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Southfield, Michigan

State of the Art  
of Underground  
Coal Mine Tracked  
Vehicle Brake Systems  
Revised Report

October 1973

Prepared for:

The United States  
Department of Interior  
Bureau of Mines  
Pittsburgh Mining and  
Safety Research Center  
4800 Forbes Avenue  
Pittsburgh, Pennsylvania  
15213

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## ABSTRACT

Underground coal mine tracked vehicles have been studied to determine the state of the art and how brakes might be added to the coal haulage cars. Specific areas of interest are: brake systems, couplers, car trucks and car handling procedures. Problems related to adding brakes to the haulage cars appear to be: the limited amount of room to mount the brakes on the cars, brake line connection between rotary dump cars, achieving desirable braking characteristics without over complicating the system and keeping the installation cost to a reasonable figure.

This document combines the information contained in the first issue of the "State-of-the-Art of Underground Coal Mine Tracked Vehicle Brake Systems," BRL Report No. 6080, with that contained in a subsequent monthly report.

SECTION 1  
INTRODUCTION AND SUMMARY

1.1 INTRODUCTION

The objective of this study is to gather detailed information concerning coal mine trip practices and equipment used in United States and foreign mines. The foreign information is of interest only if it can be applied to improve U.S. practices and equipment. Information has been gathered from: literature published in this field, visits to typical U.S. production mines, and consultation with coal mining authorities. The information gathered is also used as reference material for other phases of the project.

1.2 SUMMARY

The information gathered for this report and contacts made with people involved in mining has resulted in a better understanding of the mining problems and objectives. This report covers existing brake systems used on tracked vehicles and the areas which will be affected by adding brakes to the cars. The only problem encountered in preparing this report was the difficulty of obtaining information from our foreign contacts. Due to the lack of foreign information, this study will continue and any additional important information obtained will be included as a supplement to this report. It is observed that existing mining equipment is rugged, simple and effective and any additional equipment required should be the same.

SECTION 2  
UNITED STATES MINING PRACTICES

2.1 TRACKED VEHICLES

Track coal haulage cars are a prime method of transportation used in the main haulage routes. This system is characterized when high capacity, long distances and long term operations are important factors.

2.1.1 Brakes

A trip, locomotive and cars, is braked by the locomotive under service operating conditions. A trailing locomotive or a special braking car is used on a grade to reduce the possibility of runaway cars. The brakes of a car may be applied by a speed sensor or manual hand lever. Two types of brakes are used, the rail brake and the wheel brake. The wheel brake has a brake shoe which contacts on the wheel tread. The brake shoe is of a low grade of cast iron which results in most of the wear occurring on the shoe and provides a coefficient of friction of approximately 0.23. When the wheel tread becomes uneven due to track wear, brake shoes with hard chrome slugs cast into the bearing surface may be used in order to trim or reshape the wheel. The basic locomotive brake system is a four bar linkage as shown in Figure 1. The adjustable link is provided to take up the clearance as the shoes wear. The power to apply the brakes is provided by a hand wheel (commonly used for parking), pneumatic or hydraulic pressure. Pneumatic brakes may have an interlock system which senses the main reservoir pressure or a fail-safe system which uses a reservoir to apply the brakes when the main tank pressure is low. This safety reservoir is constantly kept pressurized while the locomotive is running. Another method is to have a spring apply the brakes and have the pneumatic or hydraulic power release the brakes. In this second case the brakes are normally on and have to be energized to be released.

In conjunction with the mechanical brakes, may be a dynamic braking system which uses the driving motor as a generator to impede the trip. Electromagnetic track or rail brakes are sometimes used in conjunction with dynamic brakes. The current from the generator is used to magnetize a track brake, and the magnetic attraction between the track and brake block provides the braking effort. Power brakes are not used on small and medium size coal cars because of space limitations, cost and maintenance inconvenience. The U. S. Bureau of Mines has statistically related a number of fatal accidents to the coal haulage systems.<sup>1</sup> The U.S. Government has recently enacted legislation which requires the industry to up-grade, among other things, the haulage

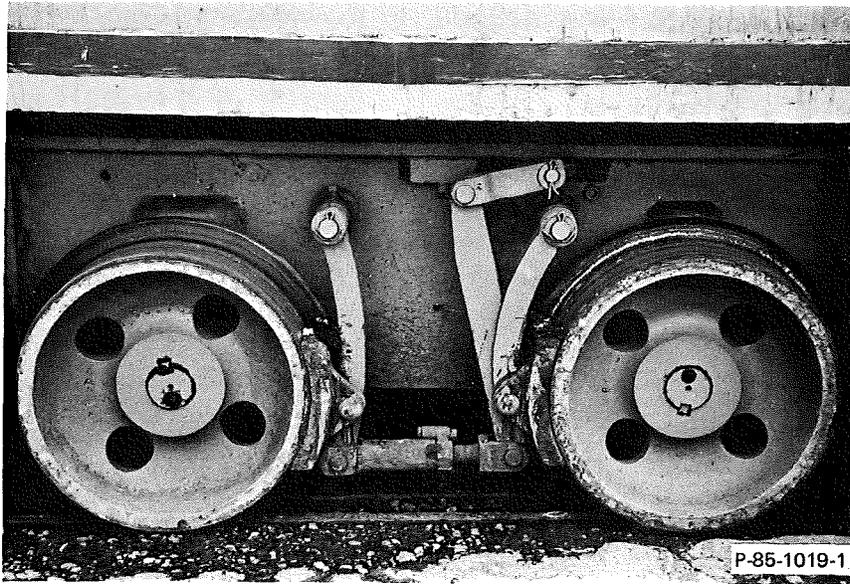


Figure 1 - Locomotive Brake Mechanism

system. Federal law 91-173, Section 314, Part E requires speed reduction gear or brakes on every car of a trip. Surface railroads have brakes on all the cars and the locomotive and Appendix B has a brief description of these brake systems.

#### 2.1.2 Car Trucks

Most of today's coal haulage cars have eight wheels; four wheels in a truck and one truck at either end of the car. This truck is similar to surface railroad trucks except that they are smaller and do not have power brakes. Those cars used near the mining face or for special purposes, such as personal carriers, do have hand brakes. The truck, as shown in Figure 2, supports the weight of the car on rollers mounted on a crossbeam, on which is also mounted the king pin. This crossbeam is mounted on springs which are grounded on the side plates which hold the axles. A variation of this type of truck is shown in Figure 3. These trucks are made by the "Differential Steel Car Company" with two 8 inch wheels in line, each pivoting about their own king pin. The two two-wheel trucks are connected by a cross bar which keeps them parallel. This type of truck is used more often in low-seam mining. A wheel system, which is used less, has four wheels located approximately 1/3 the length of the car from the end of the car as shown in Figure 4.

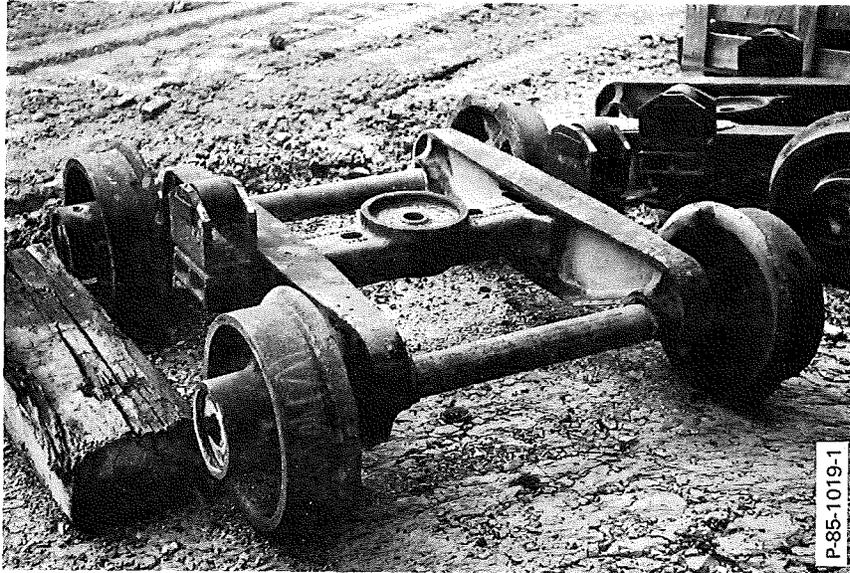


Figure 2 - A Typical Four Wheel Haulage Car Truck

### 2.1.3 Couplers

Automatic couplers, shown in Figure 5, which couple by impact are presently in use on most of the U.S. equipment and will be required on all U.S. equipment as of December 30, 1973. Rotary dump car couplers have one square and one round shank. When a car is rotated, the cars remain coupled and the round shank rotates in its housing. The car connection is released by pulling the uncoupling chain which releases the lock lever. The lock lever can also be released remotely when controlled by an air operated device. During coupling, the impact shock is absorbed by a spring or rubber shock absorber which reduces the possibility of derailment. The old and hazardous pin and link couplers shown in Figure 4 on a bottom drop car are in limited use.

### 2.1.4 Car Handling

In handling the cars, the cars are never turned around on the tracks. The coal is loaded into the haulage cars by conveyer belts or shuttle cars in the mining area and brought to a central dumping area. Two loading methods are generally used; the most common has a "U" shaped track. The empty cars are left at one end of the "U" and either a cable pull or power ram system is used to drive the cars through the bottom of the "U" where they are loaded. The locomotive picks up the loaded cars at the other end and brings them to the dumping area. In order to hold the cars while loading, it is necessary to use

