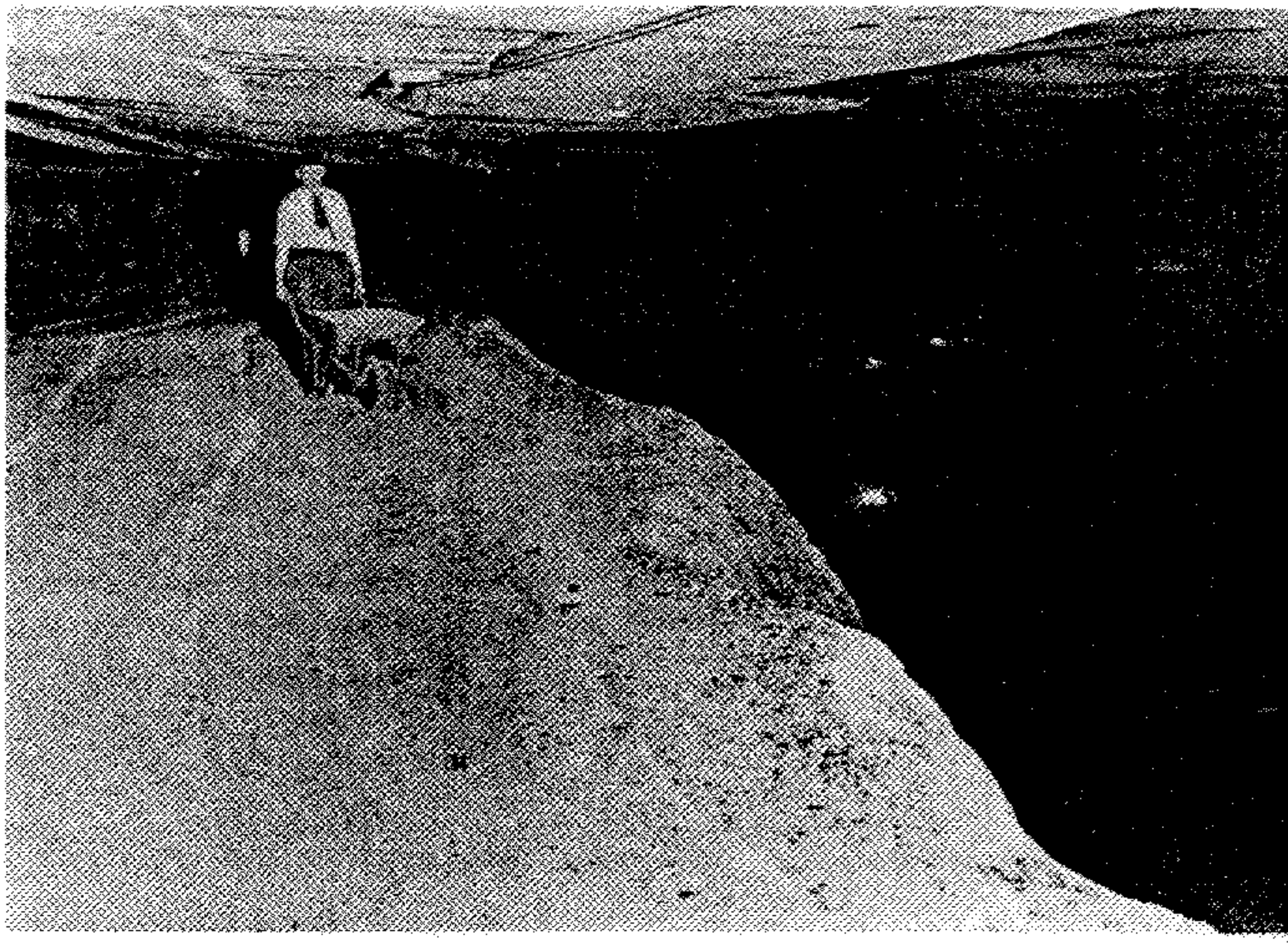


Figure 5. Top bench 1939.

DESIGN CONCEPT

The initial design brief was to provide a machine to overcut a face at a height of 7.62 m to a minimum depth of 4.57 m across the full width of the face, thereby eliminating the need for subsequent roof sealing operations.

To accomplish this duty, the overcutter would consist essentially of a modified Goodman Model 2500 Universal cutter mounted upon a purpose designed self-propelled steerable gantry unit, the assembly being designed to overcut an 18.29-metre-wide face from two positions at a rate in excess of two headings per shift inclusive of travelling the gantry between faces sited in the same mining area.

In addition, the gantry would be capable of negotiating an 8.3 percent grade plus steps in the floor of 230 mm and have a turning circle such that a 90° turn could be accomplished in a 15.24-metre-wide heading.

The gantry is a substantial, fabricated unit produced basically from structural hollow steel sections and supported by heavy duty rock tyres mounted upon high torque/low speed, hydraulic wheel motors (see Figure 6). Due to the distribution of loads throughout the structure, a pair of twin wheels are used at the front of the gantry with a pair of single wheels at the rear, all six wheels being motorised. The front wheels have a rigid suspension but are pivoted in the horizontal plane at right angles to the direction of travel, whilst the rear wheels have independent hydro-pneumatic suspension. To provide a stable platform during cutting, the gantry is 'locked' into the heading by means of six staking jacks, four of which are located at the driving wheel positions and are used for levelling purposes, whilst the other two are positioned at the upper level and staked against the roof. The gantry structure is designed to withstand the maximum locking forces provided by these staking jacks.

Two working levels are provided on the gantry. The lower one accommodates the hydraulic power pack required for all functions except those associated with the cutter, the electrical control panel, cable reeling drum for

