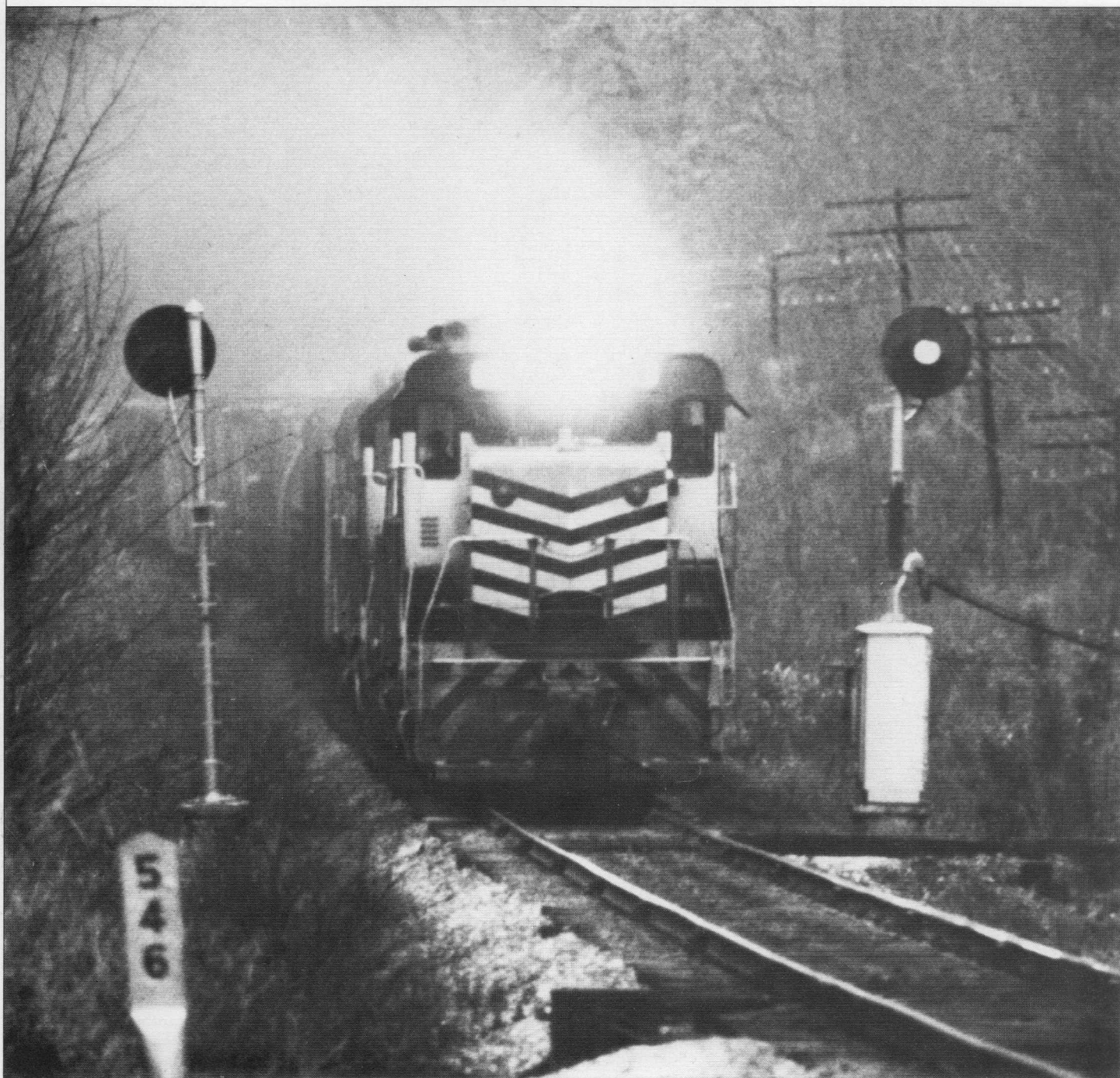


THE DIESEL from D to L

... an explanation of the machine that rejuvenated railroading

BY VERNON L. SMITH

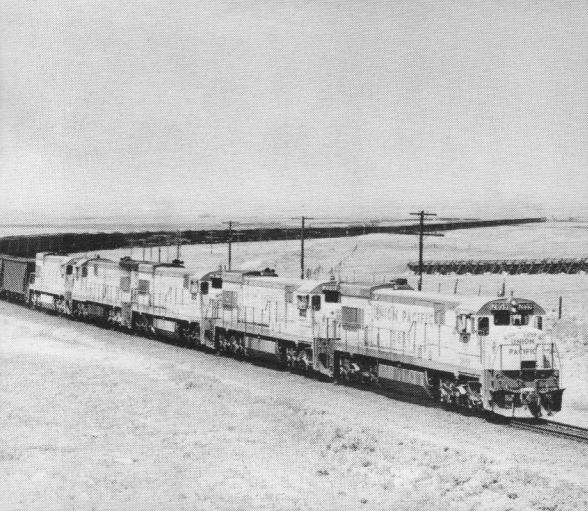
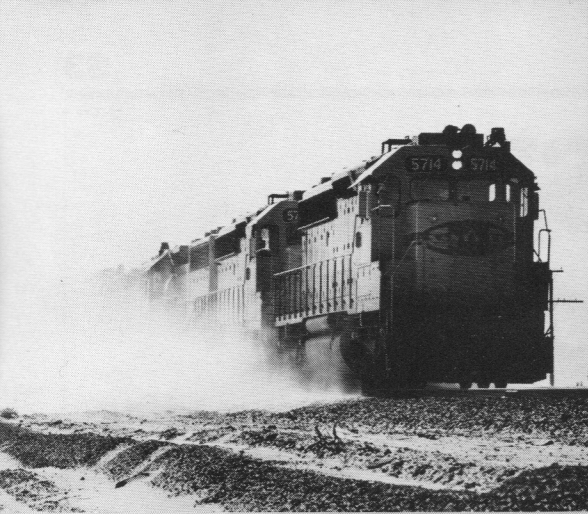


Steven Mueller.