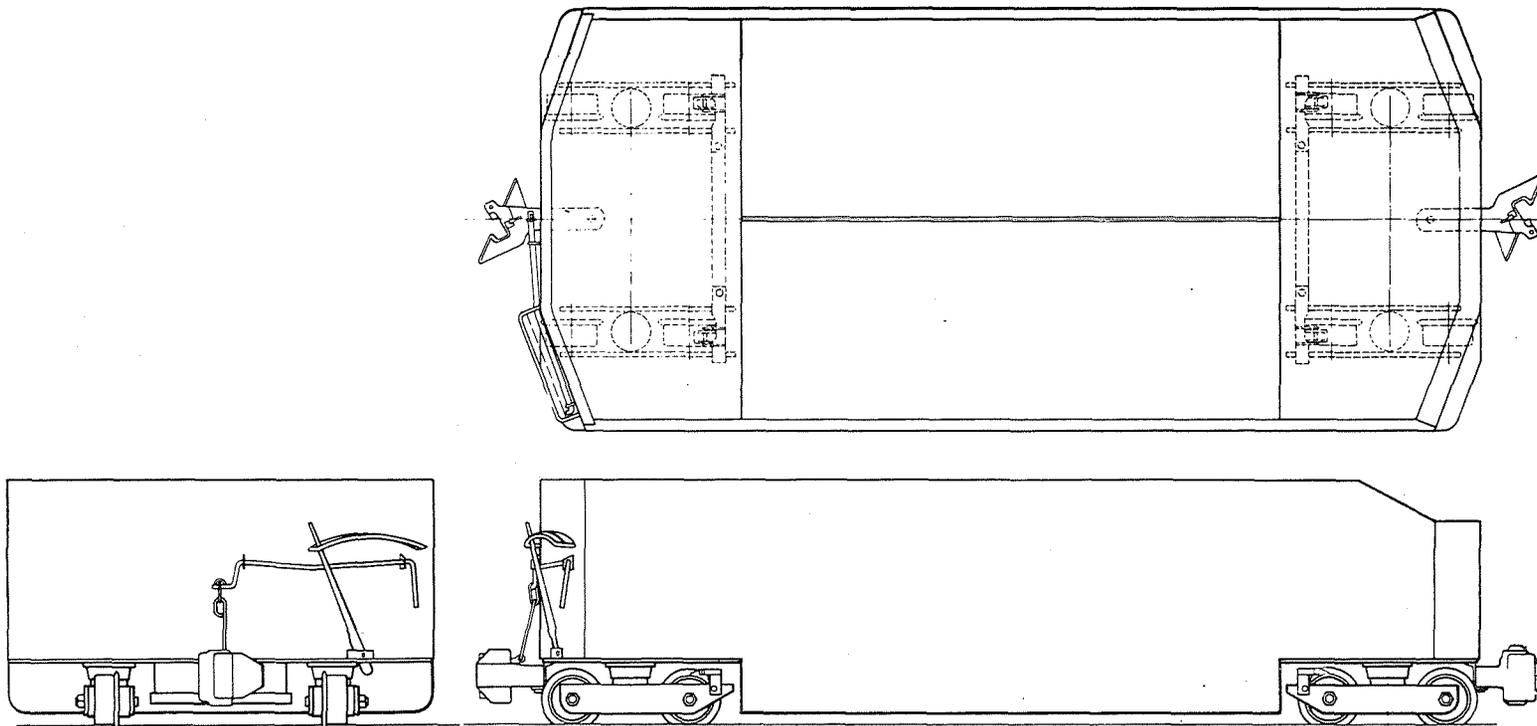


Figure 3 - Differential Car Truck Assembly

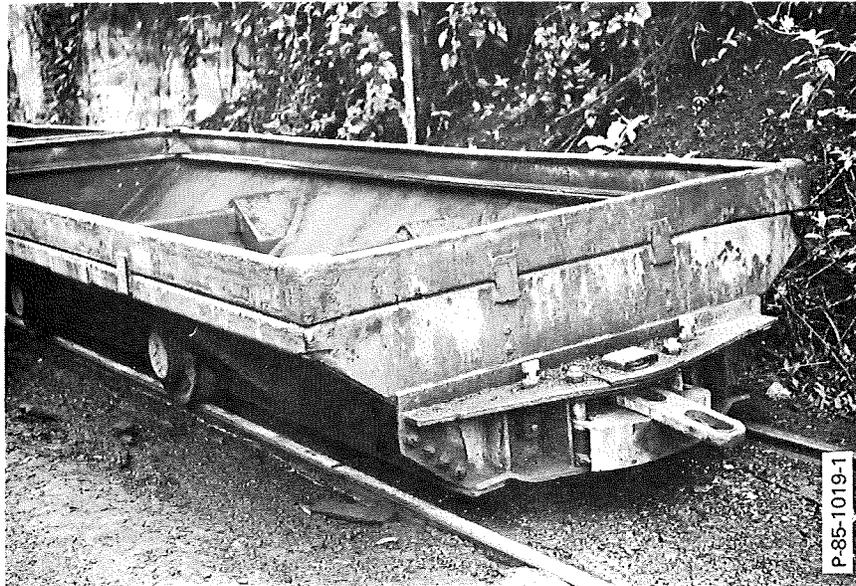


Figure 4 - Bottom Drop, Four Wheel Coal Car  
With Pin and Link Coupler

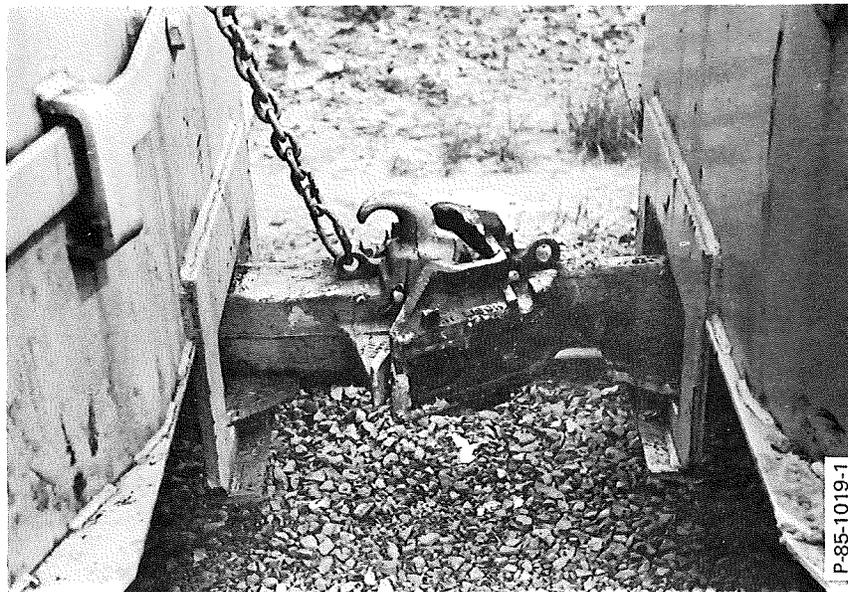


Figure 5 - Automatic Coupler on Rotary Dump Cars

slides or ramps under the wheels. Another method of loading cars is to have a small in-mine locomotive pick up a row of empties and back them past the loading equipment. They are then periodically pulled forward by remote control as they are loaded. The locomotive pulls the loaded cars out where they are picked up by the main line locomotive and brought to the dumping area. From the dumping area, the coal is loaded into trucks, surface trains, or barges to be shipped. There are several methods for unloading coal cars. The most common method is the rotary dump. One or more cars are driven onto a platform which retains the cars while rotating 360°. <sup>or 180°</sup> In this procedure the cars remain connected to the adjacent cars and the rotary coupling allows the required motion. Another method is the drop-bottom car where the car is driven over the dumping area and a catch opens the doors in the bottom of the car to let the coal fall from the car. The doors are then shut automatically at the end of the hole. Other dumping methods are side-dump and end-dump cars which apparently are no longer widely used in the United States.

#### 2.1.5 Locomotives

Locomotives are primarily powered by electric motors. Electric locomotives are identified by their electrical power supply, for example: trolley, cable-reel, and storage battery. "Permissibility" is required if the locomotive is to operate near the working face. The trolley type cannot be made permissible because of the possibility of a spark between the trolley shoe and wire. Locomotives required to operate near the working face and main haulage may have a combination of trolley and cable-reel or storage battery power supplies as shown in Figures 6 and 7, respectively. The locomotive may have four wheels as shown in Figures 8a and 8b or two four wheel trucks. There are two general types of four wheel truck assemblies: central pivot solid frame type, as shown in Figures 9a and 9b and the differential type with two wheels connected in-line and the pivot point between the wheels as shown in Figures 10a and 10b. Standard features generally include a dead man control to shut off the power if the locomotive operator becomes incapacitated. Also a mechanical brake capable of stopping the trip in a reasonable distance. Diesel powered locomotives as shown in Figure 11 have the advantage of permissibility and main line haulage capability in one system. The diesel exhaust is treated before it is released into the mine air. The treatment may be a simple water bath to remove smoke particles and cool the gas or more complicated gas treatment to reduce dangerous emissions.

Appendix A has more detailed information on locomotives, cars and regulation is described in U.S. Bureau of Mines Information Circular 8506, "Causes and Prevention of Transportation Accidents in Bituminous Coal Mines," by Ernest A. Curth.

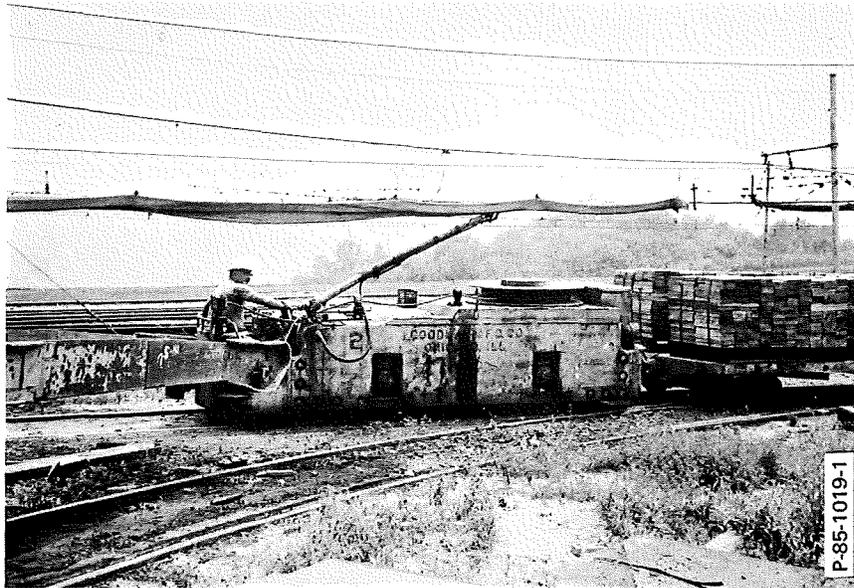


Figure 6 - Combination Trolley and Cable-Reel Locomotive

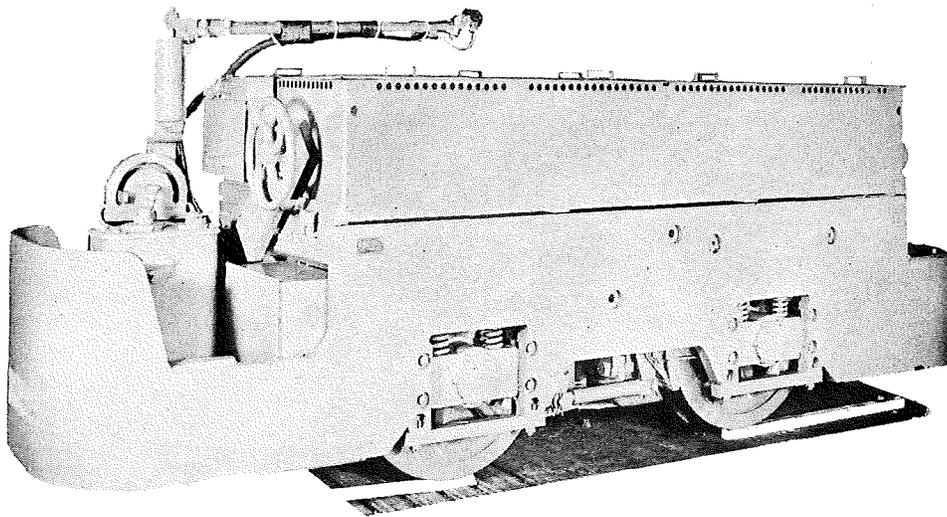


Figure 7 - Combination Trolley and Storage Battery Locomotive

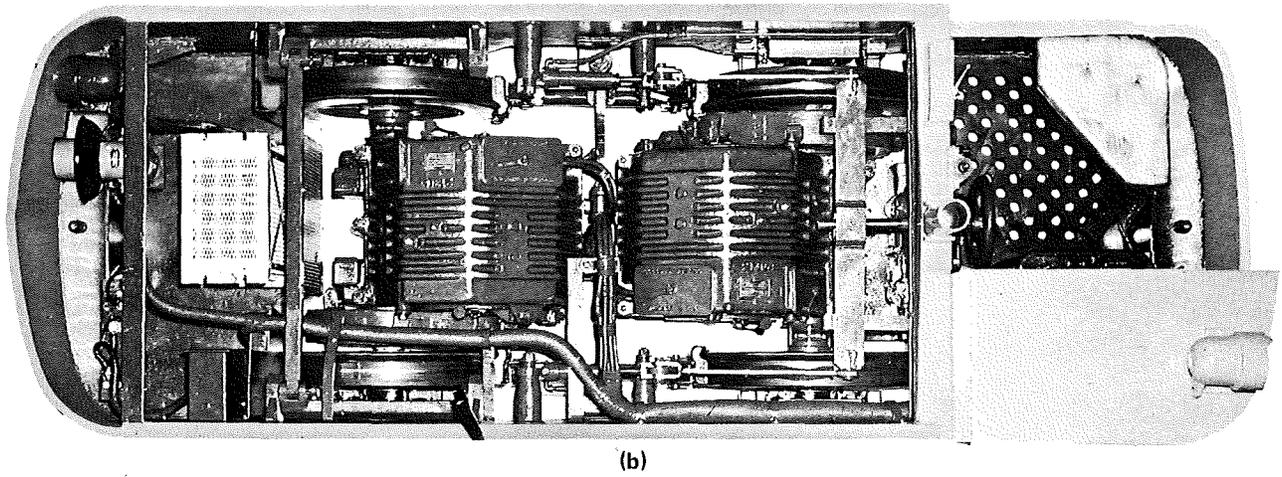
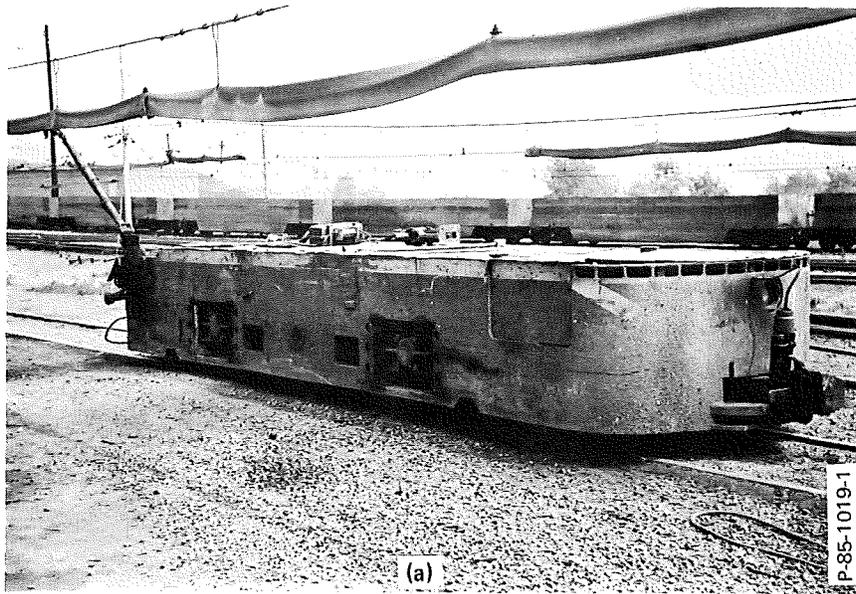


Figure 8 - A Typical Four Wheel Locomotive

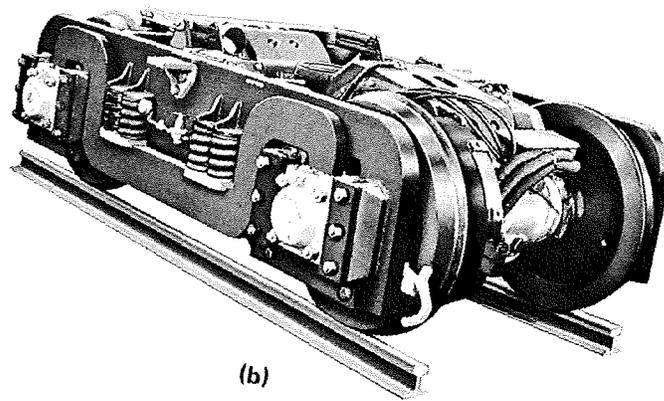
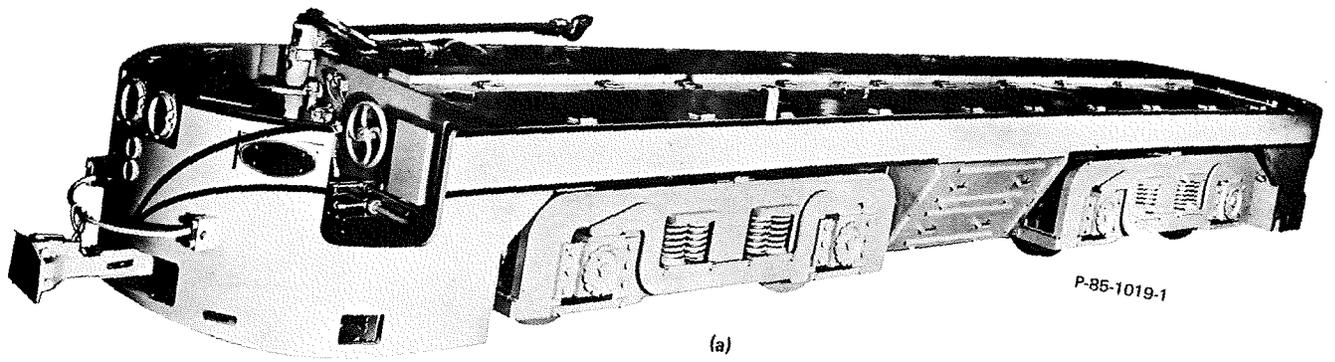