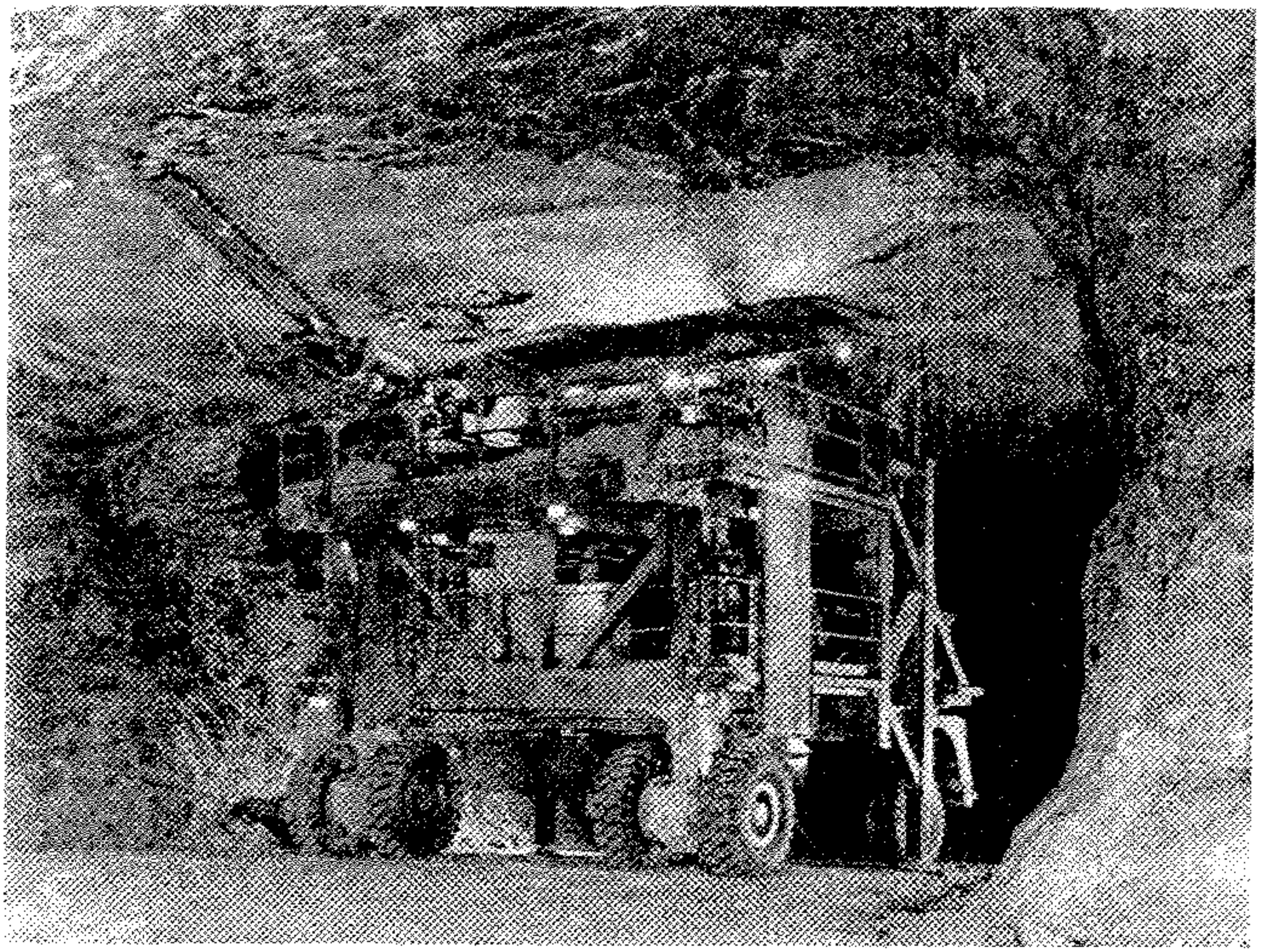


Figure 6. The Priestley overcutter.

the trailing flexible power cable and three operator driving positions for use when travelling the gantry around the mine. The upper working level incorporates the mounting and lateral slideways for the cutter plus a full width, ventilated operators cab and two hydraulic buffers to prevent collision with the face. Open mesh flooring is used at both working levels to prevent a build-up of spoil. Heavy duty flexible screens were provided to deflect spoil away from the gantry wheels during cutting.

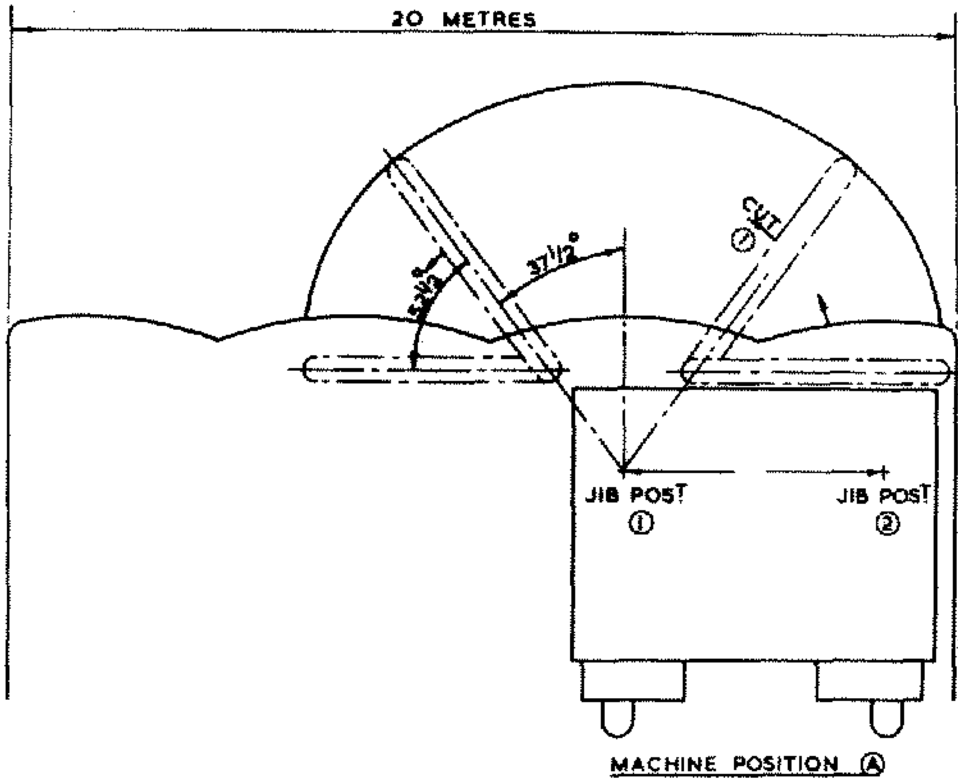
The complete machine was designed in modular form for assembly underground and within the limitations of the mine handling facilities. This limited unit dimensions for lowering in the shaft cage to Height—1.83 m, Length—2.29 m, Width—1.24 m, Weight—2.75 t.

Larger pieces can be handled by underslinging from the cage, but this disrupts the shaft operation and is kept to a minimum.

DESIGN FEATURES

Hydrostatic Transmission. A closed loop hydrostatic transmission (see Figure 8) was selected for the gantry because such a system is ideally suited for low speed control of heavy, low-speed, off-the-road machines.

Each of the six wheels is fitted to a high-torque/low-speed hydraulic wheel unit consisting of a high-speed, fixed displacement, axial piston hydraulic motor driving through a two-stage planetary gearbox (see Figure 9). Each motor produces a torque of 10 kNm (7,340 lb ft) at an hydraulic pressure of 140 bars, resulting in a total tractive effort for the gantry of 80 kN (18,000 lbs). The system provides for stepless speed control up to one km/hr in both directions of travel, control of which is effected by pilot operated, proportional, joystick control valves which influence the output of the variable displacement hydraulic pumps.



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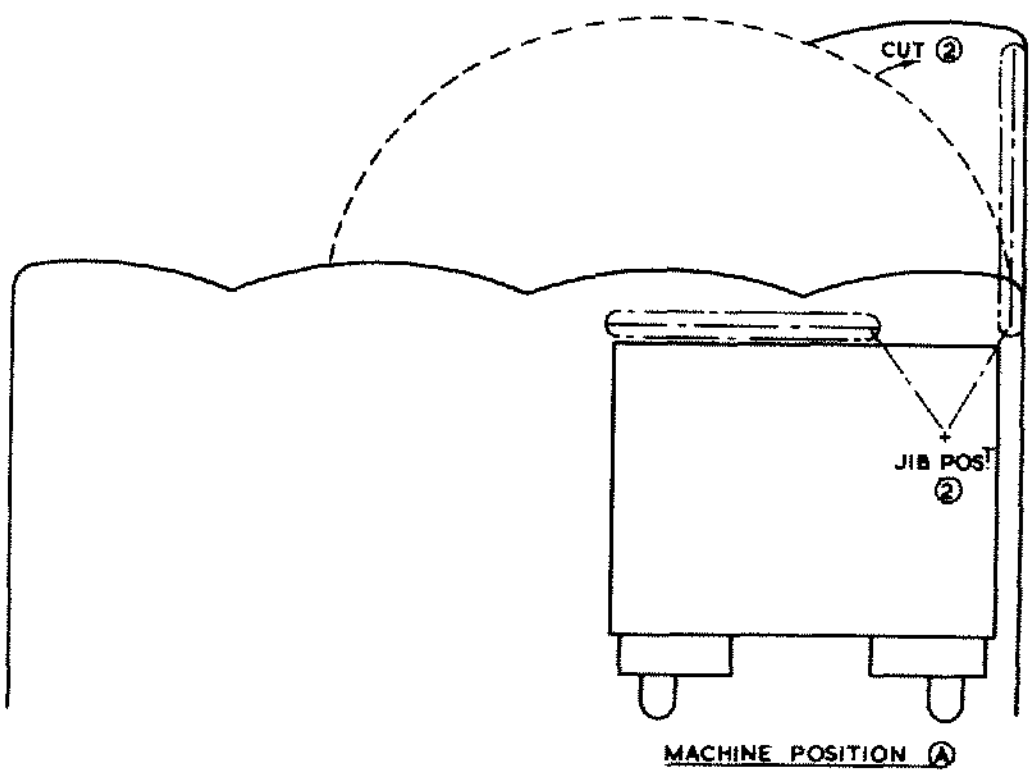

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Figure 7. Cutting sequence with Priestley overcutter a, b, c, d.