Figure 9 - A Large Eight Wheel Locomotive With Two Central Pivoted, Solid, Four Wheel Trucks

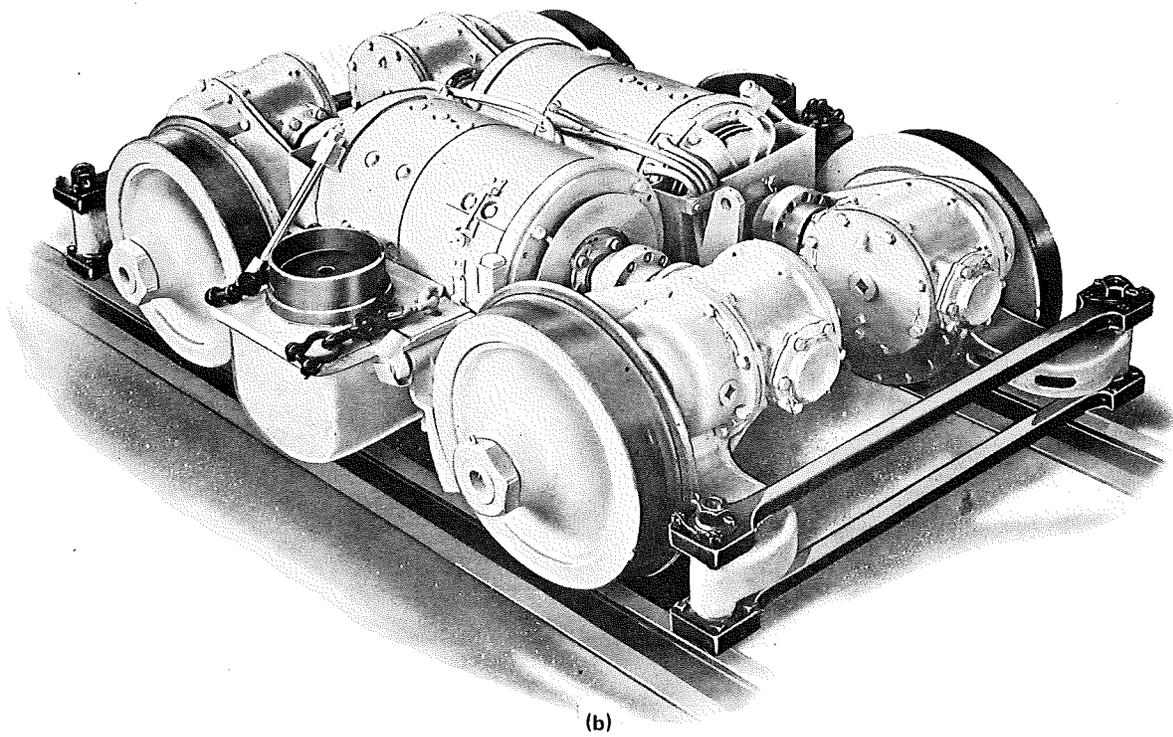
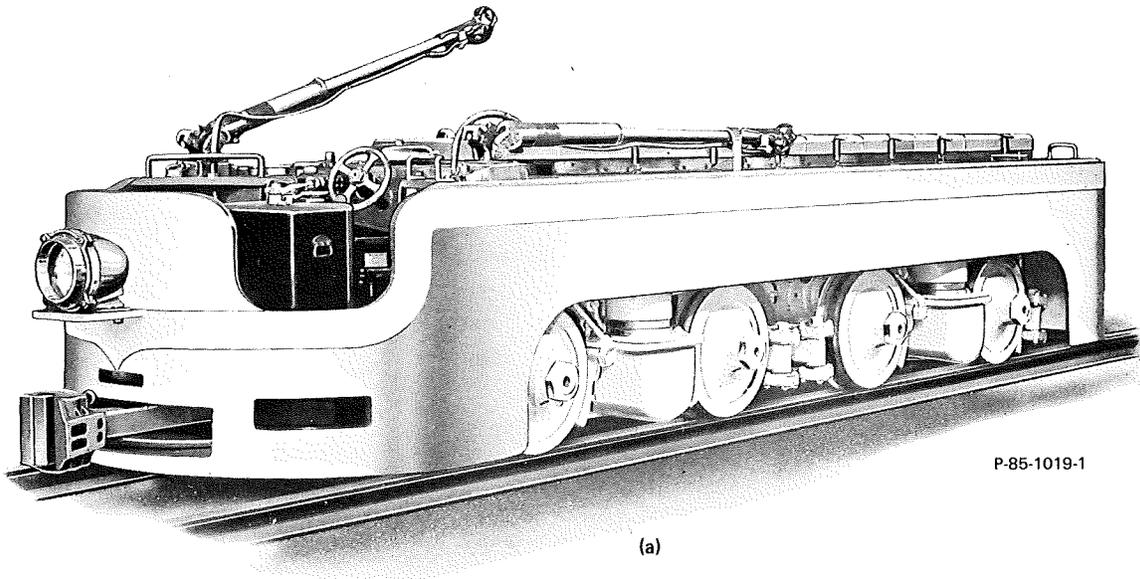


Figure 10 - A Differential Eight Wheel Locomotive With Two  
Wheels in Line and a Pivot Point Located Between the Wheels

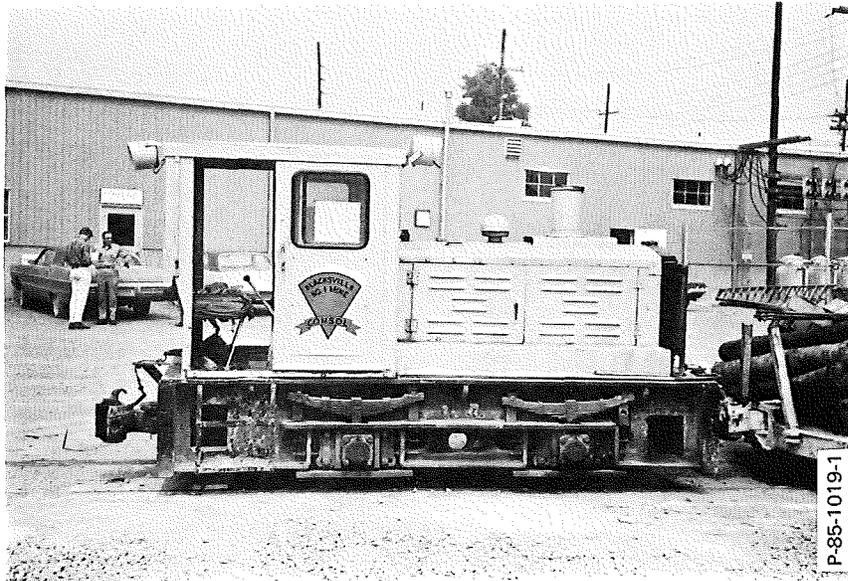


Figure 11 - A Diesel Locomotive

## SECTION 3 BRAKE SYSTEMS

### 3.1 SURFACE RAILROAD SYSTEMS

A typical surface railroad car air brake system is shown in Figure B-1. The main line is fed into a valve which operates the brakes. The valve senses main line pressure, reservoir pressure, and car load. When the main line is pressurized, the valve supplies the reservoir with the same pressure. Brakes are applied when the main pressure line is vented. The valve isolates the reservoir tank and brake cylinder from the main line when the main line pressure falls below the reservoir pressure. As the main line pressure decreases further, the reservoir supplies air to the brake cylinder with the maximum brake pressure regulated by the load sensor. Dependability of this system is improved by adding an emergency reservoir which acts in parallel with the auxiliary reservoir. Appendix B has an excerpt from 1961 "Car Builders Cyclopedia" published by Simmons Boardman which goes into detail on surface railroad brake systems.

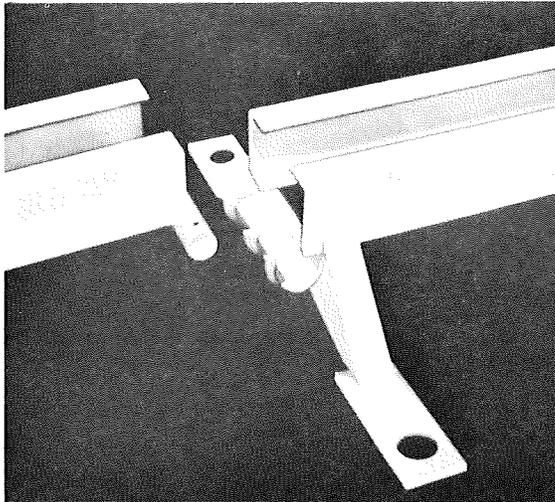
### 3.2 FOREIGN MINING TRACKED VEHICLES

A system similar to the Westinghouse air brake system is applied to a coal mine trip in the text, "Underground Electrical Haulage," by Professor Ludger M. Szklarski. A brief description of the system is enclosed in Appendix C.

Foreign contacts have provided information on tracked vehicles. Becorit Limited, a British based company, has a narrow track system, Figure 12, and a brake car which has high braking potential, Figure 13, because it is not dependent on the weight of the vehicle. The brake car friction members clamp onto the rail and are therefore, not weight dependent. Becorit also has an overhead monorail, Figure 14, which has a similar clamping mechanism to brake the trip. Arn. Jung of Germany has a "Troll" pneumatic mine locomotive, Figure 15, which uses a large supply of highly compressed air to run the main pneumatic engine.

Machine Design, a U.S. publication, provided information on European automatic couplers. A joint development program of the West-European (U.I.C.) and East-European (OSShD) surface railroad associations have developed an automatic coupler which automatically connects electrical and pneumatic connectors. Jaws are shown in Figure 16 in both precouple and postcouple positions. The service lines are covered and uncovered by protective caps. Figure 17 is a top view of cars ready for coupling.

## TRACK SECTION



### TRACK SECTION

The narrow track comprises two channel sections, B.S. 968 material, elevated from the floor and supported at the joint by a pedestal. The tracks are connected by means of a patented flexible joint which allows six degrees of movement in the vertical plane. Location points are provided on each track for the attachment of the different types of pulleys used with this system. The channel sections are raised from the floor by means of the pedestals, which assist in keeping the track section clear of floor obstructions. Despite this increased height, stability is maintained by the supporting feet, and at the same time, the minimum amount of roadway space is taken up by the track, due to its narrow section. The standard track length is 7ft. 6ins.

Special track lengths are available for main road systems if necessary.

To increase stability on bends and on gradients, floor bolts can be fitted through the hole in the pedestals.

### POINTS SYSTEM

The narrow section of the track facilitates the simple application of a well designed point. This greatly increases the flexibility of the system and allows several roadways to be serviced by one train of carriages. The point can be operated by a compressed air, hydraulic ram, electro actuator, or, if required manually, to suit the particular application.

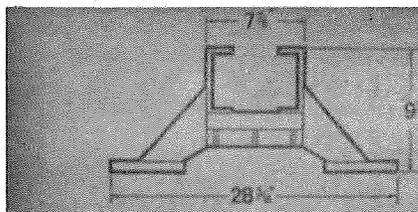
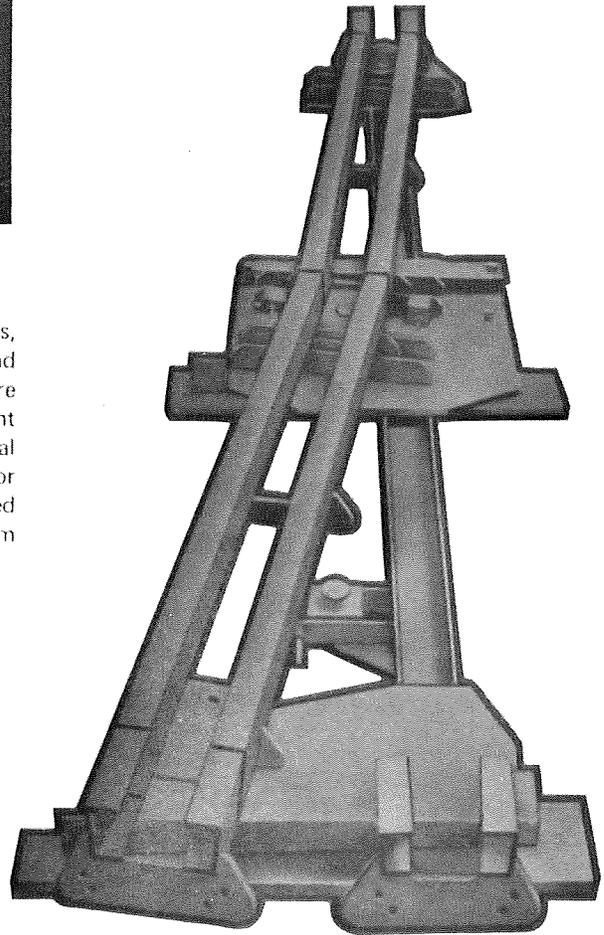
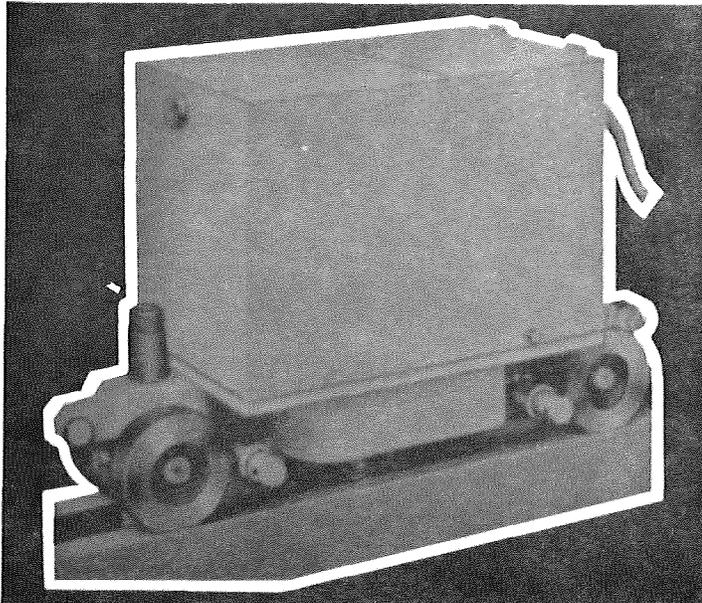


diagram showing overall measurements of track section

Figure 12 - Narrow Track System of Becorit Mining Limited

# HYDRAULIC BRAKING DEVICE



## OVERSPEED CONTROL UNIT

The braking device consists of a control unit and one or more brake units. The number of brake units is determined by the weight of the train and the maximum gradient.

**OPERATION.** A centrifugal clutch is driven by a spring loaded wheel running on the web of the track sections. In the event of the trip speed being reached the clutch engages. A cam profile on the clutch operates a release valve. This allows the fluid which maintains the brake shoes in the 'off' position to return to reservoir. The brakes are applied by springs. The system is 'fail safe'.

## BRAKE UNIT

The device consists primarily of 4 spring loaded brake cylinders which are held in the 'off' position by hydraulic pressure against the resistance of the brake springs. It has a valve, when in the 'operated' position, applying the required braking force necessary for the deceleration of the train. The train is held at a constant velocity by a spring loaded safety cylinder. The train is held in the 'off' position by a spring loaded safety cylinder. The train is held in the 'off' position by a spring loaded safety cylinder. The train is held in the 'off' position by a spring loaded safety cylinder.

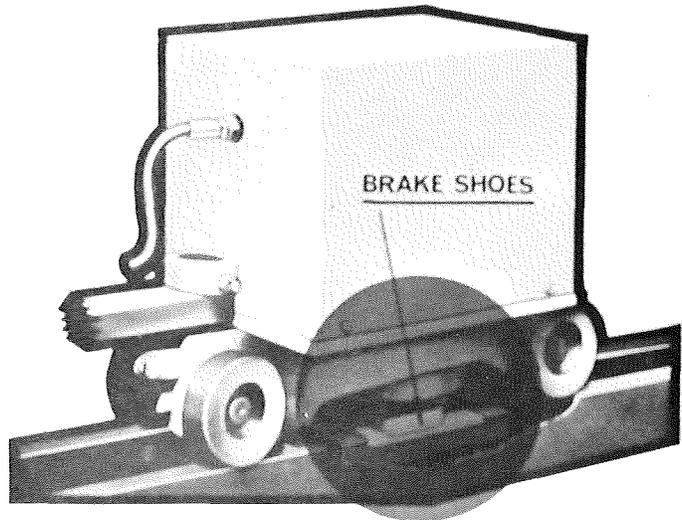
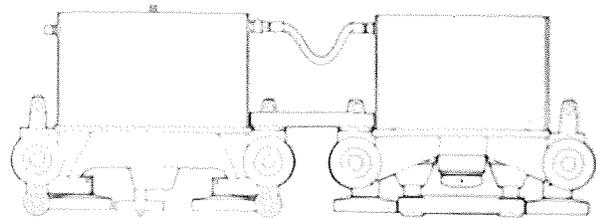


Figure 13 - Rail Clamping Brake System

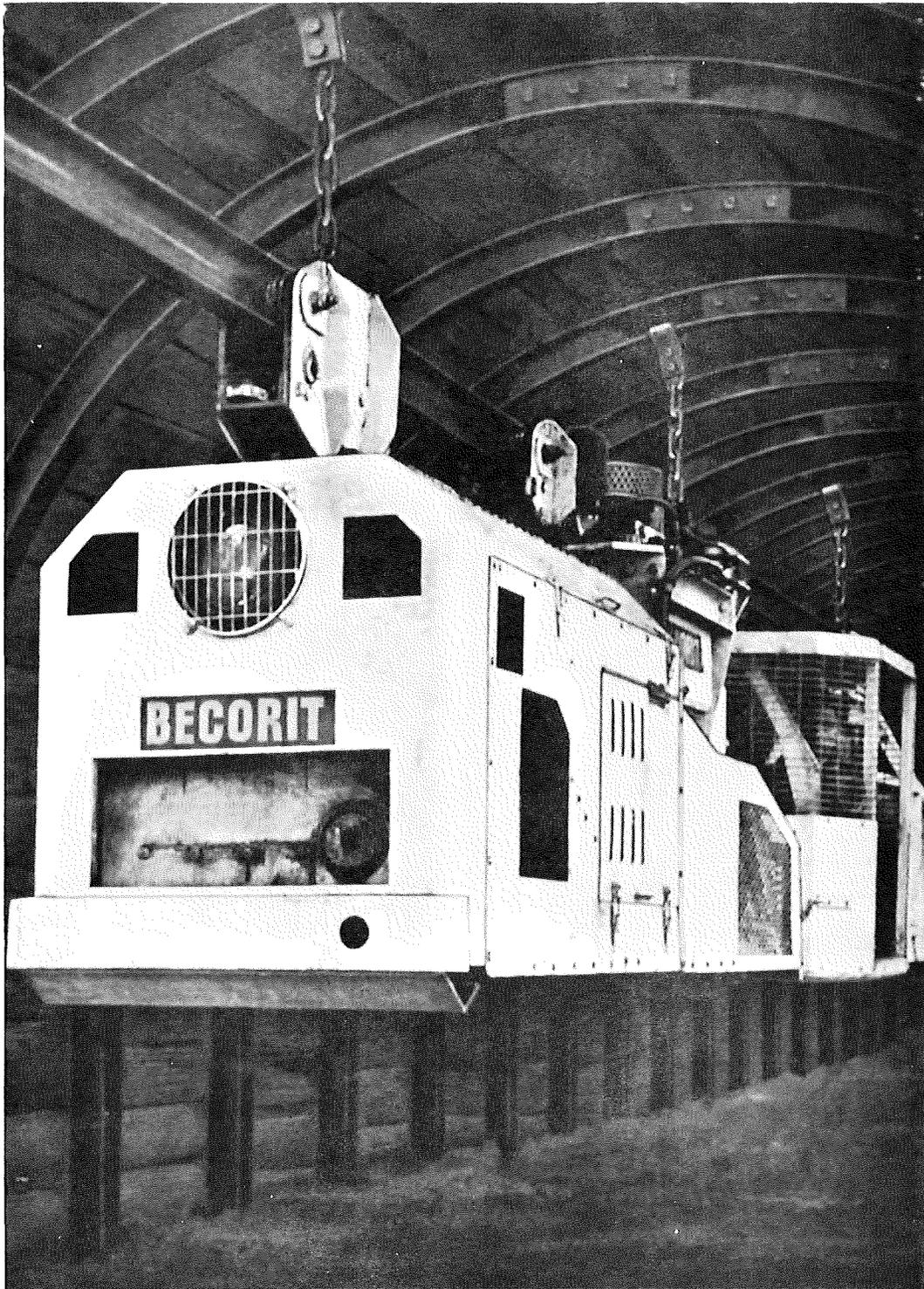
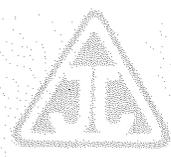


Figure 14 - Overhead Mono-Rail System of Becorit Mining Limited



PNEUMATIC  
MINE LOCOMOTIVES

Troll



**JUNG**  
**JUNGENTHAL**

Figure 15 - Pneumatic Locomotive of Arn. Jung, Lokomotivefabrik G.M.B.H.

# Design International

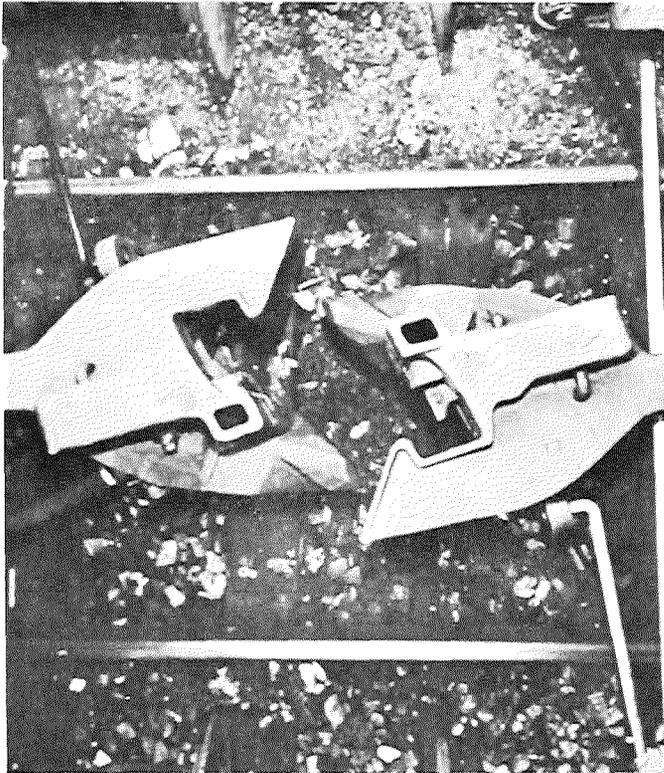


Figure 17

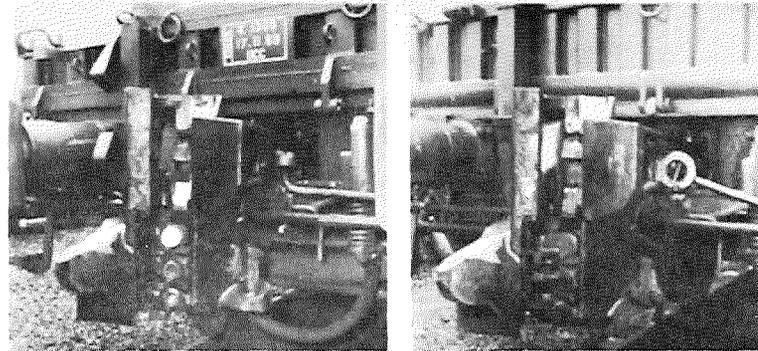


Figure 16

**AUTOMATIC COUPLERS**—West and East Europe have announced a joint program to equip all railroad cars with automatic couplers by 1981 and to make the devices mandatory after that date. Existing car buffers and screw-type couplers will be replaced with center-of-car designs consisting of electric and pneumatic-line connectors and jaws that engage when cars are pushed together. Jaws are shown open in both precouple and postcouple positions, the service lines are covered and uncovered by protective caps. A lever, operated from outside the cars, actuates a decoupling rod which opens the jaws. West and East European (including Russia) railroad associations spent 10 years developing and testing the design before formally adopting it. The all-Europe changeover will cost about \$4.8 billion, which includes \$625 million for West Germany's 250,000 cars. Expected paybacks are faster coupling operations, increased freight movement among countries, and reduced railyard accidents. —*Europe*

Figure 16 and 17 - Automatic Electric, Pneumatic and Mechanical Coupling Developed in Europe

SECTION 4  
DISCUSSION OF MINING PRACTICES

The objective of the coal miner is to mine coal safely and economically. This requires haulage equipment with: large capacity, simple operation, long life and versatility. Due to new federal requirements, the brake system will be extended to the cars. The new brake equipment should be simple, reliable and effective. It should also have certain safety and operational features. A desirable safety feature is to have the brake automatically applied on a runaway car. A desirable operational feature would be a mechanical override system which could release the brakes when the cars are being moved without the locomotive such as at the loading and unloading areas.

SECTION 5  
CONCLUSIONS

- (1) Adding brakes to the cars will mean extensive changes in the present braking systems.
- (2) Locomotives will have to increase the capacity, change to a new brake system or add a secondary system.
- (3) Cars will have to have: air transmission lines, filters and inter-car connection systems added.
- (4) Three types of wheels and axle arrangements exist: 8 wheel differential, 8 wheel truck, and 4 wheel body mounted, all have unique space limitation problems.
- (5) It will be desirable to add certain features to the braking system, such as a mechanical override or operation ability independent of the locomotive and automatic brake application in a runaway car.

## SECTION 6

### REFERENCES

- (1) Ernest A. Curth, "Causes and Prevention of Transportation Accidents in Bituminous Coal Mines," Bureau of Mines, United States Department of the Interior, Information Circular 8506, pp. 14-21.
- (2) 1961 Car Builders Cyclopedia, published by Simmons Boardman.
- (3) Professor Ludger M. Szklarski, Sc.D., "Underground Electric Haulage," pp. 24-32.
- (4) Public Law 91-173, Section 314, Parts e and f.
- (5) Bulletins D-52 and D-53, Differential Steel Car Company.
- (6) Catalogs G-155, G-193 and MED-210, Wabco, Mining Equipment Division.
- (7) Leaflet 1046, Jeffrey Manufacturing Company.
- (8) Bulletin (on Greensburg Diesel Mine Locomotive), National Mine Service Company.
- (9) Field Survey Conducted by Bendix Research representatives A. Blatter and J. R. Lorraine and Bendix consultant G. L. Judy.

## APPENDIX A

### LOCOMOTIVE AND CAR OPERATIONAL REQUIREMENTS (This Material is Quoted from Reference 1)

#### TROLLEY LOCOMOTIVES

Trolley locomotives operate on dc power, 250 or 500 volts, which is supplied over substations. The overload capacity of the motors permits them to haul heavy trips against severe gradients. Speed of underground haulage is 5 to 9 miles an hour for 4- to 15-ton units, 9 to 12 miles per hour for 20- to 60-ton units, and up to 20 miles per hour on extra-long hauls. The locomotive weight must be adequate for handling the load under adverse conditions. The required motor capacity is determined by root-mean-square calculation based on the track profile. Locomotives weighing over 20 tons are equipped with swivel trucks, eight wheels and four motors, to distribute their weight on the rails over more points and to help them negotiate curves with greater ease. Tandemizing of two smaller units will achieve some of the advantages of 8-wheel locomotives. Most tandems have air or hydraulic brakes, since mechanical brake linkage between units is not practical.