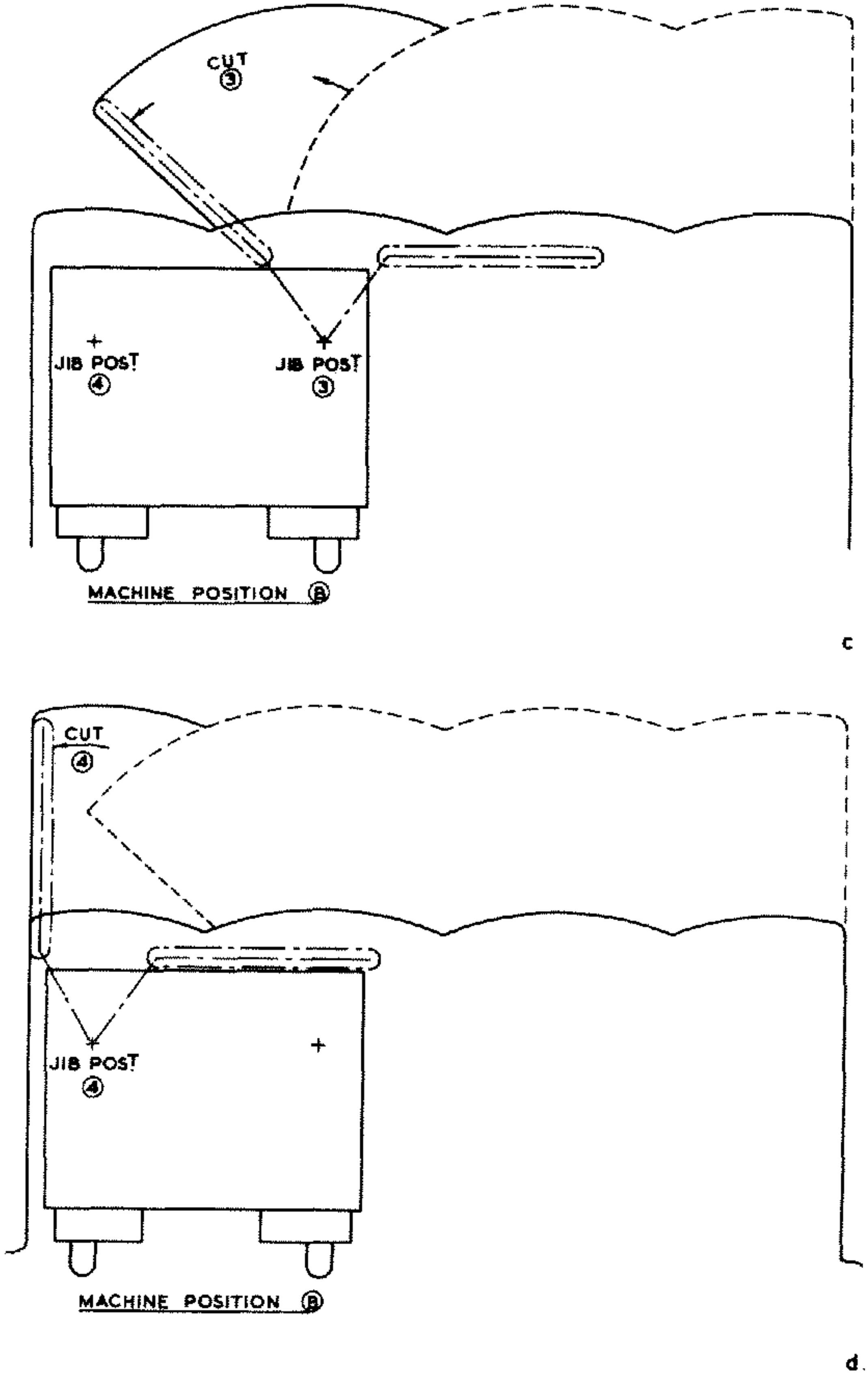


Figure 7. *(continued)*

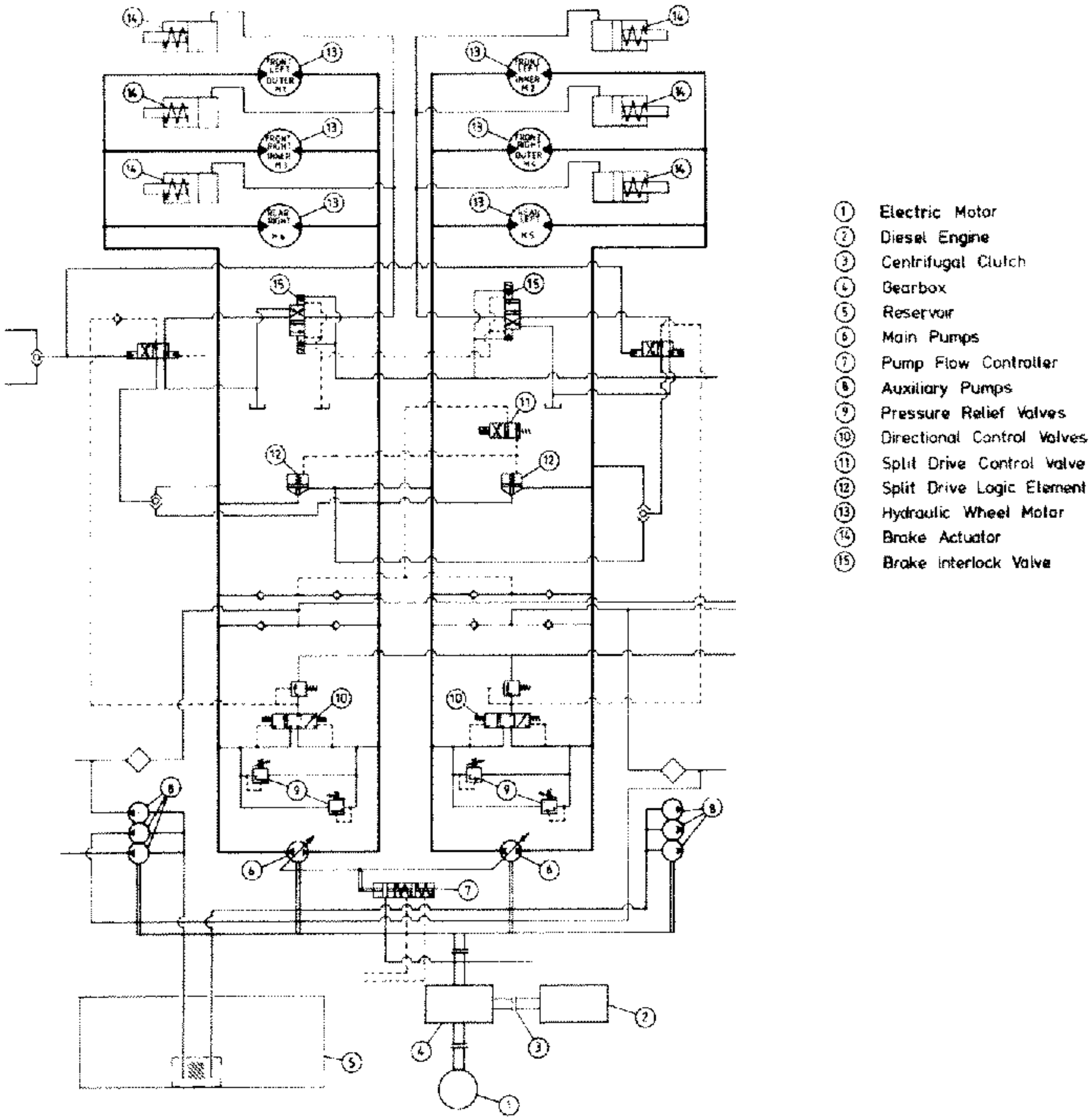


Figure 8. Simplified circuit diagram of hydrostatic transmission.