The standard locomotive brake is the handwheel, locking-screw type with large shoes acting on the wheels. Caliper brakes have been introduced in recent years. Like aircraft or automotive disk brakes, they clasp the wheels. Hydraulically actuated brakes permit faster stops. Airbrakes are desirable on units above 8 tons.

Many mine locomotives have been in service for 40 years or more and have been overhauled several times during their life. These old locomotives can be rebuilt to meet some of the safety and efficiency standards of modern equipment. The following safety features are applicable according to the size of the locomotives:

- (1) Rounded end frames, as high as the side frames and welded to them, serve as cab guards and offer protection and space for motormen and brakemen within their enclosure. Side cutouts give access to the cabs. Minimum thickness of steel for these cab guards should be 1 inch. In derailments the round end frames will guide the locomotive to a stop parallel to the roadway where a square-ended locomotive, on striking an obstruction, often turns into the rib with sudden impact and devastating effect.
- (2) Frames are made smooth and free of projecting boltheads and nuts. Side frames are cut away along the wheels or trucks to give maximum clearance off the rail for placing of rerailers.

- (3) Handholds are cut out in the frame or firmly welded or bolted to it.
- (4) Insulating seats and floor covering protect against the shock hazard.
- (5) Windshields are recommended for high-speed haulage.
- (6) Rerailers, jacks, and chains should be kept in easily accessible places.
- (7) Sanding devices can be hydraulically or air operated.
- (8) Auxiliary motor suspension by chain, lugs, or bar is a standard requirement to prevent motors from dopping down to the track and causing wrecks when the suspension fails.
- (9) Strong headlights permit the motorman to discern obstacles in time to stop the trip within the lighted distance. Main-line trams usually have two narrow beam sealed-beam headlights of 100,000 candlepower each at each end; gathering locomotives have one wide beam sealed-beam light of 20,000 candlepower at each end.
- (10) Dimming headlights prevents blinding of personnel.
- (11) Trolley shoes and shunts must be of adequate size to reduce sparking. Where pantographs or bows serve as power collectors, (...) cabs can be fully enclosed for better operator protection.
- (12) Automatic trolley-pole retractors lower the pole if the trolley shoe leaves the wire. Air-operated manual retractors are also available.
- (13) Reverse and controller drums are interlocked to prevent reversal unless the power is cut off. Locomotives of 11 or more tons need magnetic or electropneumatic contactors. Magnetic contactors are simpler and therefore preferable.
- (14) Headlight and control systems of main-line trams are powered by 32-volt batteries to assure lighting and dynamic braking even when the mine power fails or the trolley pole flies off the wire. Another advantage is low controller voltage. The battery is charged automatically from the trolley wire. This system replaces motor-generator sets in older locomotives.
- (15) All protective devices should be replaced after failure and not jumpered out or removed. For instance nullification of the no-voltage relay after power failure or cutoff may cause a runaway whenever trolley power is restored.
- (16) Dead-man controls by foot switch or handle on the controller will remove power if the motorman is incapacitated. They can also set airbrakes.

- (17) Dynamic braking is desirable when continuous grades are in excess of 1 percent. The armature current is reversed with respect to the fields so that the motors act as generators. The current is dissipated in the motor resistor. The locomotive is slowed down by dynamic braking and the airbrakes bring the trip to a complete stop. Dynamic braking saves brakeshoes and tires. Staggered dynamic braking by two separate electric circuits will make brake application even safer. Then, if an armature burns out, only two of the four motors become inoperable for brake application.
- (18) A low-pressure alarm will warn the motorman when the main air reservoir is low. Even more effective is a system which incorporates an auxiliary air tank. When main tank pressure drops below 60 psi, air from the auxiliary tank is automatically admitted to apply the brakes until pressure in the main tanks is restored.
- (19) Airbrake interlock will prevent wheels from sliding whenever dynamic and air brakes are applied simultaneously.
- (20) A track-brakeshoe system can supplement dynamic braking. The track brakeshoes, normally floating above the track, are drawn into contact with the rails when the track brake circuit is closed. The track brake circuit is fed from the dynamic brake circuit. Track braking effort is applied and increased with the dynamic effort (...).
- (21) A speedometer can be provided to warn against applying dynamic braking at excessive speeds.
- (22) All-purpose sealed roller bearings in the journals eliminate all but annual lubrication.
- (23) Traction motor bearings and center plates of swivel trucks can be lubricated remotely through hoses.
- (24) An air-operated device eliminates hazardous manual uncoupling of automatic couplers.
- (25) Traction motor blowers are essential to maintain the motor capacity.

#### CABLE-REEL LOCOMOTIVES

Cable-reel locomotives are used for gathering, supply, and development duty and for face haulage where coal is loaded directly into mine cars. Permissible cable-reel locomotives are equipped with two-conductor trailing cables to serve as gathering or face haulage units in by the last open breakthrough in gassy mines. The cable nips have to be fused adequately. Malfunction of the reel motor control might cause the locomotive to run over the cable or to pull it apart. Also the cable, through abrasion and its contact with rails and steel ties, constitutes a fire and shock hazard.

## STORAGE-BATTERY LOCOMOTIVES

Storage-battery locomotives are self-contained units which will operate wherever there is track. Any duty which draws heavy current such as main-line service should be avoided. However, battery locomotives of the permissible type compare favorably with the cable-reel units for supply, gathering, and face loading duty in gassy mines. The absence of trolley wire or trailing cable eliminates ignition and shock hazards. Batteries may be of the lead-acid or nickel-iron alkali type. They must be maintained and kept charged in charging stations. Exchange batteries are placed on racks and handled by hand, air, or electrically operated chain blocks suspended from an I-beam. Permanent battery-charging stations must be of fireproof construction and ventilated by separate splits of air conducted directly to the return air course, because batteries under charge liberate hydrogen.

## DIESEL LOCOMOTIVES

Diesel locomotives, like battery units, are self-contained. They offer a great advantage by eliminating ignition and shock hazards from trolley and feeder lines. There is little danger of fuel oil ignition if the oil is handled properly. The high compression ratio of the diesel engine, 1:16, makes it thermodynamically the most efficient internal combustion engine. Combustion is almost complete and, if the maximum permissible fuel-air intake ratio (by weight) is set properly after testing, the exhaust fumes contain little carbon monoxide and nitrogen dioxide, and their temperature is relatively low. The thermal efficiency of the diesel engine remains high, not only at full capacity, but also at lower capacities. These properties make the diesel very suitable for underground use. The Bureau of Mines has issued permissibility schedules for testing of diesel engines at the Health and Safety Research and Testing Center at Pittsburgh along with recommendations for ventilation, maintenance including adjustment of maximum fuel-air ratio, temperature of surface, fuel handling, fire protection, and repair-shop specifications in underground service.

Testing procedures are prescribed in the following Bureau of Mines schedules:

- S 22. Procedure for Testing Diesel Mine Locomotives for Permissibility and Recommendations on the Use of Diesel Locomotives Underground.
- S 24. Procedure for Testing Mobile Diesel-Powered Equipment for Non-Coal Mines.
- S 31. Mobile Diesel-Powered Transportation Equipment for Gassy Non-Coal Mines and Tunnels.

Diesel-powered equipment requires the following safety features:

- (1) Positive intake flame arrester.
- (2) Water-cooled exhaust manifold.

- (3) Exhaust conditioner to cool the exhaust gases from 1300°F to 160°F. Temperature of external surfaces shall not exceed 300°F.
- (4) Fail-safe thermal controls to automatically shut off the engine under the following conditions:
  - (a) Final exhaust gas temperature exceeds 170°F at discharge.
  - (b) Water-jacket temperature of the engine exceeds 212°F.
  - (c) Water in the scrubber is not replenished.

However, early predictions that "diesel locomotives may soon be used in this country's coal mines" have not come true.

#### MINE CARS

When mine cars had to be taken to the face, their size was limited by the face environment and the track. In modern mines the trend is toward larger cars. The largest in underground service carry 30 tons of coal. The majority are solid-body cars that are emptied in rotary dumps. However, modern drop-bottom cars are almost as leakproof as solid-body cars, if maintained. Their doors are overlapping and locked with safety latches to minimize the danger of their opening during wrecks or derailments, thus spilling the coal. When drop-bottom cars are used on man trips, the doors should be secured with chains or clamps. Endgate cars are used for shaft hoisting with self-dumping cages. They are still found in old shaft and slope mines. Their trouble is that after prolonged use their sides spread and allow a great deal of coal to spill. Modern mine cars are made of steel, steel alloy, or aluminum totally welded to give smooth surfaces. Their antifriction wheel bearings are greased every 4, 6, or even 12 months, depending on their use. The old plain bronze sleeve bearings need to be lubricated daily with heavy oil.

Trucks of 8-wheel cars are coil or rubber spring mounted and, like railroad stock, are equipped with centrally located sockets to receive two king-pins on the underside of the car body. Bumpers serve in connection with link and pin couplings to cushion the effects of buffering and snatching. They are often of the spring-loaded design, rounded to facilitate rounding of curves by rolling on each other and designed to maintain a minimum of 12 inches between the bodies of cars on straight track. With the swivel link and pin coupling it is possible to rotary dump a string of loaded cars without uncoupling. It is dangerous to couple and uncouple any of the link and pin, multilink, clevis and link, hook and link, or rigid couplings while the vehicles are in motion, particularly on the insides of curves. Using coupling hooks will help reduce this hazard. In railroad practice the link and pin method of coupling cars was outlawed in 1893 and automatic couplers have been required since then. Automatic couplers were adapted to mine use much later. The coupling is fully automatic, but the uncoupling has to be triggered by hand. Its rigging should permit safe operation from the

side of the car. Couplers can be designed with enough horizontal and vertical swing to permit articulation on sharp horizontal and vertical curves and to minimize the hazard of accidental uncoupling. Rotary couplers are made for rotary dumping of cars without uncoupling. A winglike design of couplers provides a wide gathering range and permits coupling on sharp curves. Rubber-cushioned draft gears were introduced in recent years for application with automatic couplers. They are composed of rubber pads, sandwiched with steel plates and bonded to them. The hysteresis of these rubber pads allows them to absorb more energy within themselves than the older steel-coil, spring-loaded gear can. Therefore, they are more able to cushion the car structure against jolts, to prevent derailments, and to ease the start of heavy trips.

Both lubrication and inspection of mine cars are best done close to the dump on the loaded side because the car stops at the same spot every trip. A high-pressure grease gun should be available. Visual inspection, of course, will disclose only the exposed parts, and an inspection program for maintenance should be devised to discover worn wheels, broken flanges, and bent axles that could cause derailments. If a hazard is found, the car should be pulled out of service and directed to the carshop. A testing device which senses heat radiations from hot journal boxes is used in railroad car maintenance and has been adapted for mine use. ... (An illustration) shows a detector rail which operates on the principle that a defective wheel has more rolling resistance than a good one. The short rail is spring loaded and deflected by a bad wheel to close a switch and to light a signal lamp. Table 1 (not reproduced) shows that failures of couplings take the first place as a cause of fatal accidents due to defective rolling stock. Breakage and accidental uncoupling cause runaways often followed by derailments and collisions. This involves couplings of all descriptions, link and pin as well as automatic couplers. Therefore, the main load-bearing components of couplings should be examined frequently.

When cars have to be taken to the faces, well-maintained hand car brakes are essential in the control of cars. The brake operating lever should be in easy reach of the brakeman so that he does not have to step between cars. However, trip handling in modern track haulage makes hand car brakes unnecessary, though parking brakes are desirable.

Cars for special purposes are supply cars, flatcars, equipment carriers, ballast cars, rail, timber, or fire trucks, and man-trip cars. Defective old mine cars, no longer subject to the routine maintenance of the mine cars in circulation but still used to haul supplies to the face and refuse to the surface, cause many wrecks of supply trips. Modern 8-wheel flatcars, furnished with stakes around their outside edges and often with parking brakes, can move supplies faster and more safely. They can take packaged supplies in pallets from yards to the section with minimum handling, or they can carry the rubber-tired supply to a point where they can be pulled off and taken to the face by battery tractor. Equipment carriers, called "low boys," are used to move treaded, rubber-tired, or stationary equipment of all descriptions. This eliminates

hazards such as contacting trolley wire, running over cables, fouling of cables at ties and switches, and squeezing or crushing operators between equipment and roof or rib, which are likely to occur when rubber-tired or treaded units are trammed along the track.

Man-trip cars are 8-wheel units, mounted on steel coil or rubber sprung trucks. They hold up to 38 men and come equipped with hand parking brakes and safety chains across the access openings. They are covered to protect the workers against the falls of roof and rib and have top insulation to protect against contact with trolley and feeder lines. They provide a comfortable ride and a shelter against high air velocity, flying sand and coal particles, as well as against intemperate weather on the surface. Other advantages of portal transportation by man-trip cars are minimum interference with coal haulage, because the coal cars, relieved of man transportation, can be kept in circulation continuously. Traffic control is simplified and the safety of the system will benefit.

## APPENDIX B

### TRACKED VEHICLE BRAKE PRACTICE (This Material is Quoted From Reference 2)

#### AIR BRAKES

The Straight Air Brake is the original form of the Westinghouse air brake. With this form of brake, the compressed air is used as a direct force from the main reservoir supply of the locomotive, through direct piping to the brake cylinders on each car to apply the brakes. A valve on the locomotive is used to admit air to the brake pipe and brake cylinders in order to apply the brakes, to hold it there when admitted and to exhaust it when desiring to release the brakes.

The Automatic Air Brake is designed so that the brakes will be applied automatically in case air escapes from the system. To accomplish this there is added to each car an auxiliary reservoir, in which is stored a supply of compressed air sufficient to operate the brake on that vehicle, and a triple or other valve to which the brake pipe, auxiliary reservoir and brake cylinder are all connected.

The brake is applied by reducing the pressure in the brake pipe below that in the auxiliary reservoirs. Such reduction results when the engineer opens the brake pipe to the atmosphere through the brake valve, or accidental, as in case of a burst hose or broken pipe. The reduction in brake pipe pressure thus made destroys the equality of brake pipe and auxiliary reservoir pressures and the auxiliary reservoir pressure, being then higher than that in the brake pipe, causes the triple valve on each car to operate so as to close the passage between the brake pipe and the auxiliary reservoir, and to apply brakes by admitting compressed air from the auxiliary reservoir to the brake cylinder, where it exerts its pressure on a piston, pushing it outward and thus applying the brakes.

The brake is released by admitting compressed air from the main reservoir on the locomotive through the brake valve into the brake pipe, thus increasing its pressure above that remaining in the auxiliary reservoir. This causes the triple valve parts to return to their original positions, again opening communication from the brake pipe to the auxiliary reservoir, recharging the latter and making a connection through which the compressed air in the brake cylinder escapes to the atmosphere, thus permitting the release spring in the brake cylinder to return the piston to its former position, thereby releasing the brakes.

The application of the principle of differential pressures on which the triple valve of the first automatic air brake operated has permitted the addition of functions to the control valves of present day freight- and passenger-train brakes which have greatly speeded the serial application and release of brakes, and improved reliability of performance.

## "AB" FREIGHT BRAKE

The present standard, freight-car brake is the Type "AB". This has been required on cars built after September 1, 1933, and is now required on all cars interchanged.

The AB freight brake has increased the speed of serial action in both application and release of brakes over that possible with the K type triple valve which preceded it. It permits effective control of much longer trains than could be handled safely with the preceding brake.

The brake consists essentially of the AB valve, the brake cylinder and a two-compartment auxiliary and emergency reservoir. There are two operating parts of the AB valve and a pipe bracket to which both are bolted and to which all pipes are permanently connected. The operating parts of the valve are a service portion and an emergency portion. There are three stages of quick service; which provide a prompt and positive brake application on all cars of long trains. Using emergency reservoir pressure for the initial recharge of the auxiliary reservoir assists in securing a certain release of all brakes after a service application. The discharge of brake cylinder and auxiliary reservoir air into the brake pipe during release assists in accomplishing the same result after an emergency application. Emergency quick action can be obtained at any time, irrespective of the degree of service application or release. Emergency brake cylinder pressure is about 20 percent higher than that obtained from a full service brake application. The speed of emergency quick action through the train is approximately 40 percent faster than that obtained with the former standard freight brake.

A modification, the AB-1-B brake, is used on freight cars occasionally utilized in passenger service. For passenger service the car is fitted with a signal pipe. When charged, the AB-1-B valve is adjusted for passenger service.

## THE "AC" FREIGHT BRAKE

The AC brake valve performs essentially the same functions as those performed by the AB valve and operates in harmony with it. The arrangement of elements, however, has been changed and simplified and the weight of the removable portions reduced approximately 40 percent. Ring-packed pistons are replaced by diaphragm pistons. Except at two locations, slide valves are replaced by spool valves with rubber seal rings. By dumping emergency reservoir air to the brake-pipe side instead of to the auxiliary-reservoir side of the service diaphragm piston, as is done in the AB valve, the speed of serial action in release has been greatly increased.

Recently the air brake manufacturers have introduced conversion kits which replace some of the ring-packed pistons in the conventional AB valve with the diaphragms introduced with the AC equipment.

## EMPTY - LOAD BRAKE

Light weight materials have made possible the construction of freight cars which would be braked excessively when empty, or would be grossly under-braked when loaded. This has resulted in the development of the empty-load brake. Originally a second brake cylinder was made operative by placing a valve in Load position.

The automatic empty-and-load brake includes an operated change-over valve that is replaced by automatic change-over apparatus which consists of a strut cylinder installed on the end of the truck bolster and the automatic change-over valve. The strut-cylinder piston, normally held in release position by a spring, is pushed down until its foot contacts a bracket on the truck frame when the brake pipe is charged from a pressure below 30 psi. This measures the truck spring deflection. When the deflection is less than one-half, the strut piston uncovers a port in the cylinder wall which feeds air back through a second pipe connection to the change-over valve and determines the setting for the empty brake cylinder only. When spring deflection is one-half or more of full-load deflection the strut piston does not uncover the port and the change-over valve causes the load cylinder to operate with the empty cylinder. The change-over valve functions to cause sufficient pressure to build up in the empty brake cylinder to take up brake rigging slack before pressure is admitted to the load brake cylinder from the load-cylinder reservoir in order to keep down the air consumption. It also functions to cause the load cylinder to release in advance of the empty cylinder.

Freight cars must now be equipped with the brake cylinder release valve, a device which makes it possible to exhaust the cylinder and release the brakes on the car without draining the main and auxiliary reservoirs. This speeds the recharging of the train brake systems after cars are assembled in trains.

## HIGH SPEED BRAKE

In high speed passenger service a greater brake shoe pressure may be applied to the wheels at high speeds than at low speeds without danger of sliding the wheels. By utilizing this principle the length of the stop may be reduced. This was accomplished at first by the use of a lower brake pipe pressure with the standard quick action apparatus and the addition of a high speed reducing valve attached to the brake cylinders.

The Universal Control brake for passenger cars was one of several brakes which were developed to supersede the triple-controlled high-speed passenger brake. The universal control valve possesses features made necessary by the increasing severity of passenger train operating conditions.

The HSC electro-pneumatic passenger brake, like the Universal Control brake which preceded it, includes electro-pneumatic transmission of

brake application and release which reduces serial-action time to zero, speed-governor control by which brake-shoe pressure is reduced as speed reduces to maintain retardation force at a value approximately equal to wheel-rail adhesion as speed reduces, and Decelostat® Control of wheel slipping which reduces braking force momentarily, in anticipation of wheel sliding, until wheel-rail adhesion is fully restored.

The controlling parts of this brake are the D-22-BR control valve, the F-1864 relay valve, combined auxiliary, emergency and displacement reservoir, magnet valve, two brake-cylinder supply reservoirs, a straight-air pipe which is connected on all cars of the train, the speed-governor control equipment and the Decelostat® equipment.

Unlike the triple-valve brake equipment, the D-22-BR control valve does not directly control the development of brake-cylinder pressure during brake applications. Its direct control is over the development of pressure in the displacement reservoir which, in turn, controls the brake cylinder pressure through the relay valve. Brake-cylinder pressure is maintained from the supply reservoirs at the pressure called for by the displacement reservoir, irrespective of brake-cylinder leakage or piston travel. This pilot valve action of the control valve insures brake-cylinder pressures which precisely follow brake pipe reductions when operating automatically.

In full HSC operation the control of application and release is effected through electrical connections from the locomotive to magnet valves on each car. The application magnet valve releases air from the auxiliary reservoir to the straight air pipe which, in turn, determines the brake-cylinder pressure through the relay valve. Automatic operation is always available in case of failure of electrical circuits or of the straight air pipe.

Latest high-speed brake is the 26 equipment which incorporates many of the features of the AC brake in the more highly refined control device. Diaphragms are used throughout this lightweight equipment.

The Train Air Signal Apparatus is a substitute for the older bell cord method of passenger train signal and is arranged to give train signals by the use of compressed air. A separate line of signal pipe, similar to the brake pipe, extends throughout the trains, with hose and couplings between cars. A car discharge valve, connected to this signal pipe, is located in each car and attached to the bell cord in such manner that pulling on the cord releases air from the signal pipe. In the cab on the engine or motor car is a signal valve, which is also connected with the main signal pipe and a small signal whistle.

When the car discharge valve is opened, by pulling on the cord, the diaphragm in the signal valve is operated by the differential created by the reduction of pressure in the signal pipe, so as to blow the whistle.

## TRACTION AIR BRAKES

The Traction Air Brake is an adaptation of air brake equipment to electrically propelled cars or trains. The changed conditions of motive power and method of operating such cars or trains have necessitated changes in the details of brake equipment, and the "AMUE" Electro-Pneumatic Brake is now used. This is a modification of the "HSC" Brake.

The complete Electro-Pneumatic Brake is designed for use on long high speed electric trains, such as are used in subway service. In addition to the functions performed by a quick action automatic air brake means are provided for applying and releasing the brakes on each car through the action of electro-pneumatic valves energized by current taken from contacts on the motorman's brake valve and continuous train wires. With this device brakes on long trains can be applied instantaneously and simultaneously, eliminating surging.

Because most transit cars now have a combination of air and dynamic braking, the latest transit brake, known as the SMEE equipment, provides for control of both of these functions. Most braking of the train is done with the traction motors operating as generators. At low speeds this brake fades and the SMEE equipment operates to make a smooth air application and bring the train to a stop.

## VACUUM BRAKE

The Vacuum Brake is a system of continuous brakes operated by exhausting the air from some appliance located under each car, by which operation the pressure of the external air is transmitted to the brake levers and shoes. It is so called in distinction from air brakes, which are technically understood to refer only to brakes operating with compressed air, although in a literal sense the vacuum brake is also an air brake. An ejector on the engine, connected with the rest of the train by pipes and flexible hose between the cars, is ordinarily used for exhausting the air. Under each car is a large cylinder with a piston and rod connected to the brake levers actuating the brake shoes.

## BRAKE GEAR

Application of braking forces on freight and passenger cars has been the subject of much development over the past decade. The period has seen the introduction of the truck-mounted unit brake on many passenger cars and the application of disc-type brakes to freight cars. It has also been marked by the introduction of the non-metallic (composition) tread-type brake shoe. For many years the braking force on both freight and passenger cars was developed in a single body-mounted cylinder and transmitted to the trucks and then to the wheel treads through a system of rods and levers. This is the arrangement standard on most freight cars now in service.

The rod-and-lever system involves a large number of pinned connections; its greatest economy results from the use of only a single brake-cylinder. In addition to the lost motion which can develop in this system

when brake shoes wear, slack can develop within the mechanical linkage between the cylinder and brake shoes.

Slack adjusters, growing in popularity for some time, are now required on all new freight cars. There are several different systems. Some of the automatic adjusters are pneumatic and are mounted adjacent to the brake cylinder. Other automatics are mechanical and may be installed elsewhere in the brake system; the power necessary for their operation is usually developed during brake applications and stored in a spring system within the device. There are also several manual devices. All of these adjusters must be designed so that they may be released to permit the changing of brake shoes. Every type is intended to make it unnecessary to correct excessive piston travel during train yard inspections; this defect may even involve stopping of the car.

Because of the car weights, speeds, and precise control required for braking in passenger train operations, the introduction of the steel passenger car resulted in the use of large brake cylinders and clasp-type brakes to give high braking forces. Only on the heaviest of freight cars have clasp brakes been required. When the lightweight passenger cars came into use, it became the accepted arrangement to use truck mounted brake cylinders to operate the clasp brakes. These cylinders reduced the forces which had to be transmitted and cleared the bottom of the car body for the installation of electrical and air conditioning equipment. At the same time some of the maintenance problems involved in using conventional brake rigging were eliminated. Shortly after the truck-mounted brake cylinders came into use on passenger cars, disc brakes were introduced.

The disc brake removes the braking function from the car wheels. A finned brake disc is mounted inboard of each wheel and braking force is developed in an individual cylinder mounted so that it operates the composition shoes directly, bringing them on the brake disc. During the past five years the disc-type brake has been applied to freight cars. Some designs permit it to be used on existing freight cars with the single-body-mounted brake cylinders. Other arrangements allow it to be mounted on existing trucks, but involve truck-mounted brake cylinders which are part of the brake design. Because the design of the specialized brake such as this does not involve space and other limitations, it has been possible to proportion the elements to produce high braking forces with a minimum of maintenance.

To meet this competition, the composition brake shoe has been introduced for tread-type brakes. It has a high coefficient of friction which permits the development of high braking forces. Its frictional characteristics, according to its proponents, do not vary with speed and give uniform retardation during stops. Latest development has been the use of this shoe with package-type brake units which are mounted on the trucks. Package type brake units eliminate the level-and-rod systems on the trucks. One freight car design has a pair of direct-acting cylinders which are mounted between the brake beams and eliminate all need for slack adjusters. The passenger

car designs involve a separate cylinder for each wheel and includes the lever system, slack adjuster, brake head and brake shoe in a single package which is mounted on the truck frame.

#### DESIGN FUNDAMENTALS

The AAR Mechanical Division specifies the braking forces which are to be developed on freight and passenger cars. All freight cars in interchange service having single-capacity brakes must have a nominal braking ratio of not less than 50 percent, nor more than 75 percent, of the empty car weight, based on a brake cylinder pressure of 50 psi. Minimum braking ratio for new freight cars must be 18 percent, and preferably 20 percent, of the gross rail load, based on 50 psi brake cylinder pressure. The braking ratio of freight cars with empty-load brakes is not to be more than 60 percent of the light weight of the car, based on 50 psi brake cylinder pressure. The braking ratio of such cars, when loaded, is to be from 27 to 33 percent of the nominal capacity plus light weight, based on 50 psi brake cylinder pressure.

When cars weigh too much to permit the use of the AB-10 single-capacity freight brake with 10-inch diameter brake cylinder, it may be necessary to use a dual AB-10 installation or to utilize a 12-inch brake cylinder. If multiple brake cylinders are utilized, it is permissible to use relay valves in conjunction with a single AB control valve.

For freight cars with single-capacity brakes, the brake cylinder must be of a size that will require a lever ratio of no larger than 10.5 to 1. Piston travel for freight cars with body-mounted 8-inch and 10-inch cylinders is not to be less than 7 inches nor more than 9 inches.

Passenger cars must have a braking force of 90 percent of the light weight of the car, based on an equalized brake cylinder pressure of 60 psi. The braking force is to be 150 percent of the light weight of the car with brake cylinder pressure equalized at 100 psi. When the brake equipment includes HSC speed-governor control, a braking force of 250 percent of the light weight of the car is to be produced with a cylinder pressure equalized at 100 psi. With passenger cars having six-wheel trucks, the brake leverage ratio must not exceed 8 to 1 for single-shoe brake gear, and 9 to 1 for clasp-brake gear.