Each wheel motor incorporates a drum brake operated automatically by an external actuator comprising a single-acting hydraulic cylinder with a high-rate spring to apply to brake. The system is thus 'fail safe' and the brakes are automatically released as pressure is applied to the wheel motor.

A 'split' drive facility is incorporated which, by operator selection, allows all six wheels to be driven in parallel or alternatively in two independent groups. In the latter case, the driving wheels are split such that the front left outer, front right inner and rear right wheels are driven separately but concurrently with the front left inner and front right outer and rear left wheels. Whilst this feature at first

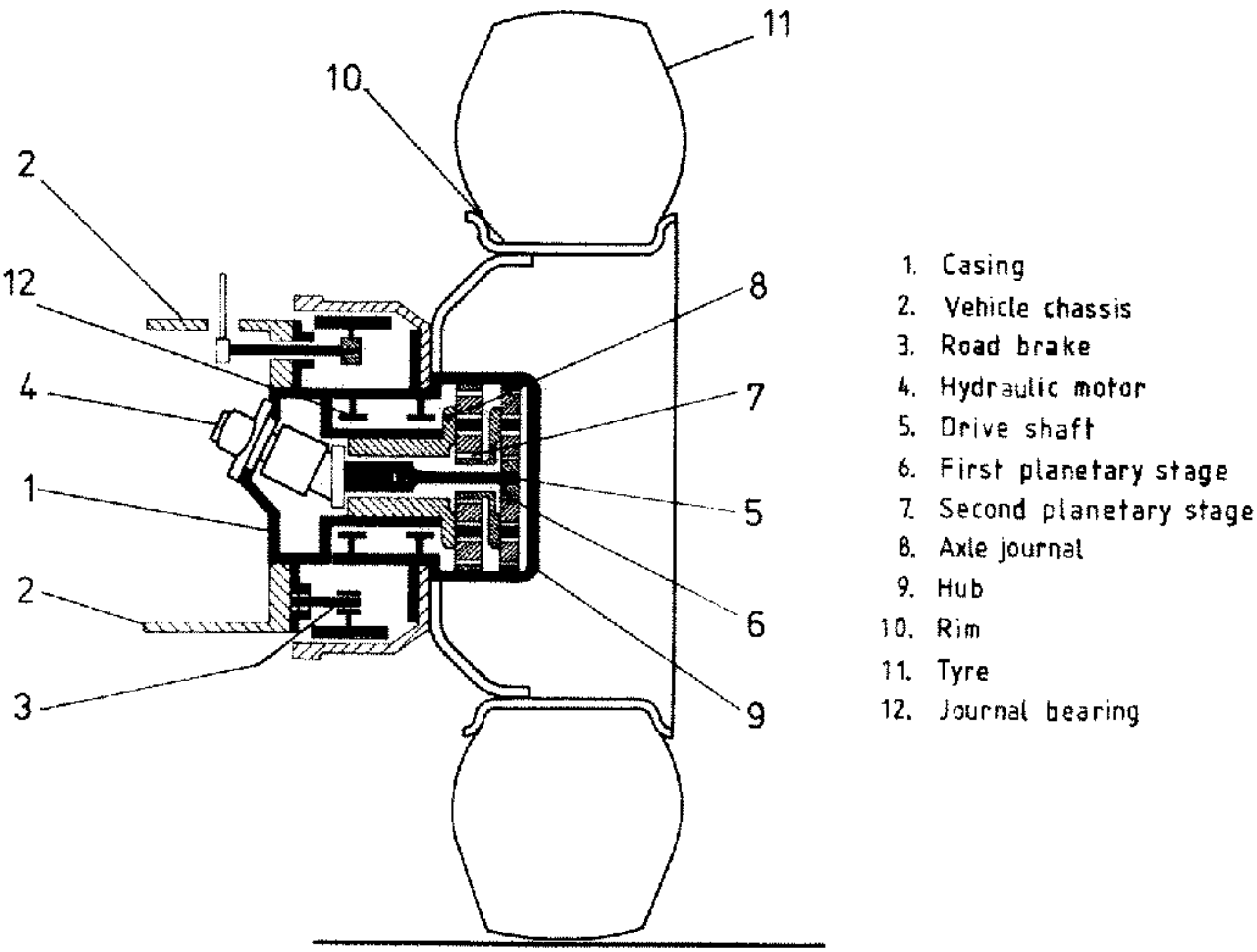


Figure 9. Diagrammatic view of front wheel suspension.

sight may appear to be unnecessarily complicated, it does provide two advantages, namely:

1. A differential effect is obtained for use when negotiating corners
2. Drive is maintained in the event that, due to undulations and steps in the floor, one wheel loses contact with the ground.

The operator has push-botton control over the use of this split drive feature.

The main power pack is situated on the lower working level and provides the hydraulic power for all gantry services except those of the cutter itself. The main power source for the gantry is electric, but to provide for a situation where an electrical supply is not available, it was a requirement to be able to power the gantry from a stand-by diesel engine.

The pack, therefore, consists of a 37-kw squirrel cage electric motor connected via a 1 : 1 ratio gearbox to the main hydraulic pump unit.

The gearbox has a further input shaft at right angles to the main through shaft with a reduction of 1.4 : 1 to which is connected a twin cylinder Deutz air-cooled diesel engine via a centrifugal clutch coupling. The diesel engine develops 15 kw at 2200 RPM and, as a standby unit, is only required to be capable of moving the gantry at low speed.

The main hydraulic pump unit consists of a splitter gearbox to which are coupled two variable displacement, reversible, axial piston pumps which power the hydrostatic transmission system. The splitter gearbox also has two additional output shafts that drive banked gear type pumps to provide auxilliary services as follows:

P1	Cable reeling drum and staking jacks
P2	Steering and staking jacks
P3 & P4	Boost supply to make up the losses within the closed loop hydraulic system

P5 Pilot supply and filling of cutter hydraulic reservoir
P6 Cable reeling drum and staking jacks.

The power pack incorporates all the necessary control valves, pressure relief valves and filters to enable all hydraulic functions to be performed. The fluid reservoir has a capacity of 1,000 litres (220 gallons) and is sized to maintain a fluid temperature of not more than 60°C but an oil-to-air heat exchanger with a 3-kw heat dissipation was also incorporated.

Steering and Suspension. The rear wheels are mounted on the gantry structure via taper cross-roll slewing bearings that are designed to accept the eccentric loading imposed by the suspension system. The wheels are connected by means of a conventional track-rod powered by a pair of push-pull hydraulic cylinders, control of which is by means of joystick valves at each of the operator stations.

The steering geometry is such that a 90° turn can be negotiated within a 15.24-metre-wide heading.

When appraising the types of suspension to be used on the gantry, the main consideration was to ensure that all wheels maintained contact with the ground. The reason for this requirement was twofold: 1) to ensure no loss of transmission and 2) to eliminate as far as possible any racking in the structure, and hence excessive loadings.

This was achieved by mounting the front wheels on a horizontal pivot (see Figure 10) and designing a pivotted trailing arm system for the rear wheels (see Figure 11). The rear trailing arm is supported by a hydraulic strut whose stiffness is controlled by a nitrogen-pressurised accumulator.