All interchange cars, both freight and passenger, must be fitted with handbrakes. On cars with multiple brake cylinders, it may be effective on only one truck.

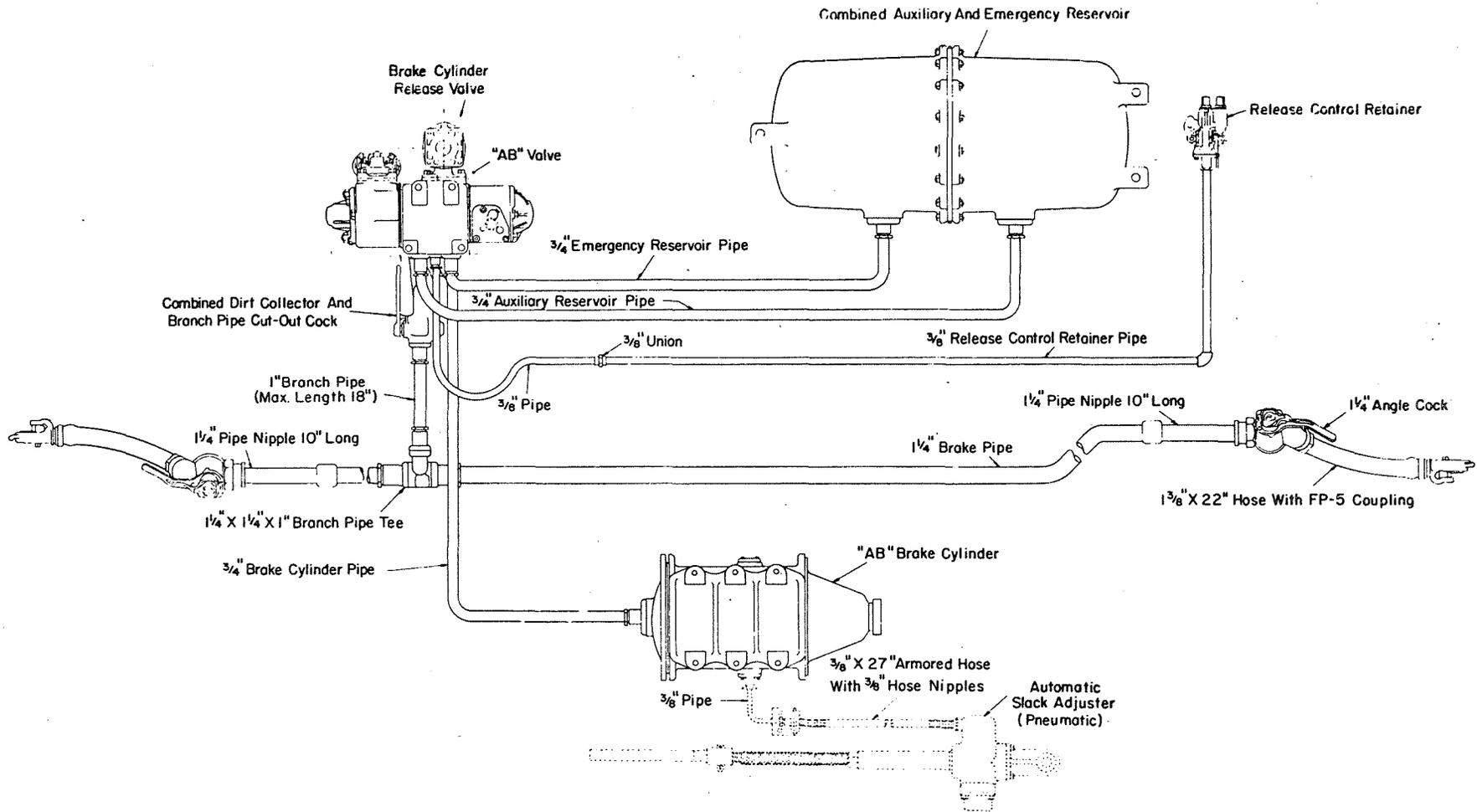


Figure B-1 - Westinghouse AB Freight Car Brake Piping Diagram

## APPENDIX C

### ELECTRIC LOCOMOTIVE BRAKE GEAR (This Material is Quoted From Reference 3)

#### HYDRAULIC BRAKE

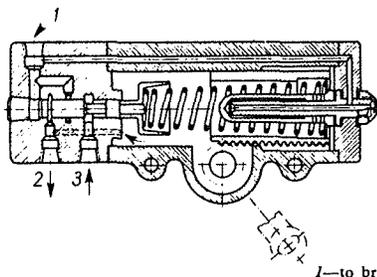
The design and the functioning of the brake valve are shown in Figures C-1 and C-2. Figure C-1 shows the valve in the BRAKE OFF position when the brake is released and no oil is forced into the brake cylinders. By turning the handle of the brake valve to the BRAKE ON position (Figure C-2) the slide valve inside the valve cylinder is moved to the left thus allowing oil to be forced into the brake cylinders. As the slide valve is moved to the left, more oil is forced into the brake cylinders and a greater force is applied on the brake shoes. Brake valves of this type allow the driver to regulate the oil pressure in the brake cylinders and they also facilitate emergency braking. In case of emergency the valve handle is turned with one quick movement to the extreme BRAKE ON position.

The arrangement of the particular parts of the oil brake inside a locomotive is shown in Figure C-3. The oil brake can be combined with a hand brake by providing with longitudinal slots (1) the coupling bars activated by the traverse in the manner shown in Figure C-4.

#### AIR BRAKE

The air brake can be activated either by compressed air or by vacuum, i.e., by the decompression of air in the brake cylinder. The braking system used in mine haulage is of the compressed-air type.

Figure C-5 shows the simplified air-piping connections for a compressed air brake. The low-power compressor (2) driven by the d.c. motor (1) forces air from the intake filter (3) through the non-return valve (18) to the main reservoir (4). When the pressure in the main reservoir reaches the desired maximum the pressure control governor (5) switches off the compressor motor. The main reservoir is equipped with a safety valve (16). From the main reservoir (4) air passes through pipe (6) to the driver's brake valve (7). On starting the train the driver sets the brake valve (7) to the position in which air can pass from the main reservoir through the main pipe line (13) to all the secondary pipes (9) of the braking system. At the same time the auxiliary reservoirs (11) are filled through the triple valves (10) actuated automatically by air pressure in pipes (9). The position of the triple valves (10) is then such that the brake cylinders (12) are disconnected from the pressurized pipes and the brake is released. The driver can now start the train. To apply the brake the driver sets the brake valve (7) to the position which allows air to escape from the main pipe



1—to brake; 2—return pipe; 3—brake pipe.

Figure C-1 - Hydraulic Brake Valve in Off Position

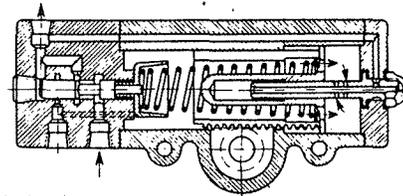
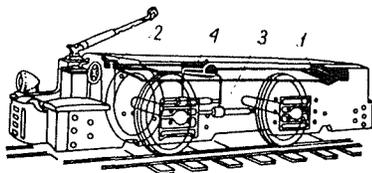
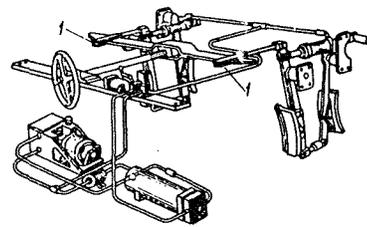


Figure C-2 - Hydraulic Brake Valve in On Position



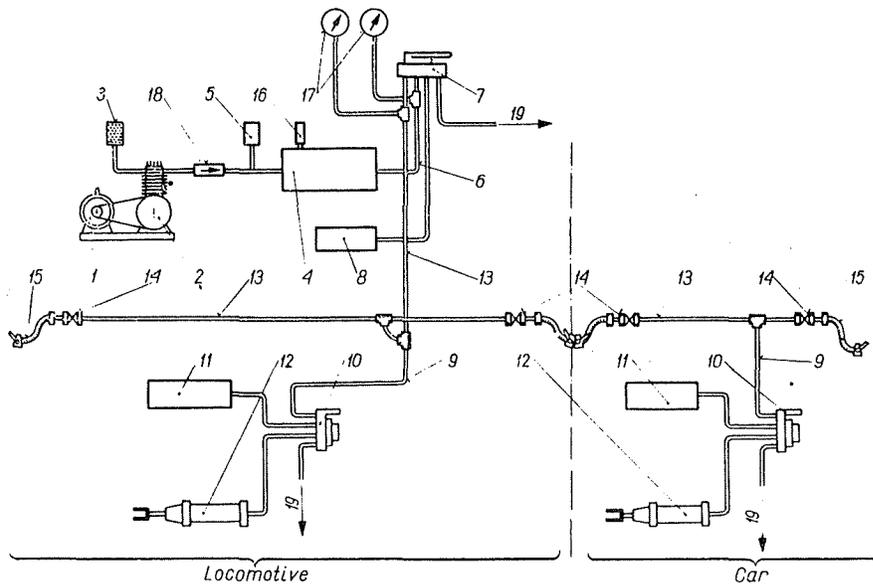
1—oil reservoir; 2—brake valve in driver's cab; 3—brake cylinder; 4—oil pump.

Figure C-3 - Scheme of Oil-Brake Rigging Inside Locomotive Frame



1—longitudinal slots.

Figure C-4 - Method of Connecting the Oil Brake with the Hand Brake



1—d.c. motor; 2—low-power compressor; 3—filter; 4—main reservoir; 5—compressor pressure control governor; 6—pipe; 7—brake valve; 8—main pipe; 9—secondary pipes; 10—triple valves; 11—auxiliary reservoirs; 12—brake cylinders; 13—main pipe; 14—extreme cocks; 15—flexible hoses; 16—safety valve; 17—pressure gauges; 18—non-return valve; 19—output.

Figure C-5 - Air-Brake Scheme for Locomotive and Car

to the atmosphere through the discharge pipe. This action causes the pressure in pipes (13) and (9) to drop. The triple-valves then connect the brake cylinders (12) with the auxiliary reservoirs (11) and air from the reservoirs flows into the cylinders activating the brake. The pressure in the brake cylinders, and thus the force pressing on the brake shoes, depends on the time the driver keeps the brake valve in the BRAKE ON position. When the need for very rapid braking arises, e.g., in case of emergency, the driver sets the brake valve to the OPEN position so that air is rapidly discharged from the main pipe, the triple valves immediately react to the sudden drop of pressure, and the train is quickly stopped.

Before bringing the locomotive into service, the driver must check the closing of the two extreme (foremost and rearmost) cocks (14) of the main air pipe. If these cocks are open, pressure cannot be built up in the main pipe and the brake remains applied as long as there is any pressure in the auxiliary reservoirs. It will be noted that in the event of the train breaking into two the pressure in the main pipe immediately drops and the brake is automatically applied in both parts of the train.

The driver can control the functioning of the braking system with two pressure gauges (17) of which the right one is connected to the pipe leading to the main air reservoir and the left one to the main pipe. The left pressure gauge also serves to control the functioning of the brake cylinders.

The description that follows explains the function of the most important elements of the air brake.

#### DRIVER'S BRAKE VALVE

The driver's brake valve (Figure C-6) consists of a cylinder containing the revolving block (9) which has a number of channels cut in it. The block is revolved with a handle and can be set to six different positions.

(i) FILL: Before starting the train the driver must fill the pipes of the brake with air. To achieve this he sets the brake valve to the FILL position thus allowing air to flow from the main reservoir through chamber (2) of the brake valve and the suitable channel in the revolving block to the main pipe (8) [in Figure C-5 the main pipe line is marked (13)].

(ii) RELEASE: In this position the revolving block cuts off the main reservoir from the main pipe. The brake is now released. Any drop of air pressure in the main pipe caused by unavoidable leaks from the system is automatically compensated through the auxiliary channel provided with the pressure-control valve (7). Air entering in small amounts from the auxiliary channel maintains the main pipe at constant pressure. At the same time air from the main pipe also passes to the pilot-valve

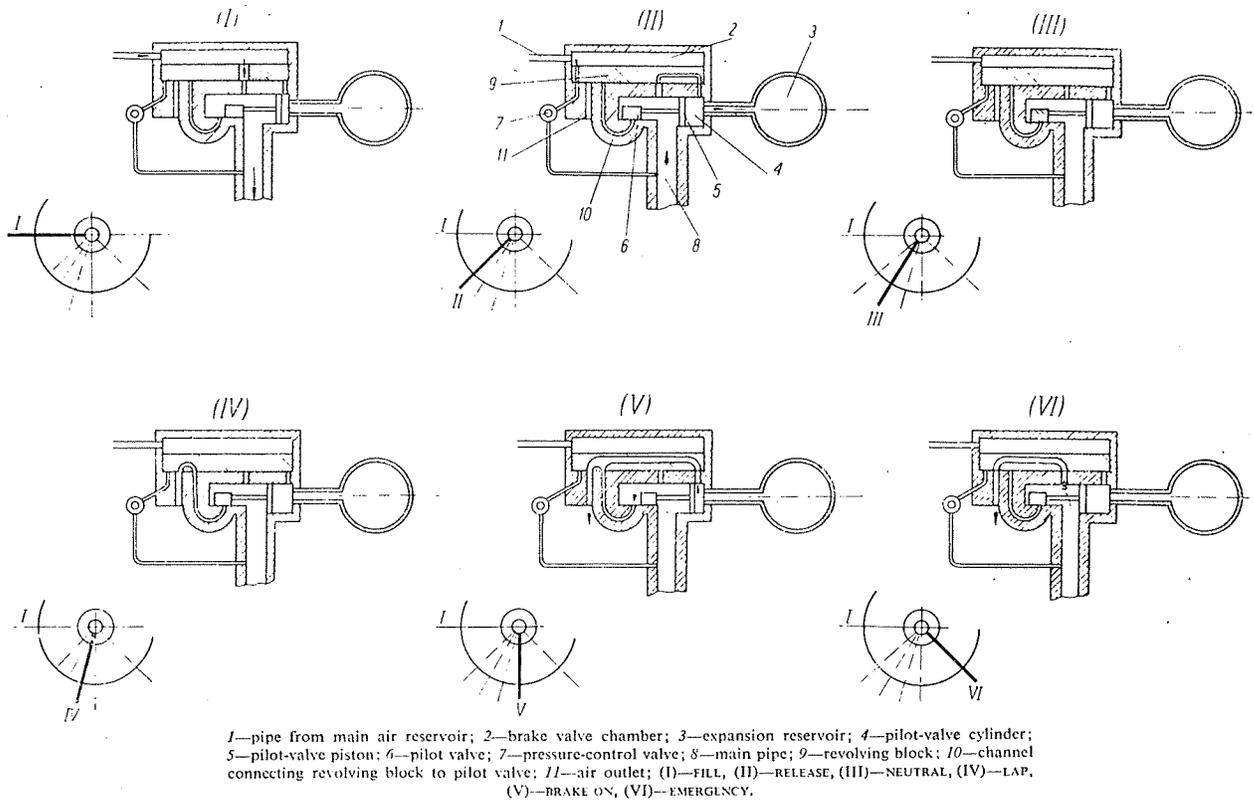


Figure C-6 - Diagrams Showing the Functioning of the Driver's Air Brake Valve

cylinder (4) and to the expansion reservoir (3) through another channel in the revolving block. As the pressure in the expansion reservoir rises, the pilot-valve piston (5) moves to the left. Inside the pilot-valve cylinder there is a spring pressing the piston in the same direction. The piston is connected to the pilot-valve (6) and when the piston is in the extreme left position the pilot-valve shuts the inlet of channel (10).

(iii) NEUTRAL: In this position the revolving block cuts off the spaces (2), (3), and (8) from each other, shutting off the connection between the expansion tank and the main pipe. Any losses of pressure in the braking system are not compensated.

(iv) LAP: This position gives an unchanging state of pressure both in the reservoirs and in the braking systems, since the main pipe is cut off from the air reservoirs as well as from the atmosphere.

(v) BRAKE ON: In this position the revolving block opens the expansion reservoir to the atmosphere allowing the pressure in it to

drop slowly. The pressure in the main pipe being now higher than in the pilot-valve cylinder, the piston overcomes the force of the spring and moves to the right. The pilot-valve opens the inlet to channel (10) and air can be now discharged to the atmosphere through channels (10) and (11). The pressure in the auxiliary reservoirs activating the brake cylinders now being higher than in the secondary and the main pipes, the triple valves change over and connect each auxiliary reservoir with its corresponding brake cylinder, thus applying the brake. Air continues to be discharged from the main pipe as long as the pressure in the main pipe is higher than in the expansion reservoir. When the point of equal pressures is reached, the pilot-valve piston is pushed back by its spring and the pilot-valve closes the inlet to channel (10), cutting off the main pipe from atmosphere. No more air is now discharged from the main pipe and the pressure in it depends on the time the main pipe and the expansion reservoir were left open, i.e., the time the brake valve was left in the BRAKE ON position.

Since the bore of channels (10) and (11) in the revolving block is very small, the discharge of air is moderate and the braking of the train can be very gentle.

(vi) EMERGENCY: Emergency braking must be very rapid. For this purpose in the EMERGENCY position the main pipe is connected directly to atmosphere through a channel of large bore in the revolving block. Air is discharged very rapidly from the system so that the auxiliary reservoirs are immediately switched over to the brake cylinders.

When air is let out from the brake cylinders, the brake shoes must return to the OFF position. Usually, this is obtained by the action of a spring inside the brake cylinder. The spring pushes back the piston when the pressure inside the brake cylinder drops nearly to atmospheric pressure.

#### TRIPLE VALVE

(i) FILL: When the triple valve (Figure C-7) is connected with the main reservoir through the brake valve and the air pipes by means of the channel (1), the air pressure in the system moves the triple-valve piston (2) to the right (to the FILL position): air will now pass through channel (3) to the auxiliary reservoir (7) until the pressure in the auxiliary reservoir is the same as in the main reservoir. The pressure in the auxiliary reservoir should be build up to at least about 5 atmospheres. Now the brake is ready for operation. As is to be seen in Figure C-7, in the FILL position of the brake valve the brake cylinder is connected with outside atmosphere (channel 6) and the brake is released.

(ii) BRAKE ON: Any drop of pressure in the pipes leading to the driver-operated brake valve immediately causes a drop of pressure in channel (1). The pressure in the auxiliary reservoir moves the piston (2)

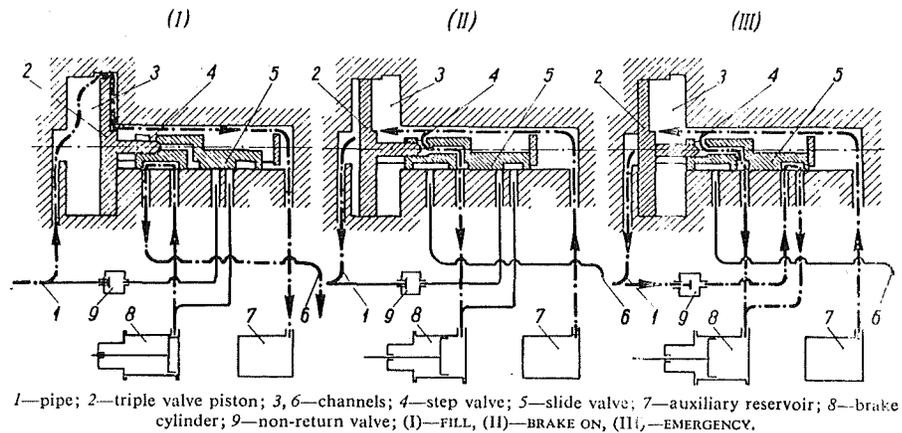


Figure C-7 - Diagram Showing the Functioning of the Triple Valve

to the left and thus opens the step valve (4). Subsequently, piston (2) moves also the slide valve (5). When the step valve is open, air can pass from the auxiliary reservoir through the step valve, and a channel cut in the triple-valve body to a pipe leading to the brake cylinder.

When the pressure drop in the main pipe of the brake system is only partial, air continues to pass from the auxiliary reservoir to the brake cylinder only so long as the drop of air pressure in the triple-valve compartment containing the slide valve does not make the triple-valve piston move to the right shutting off the step valve and thus the connection between the auxiliary reservoir and the brake cylinder. This allows the driver to control the braking effort.

In both instances, i. e., in the FILL and the BRAKE ON positions of the triple-valve, the non-return valve (9) is shut, its connection with the compartment containing the slide valve being cut off.

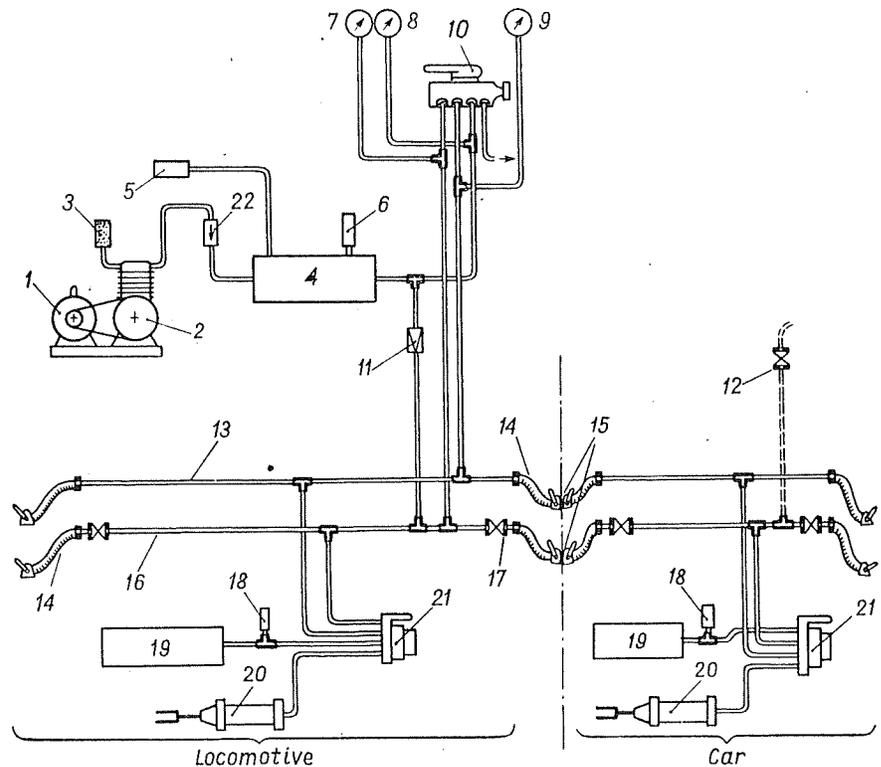
To release the brake the pressure in the main and secondary pipes must be raised: the pressure in channel (1) (Figure C-7) and in the left compartment of the triple-valve cylinder then moves the piston (2) and the slide valve (5) to the right, thus opening the connection of the brake cylinder with the atmosphere.

The main air pipe lines of the particular cars and of the whole train and the locomotive are connected with each other by means of flexible hoses [marked (15) in Figure C-5] provided with rubber couplers. Couplers of this type have no self-sealing valves and therefore the main air pipes of all cars and of the locomotive must be provided with cocks [marked (14) in Figure C-5] at each end. Hose couplers are sometimes provided with self-sealing valves kept closed by air pressure in the hose. When two such couplers are connected together, the valves press one against the other and open.

The brake described here is known as the automatic Westinghouse system; it has many advantages and some defects. One of the defects is that braking may be too rapid since the pressure upon the braking shoes is actuated by the air-pressure drop in the main air pipe. Another defect is that the brakes cannot be applied repeatedly in a long series of braking operations or kept on for a long time, as the number of braking operations and the time of braking depends upon the capacity of the auxiliary reservoirs. When the auxiliary reservoirs are empty, the driver must set the brake valve handle at the FILL position and while the auxiliary reservoirs are being filled with air from the main reservoir the brakes are released. In this respect better results are obtained with a straight air brake. In this system the driver fills the brake cylinders directly from the main reservoir and not through the triple valve. The straight air brake is very simple and very flexible in operation, but its defect is that if the train breaks into two parts, the brake fails completely and cannot be applied automatically as with the Westinghouse system.

To combine the advantages of the automatic air brake and of the straight air brake, various dual systems have been developed. The schematic representation of one such dual system is shown in Figure C-8. Similarly, as in the Westinghouse system, the compressor (2) driven by the electric motor (1) forces air from the intake filter (3) to the main reservoir (4) provided with the safety valve (6). The main reservoir is connected through the driver operated brake valve (10) with the main air pipe line (13) of the straight brake used for service or traffic braking and with the main air pipe line (16) of the emergency brake, which acts automatically on the same principle as the Westinghouse brake. The main pipe line of the automatic brake is connected to the main reservoir through the reduction valve (11), since in order to accelerate the action of the triple-valve (21) the pressure in this pipe line must be somewhat lower than the pressure in the straight brake. If the air pipes fail or are broken, the pressure in the main air pipeline of the emergency brake drops causing the slide valve in the triple-valve to move to the position connecting the auxiliary reservoirs (19) of the emergency brake with the brake cylinders (20). The changeover brings air from the auxiliary reservoirs to the brake cylinders and causes rapid braking of the train. Any part of the train that might have been disconnected from the locomotive will also be braked since the air pressure in the auxiliary reservoirs of the disconnected cars is sufficiently high to activate the brakes.

The driver can apply the emergency brake by setting his brake valve to the position in which air from the main pipe of the safety brake is discharged to atmosphere. The pressure in the emergency brake pipe then falls to atmospheric pressure. When necessary, emergency brake valves (12) can be fitted on all the cars and can be operated by the guard. If he opens one of them, the pressure in the main pipe of the emergency brake will drop and the triple-valves will switch over the brake cylinders of the auxiliary reservoirs.



1—electric motor; 2—compressor; 3—intake filter; 4—main reservoir; 5—compressor pressure control governor; 6—safety valve; 7—pressure gauge of the emergency brake; 8—main pressure gauge; 9—pressure gauge of the straight brake; 10—brake valve; 11—reduction valve; 12—emergency brake valve; 13—main air pipe of the straight brake; 14—flexible hose connections; 15—hose couplers; 16—main air pipe of the emergency brake; 17—cocks; 18—release valves; 19—auxiliary reservoirs; 20—brake cylinder; 21—triple-valve; 22—non-return valve.

Figure C-8 - Dual, Automatic and Straight Air-Brake Scheme for Locomotive and Car

To start the train after emergency braking, the driver must set his brake valve to the position in which the auxiliary reservoirs of the emergency brake are again filled with air. When the pressure builds up, the triple-valves disconnect the brake cylinders from the auxiliary reservoirs and switch over to the main pipe of the straight brake. The valves of the automatic brake and the valves at the ends of the air pipes must be closed, otherwise the brake cannot be released.

In addition to the equipment already mentioned, the dual system incorporates the compressor control governor (5), the pressure gauge (7) of the emergency brake, the main pressure gauge (8), the pressure gauge (9) of the straight brake, flexible hose connections (14), the hose couplers (15), cocks (17) at each end of the safety-brake main air pipe of the locomotive and of all the cars, the release valves (18) and the non-return valve (22) between the compressor and the main reservoir.

The compressor supplying air for the dual system air brake is driven by a motor usually of 1-2 kW. The pressure in the brake cylinders is not higher than 2.5 or 3.5 atmospheres and the air pressure in the main reservoirs varies between 6 and 8 atmospheres.