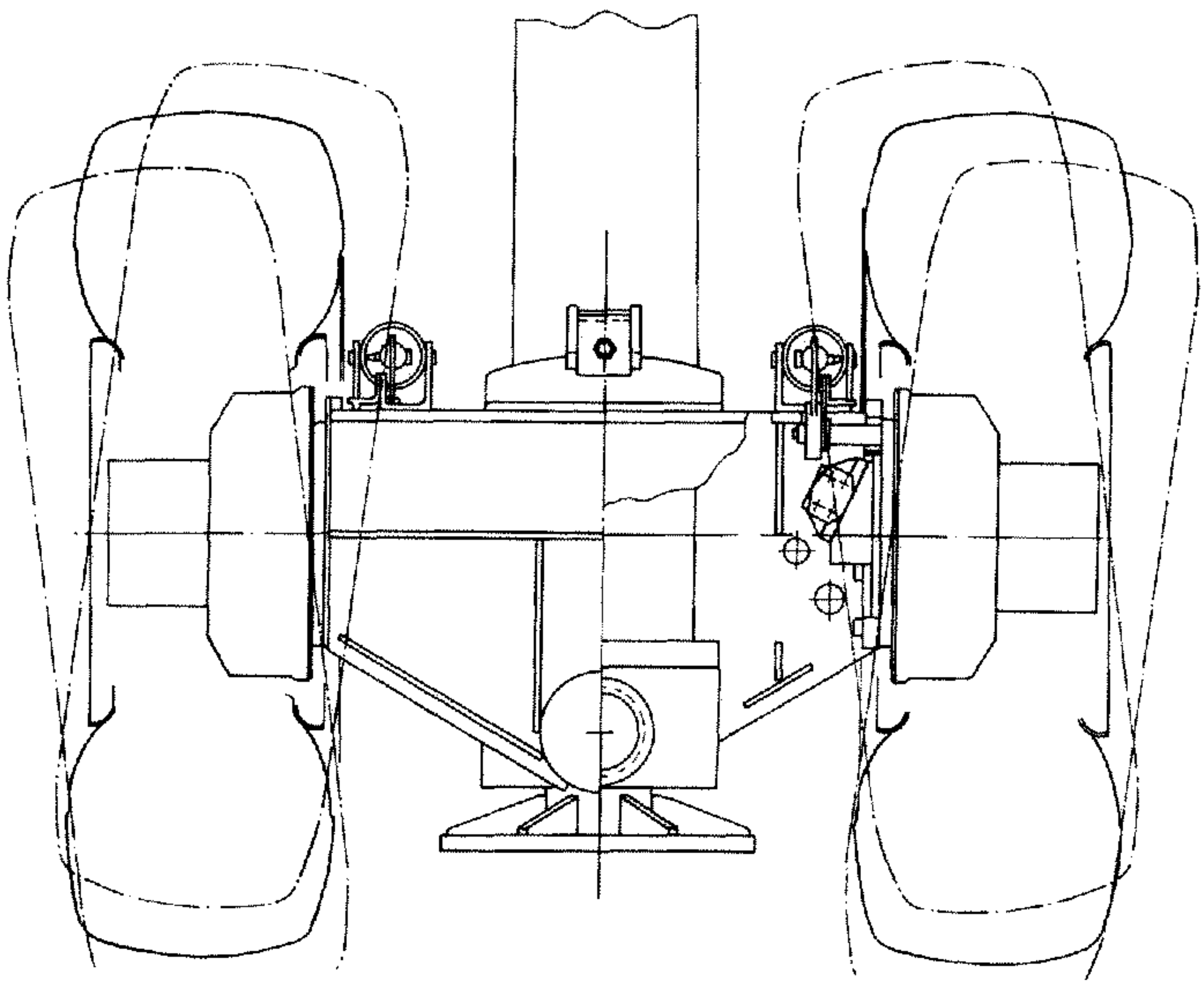


Figure 10. Diagrammatic view of real wheel suspension.

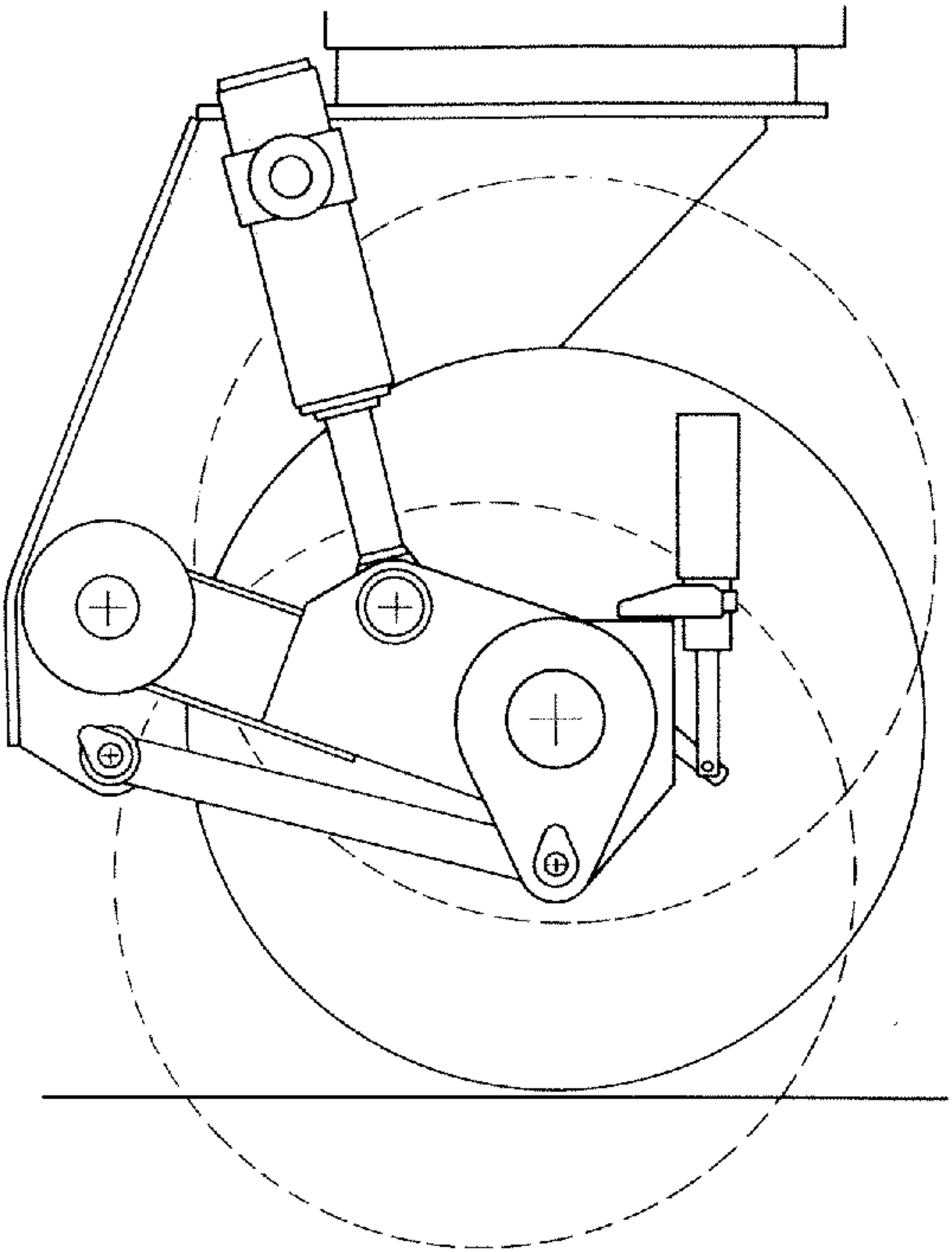
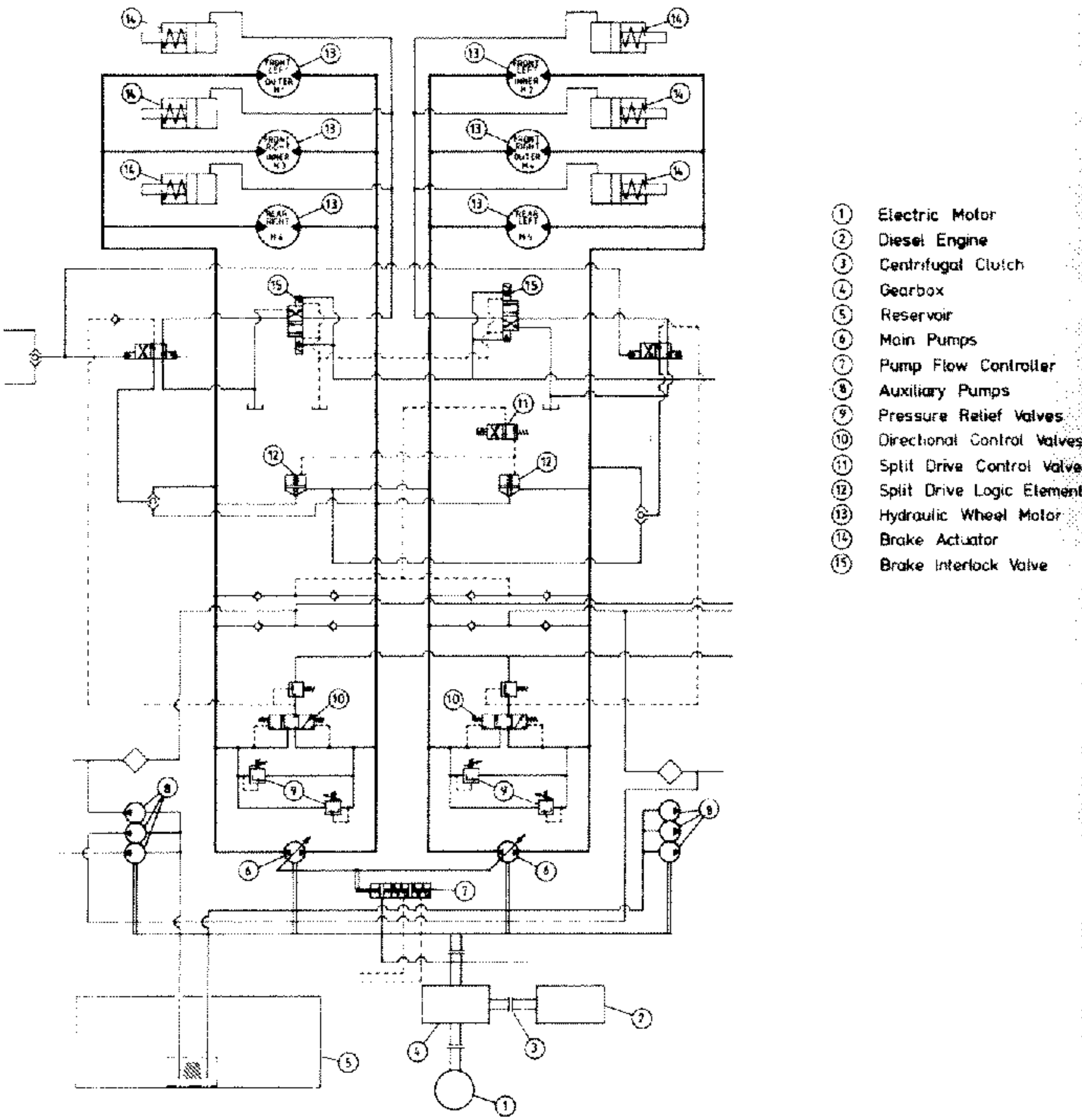


Figure 11. Diagrammatic view of wheel motor.

Cutter. The cutter is a modified version of the Goodman Model 2500 Universal cutter with a redesigned main frame and fitted with a 4.88-metre-long Bowdil bar (see Figure 12). The hydraulic power pack is mounted within the new main frame to eliminate the need for trailing hoses from the gantry power pack.

The main frame is designed to run on a pair of dovetail slide rails, which provide the traverse motion and accept the working loads of the cutter. The female slides are fitted with replaceable phosphor bronze strips whilst the male slides use replaceable hardened steel strips. Automatic grease lubrication is used for the traverse sliders and nylon



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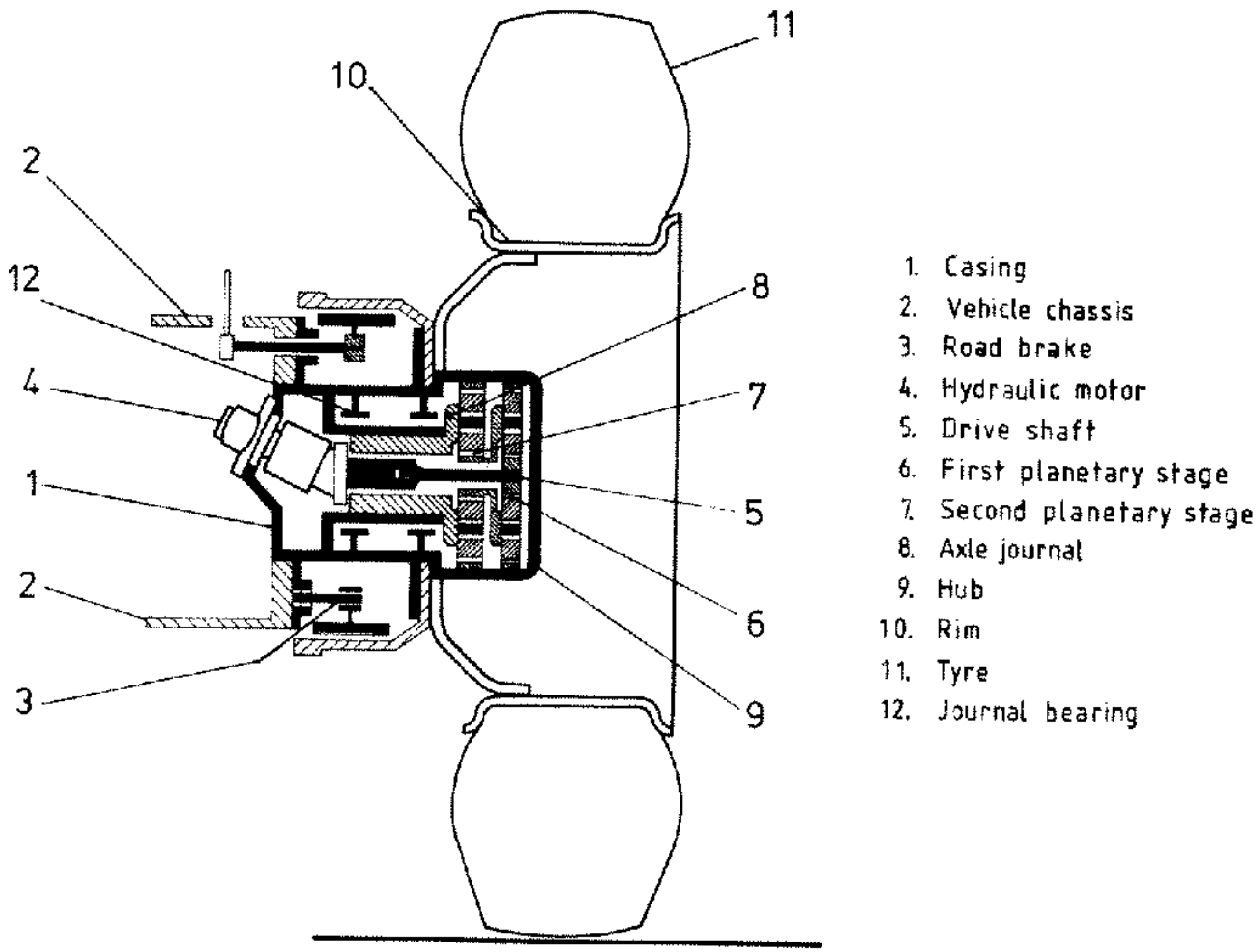

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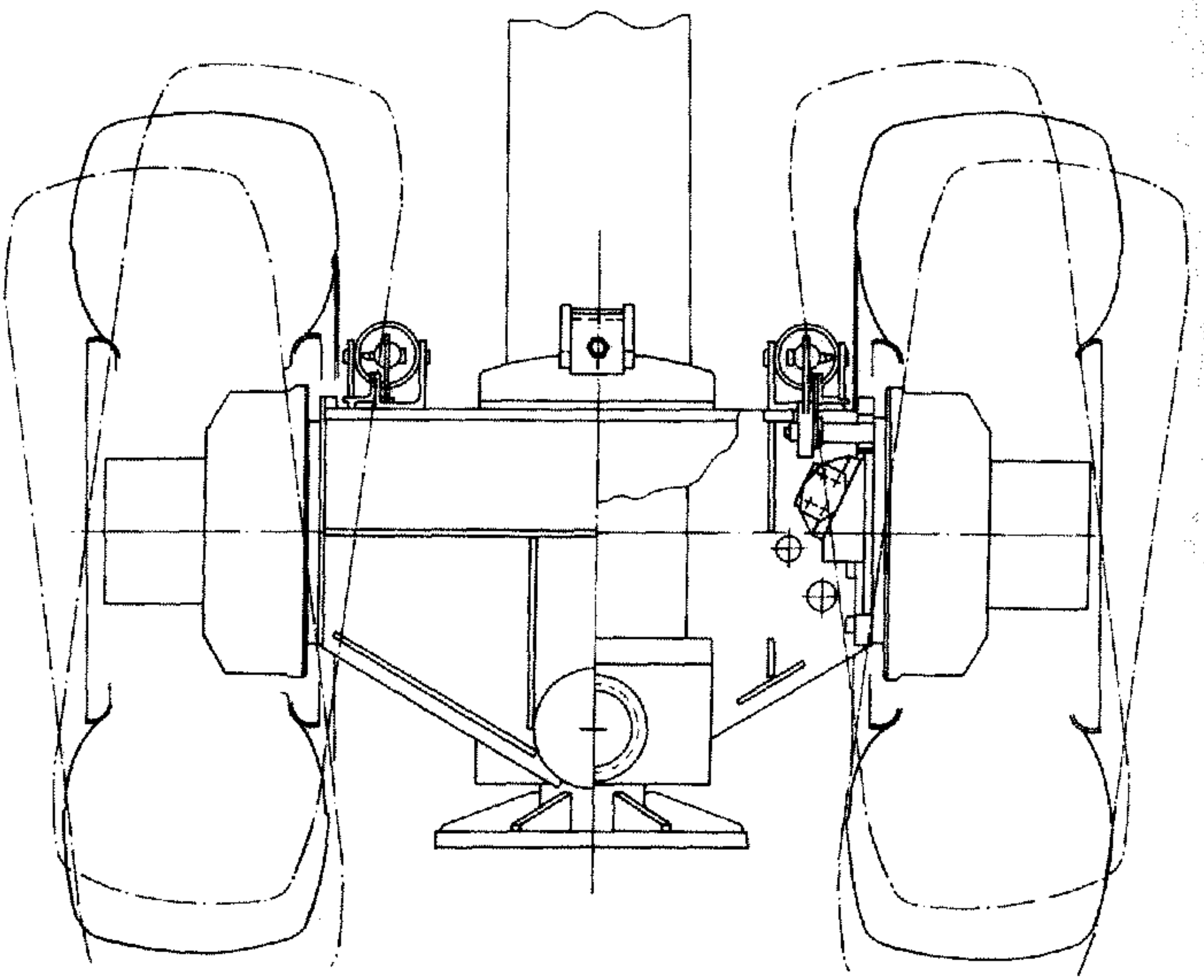

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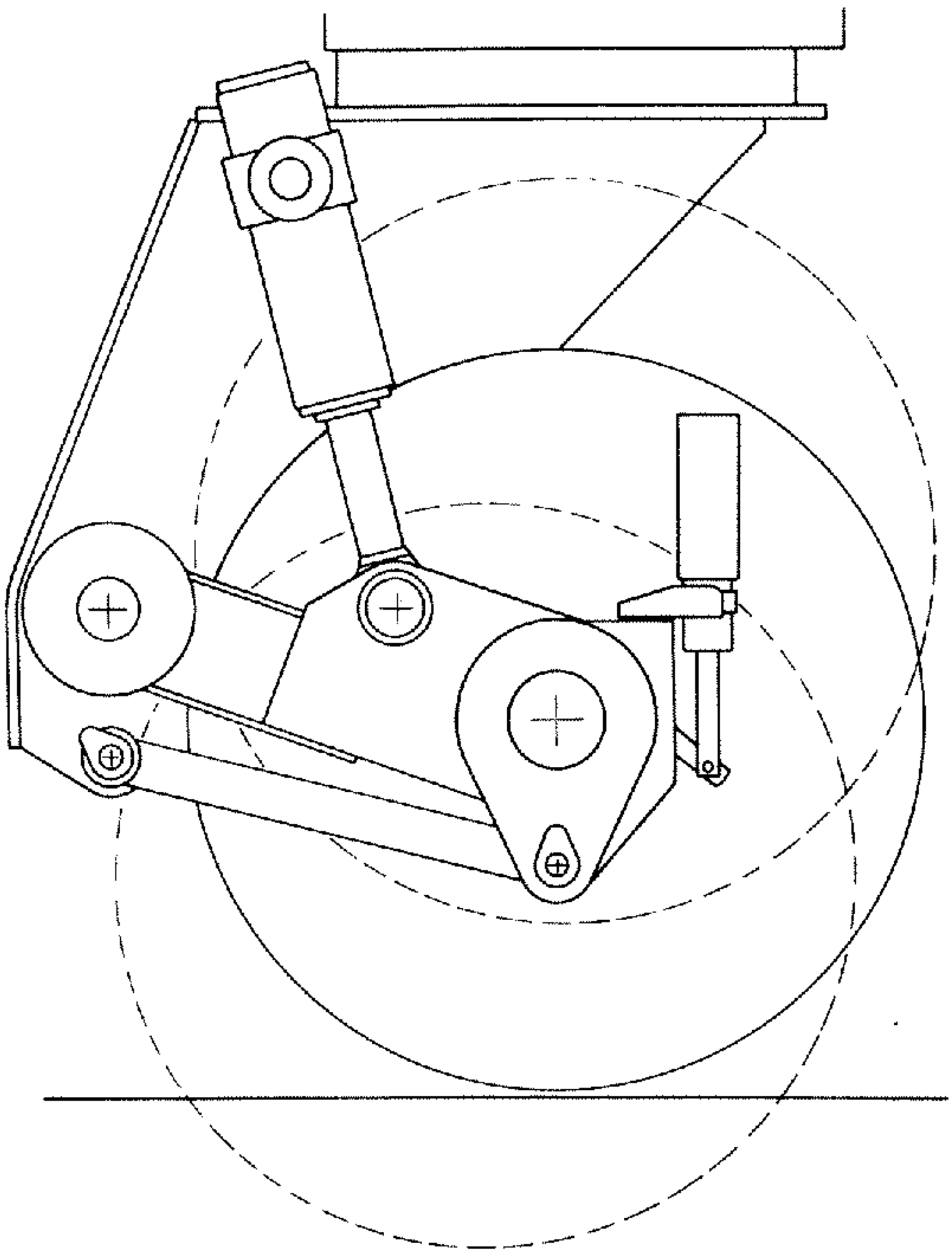

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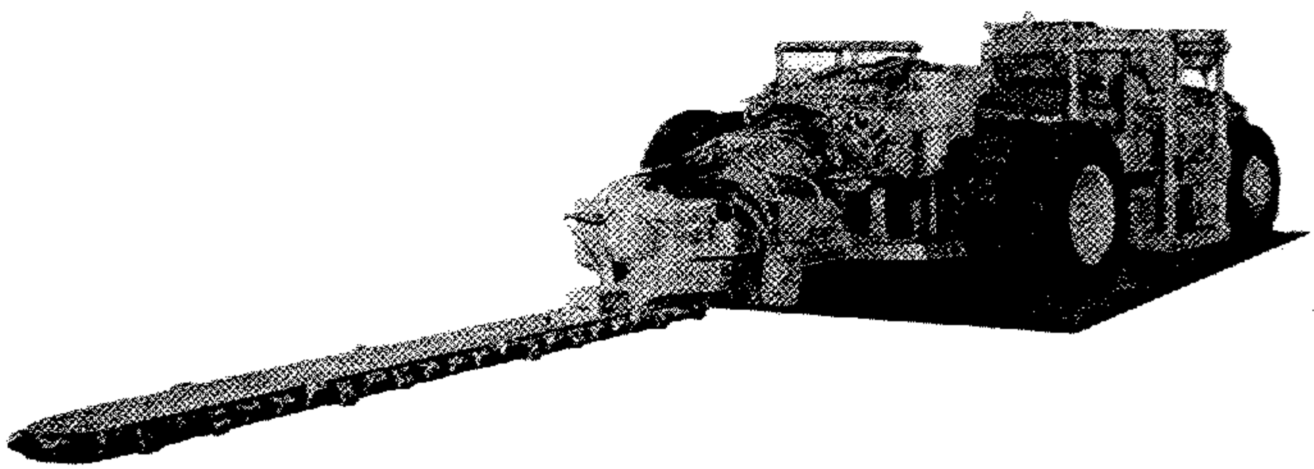

Figure 12. View of Goodman cutter.

scrapers act on the slides to limit the accumulation of foreign matter.

Traversing of the cutter unit is achieved by means of a hydraulic cylinder with a chain and sprocket multiplier, the chain being of the forged round link type. The gantry is designed to accommodate the cutter loads at the two extreme ends of the cutter traverse, and in these positions the cutter unit is hydraulically clamped to the slide rails.

The slewing geometry of the standard Goodman cutter provides for a total of ±75° made up of 30° boom swing and 45° bar swing. Because the concept of the overcutter required a total slew of ±90° the movements were modified to achieve this by increasing the boom and bar swings to 37.5° and 52.5°, respectively.

All operator controls for the cutter are mounted on the rear of the main frame and are easily accessible from the operator's cab.

Electrical System. The electrical equipment incorporated into the gentry was selected to be as near standard as possible with equipment already in use in the mine and to comply with the UK Mines and Quarries Regulations and the mine owners' requirements.

The basic power supply to the gantry is 550 V, 3 ph, 50 Hz via a flexible armoured cable from a gate end box and is fed into the gantry on an hydraulically powered cable reeling drum.

A main control cabinet (see Figures 13 and 14) is positioned on the lower working deck and contains one main incoming isolator, three main fuses, four contactor starters complete with overloads and one 55-volt/24-volt control circuit lighting transformer.

All the necessary fuses, contactors, transformers, timers, relays, push buttons, interlocks and selector switches, etc. are contained on and within the main control cabinet. Lighting and control systems are all from a 24 V DC supply and are arranged to operate either from the gantry's main electrical source or, when the gantry is powered by the diesel engine, from a 24 V lead acid battery.

A phase rotation relay is incorporated to protect the equipment against the possibility of phase reversal.

OPERATION AND SAFETY

During travelling and manoeuvring operations of the gantry, the operator can select any one of three operator stations so as to provide him with the best visibility for the manoeuvre concerned. The operation stations are equipped with four controls:

1. Forward/reverse with speed control
2. Steering
3. Split drive button
4. Emergency stop button. This control cuts out the electric or diesel drive, whichever is in use at the time, and applies the wheel brakes.

Operation of the cutter is carried out from within the operator's cab at the upper deck level. The full width of the cab is fitted with hinged, transparent polycarbonate vision panels to protect the operator from any flying debris. The cab is force ventilated by an automatic dry bag filter unit situated on the middle deck. The fan unit has a 1.5-kw motor and delivers 2000 m^3/hr of filtered air at a static inlet pressure of 120 mm water gauge and is arranged to start automatically when the cutter is started.

Whereas considerable dust clouds are inevitably caused by the spoil from the overcut, dropping directly to the floor below, the operator compartment is virtually dust free. Visibility of the cutting operation by the operator is not impaired by the dust.

The travel system is fully interlocked so that a flashing amber light and siren have to be energised before the brakes can be de-energised.

All working levels of the gantry are protected by regulation hand rails and toe boards.

The fluid used for both the gantry and cutter hydraulic system is a fire-resistant water-in-oil emulsion that has been universally adopted by the mine in order to minimise the underground fire hazard.

The limitation imposed on maximum hydraulic fluid temperature is intended as a safeguard to prevent operators from being scalded as the result of a burst hose.

MANUFACTURE AND ASSEMBLY

Manufacture of the gantry was quite straightforward and presented no insuperable problems. All structural members were designed with flanged and bolted connections and the flanges were machined to minimise any assembly problems. Due to the inconvenience of carrying out repairs in the mine, great attention was paid to the welding of the structure and all welds were subjected to 100% ultrasonic inspection.

The complete gantry was fully assembled in the Works, including the hydraulic and electrical installation, and subjected to a full functional test. It was then dismantled and transported to the mine.

Preparations had been made to receive the gantry and a special underground erection area was constructed. This consisted of an inclined excavation to a depth of 4 m below floor level. Two steel joists were rock bolted to the roof to provide runway beams for hand-operated hoists, which, with the aid of a truck-mounted 6-tonne telescopic crane, were used to reassemble the gantry.

Assembly at the mine was completed in six weeks with a crew of six fitters, one electrician and a supervisor. After completion of assembly, the gantry was subjected to a further series of functional tests during which minor adjustments were made before it was put into production.

PROTOTYPE PERFORMANCE

Considering the fact that this machine is very much a prototype, the normal teething troubles associated with such a project have been relatively few and of a minor nature usually involving various aspects of the environment and practical use of the gantry. Such modifications include the following:

1. The hydraulic buffers provided at the upper deck level to assist in positioning the gantry at the face have proved to be unnecessary because control of the gantry is such that the operator finds it simple enough to manoeuvre by eye. The buffers have been isolated.
2. An interlock has been introduced to prevent the cutter traverse system being energised whilst the cutter table clamps are in use.
3. An interlock has been introduced so that the floor staking jacks must be under load before the roof jacks can be energised. Prior to this change, it was possible to energise the roof jacks first and impose unacceptable loads on the gantry suspension system and, in fact, the rear wheel trailing arms were damaged as a result of such action.
4. The original staking jack feet were connected to the legs with a ball joint that provided ±23° of articulation. This proved to be insufficient in practice and the feet failed. They have now been redesigned and operate satisfactorily.
5. The original emergency stop buttons at the operator control stations suffered intermittent malfunctions due to the ingress of fine salt dust and have been replaced by shrouded controls.
6. The fair lead for the incoming flexible electric cable has been redesigned because it was possible to drive the gantry over the cable with the original design.
7. The oil-to-air hydraulic fluid cooler has been found to be unnecessary because heat dissipation by radiation is more than sufficient to maintain the fluid temperature below the required maximum figure.
8. The original spoil deflectors, provided to keep the spoil away from the front wheels, failed due to the accumulated weight of material collected on them. This meant that, when the gantry was repositioned from one side of the face to the other, the front wheels in the centre of the face were confronted with a large heap of fines. This problem disappeared when the width of the heading was increased from 18.29 m to 20 m which took the gantry wheels outside the position of the spoil heap.

CONCLUSION

The overcutting operation at Winsford has been an unqualified success, having achieved its main aims of a completely safe roof that is maintenance free. The manpower and ancilliary savings compared with the previous methods, together with future capital savings for alternative scaling machines and platform trucks, have made it financially attractive.

Considering that the first overcutter was a prototype to introduce a new technique, there have been remarkably few teething troubles and certainly no major problems have been encountered. A second unit is now on order.