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THE DIESEL

**Delivering designed performance
in a hostile environment,
mounted on a mobile frame,
dispatched down an imperfect**



I IT is early evening as you stand on a suburban station platform watching an approaching time freight bear down on the center main. Accentuated by the brilliant white headlight, the dark quarter-outline of the train appears to linger motionless in the distance, but only for a moment, for with the enlargement of the image this deception suddenly gives way to the true speed of the rushing train. The platform trembles; the roar of the engine rises and declines as each unit passes; the rails vibrate under the weighted wheels; the self-created windstorm lifts the ballast dust—all these events mark the passage of the train. What about the motive power that propels this heavy, mile-long caravan at 60 mph toward the sunset, toward any of a thousand destinations?

Look at the diesel-electric locomotive and the life it leads. It is expected to promptly start a train with frozen journals out of Proviso on a below-zero night, to work successfully through a sandstorm at Tucumcari, to plow through snow over Donner Pass, to accept the merciless heat of the desert at Needles, to breathe normally at the high altitude of Tennessee Pass, and to meet head-on the wind and dust of Wyoming.

Our locomotive does not ask for, or receive, much attention en route—there are no

Top to bottom: Steve Patterson; Tim Zukas; Tim Zukas.

VERNON L. SMITH

I WHAT makes up today's diesel-electric locomotive? For those of you who have not had the opportunity to closely explore one, we will try to give you a thorough introduction to it. This examination will focus on design, construction, operation, and maintenance.

First, though, a reflection on steam power near the end of World War II, the time of steam's displacement. Those railroads that had modern power in good repair obtained high-class performance from their steam locomotives. Witness the Santa Fe, which in



F. J. Peterson.

from D to L-1

rmance

*Beginning an examination of today's
motive power—from the bottom up*

roadway



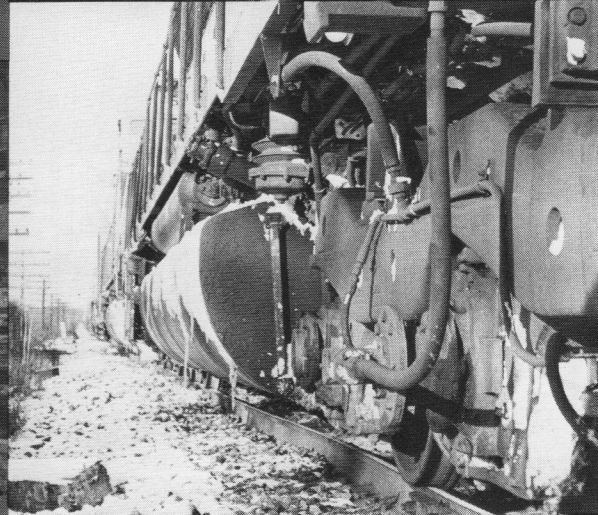
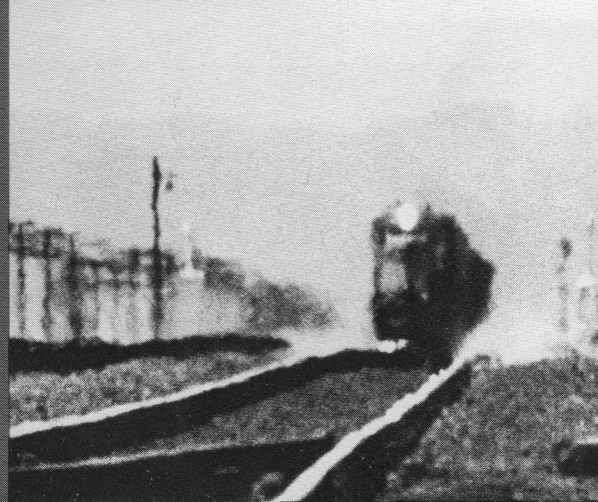
Kalmbach Books: Mike Schafer.

attendants monitoring its condition as occurs on similar equipment at a stationary plant. Nor does the railroad diesel run at nearly constant speed and load, and at its most favorable rating, as do many marine and power-plant engines. Instead, when the locomotive engineer widens out on the throttle in order to kick a cut of cars, he expects the engine to quickly respond to his demands.

Stationary plants of comparable power usually are mounted on concrete foundations which absorb engine vibrations, but the railroad diesel is mounted on a steel frame and is dispatched at speed down an imperfect metal roadway that abounds in curves and vertical irregularities that continually severely test the whole assembly.

The railroad diesel is also versatile in its several configurations: it has whirled the old Panama Limited through Illinois at 100 mph, drawn heavy freights up Saluda Mountain, and butted 14,000-ton cuts over the hump at Clearing Yard.

When the locomotive leaves the enginehouse area, passing out of the hands of the Mechanical Department into those of the Operating Department, it will deliver its designed performance in an economical and reliable manner. Not bad; not bad at all! — V.L.S.



Top to bottom: Richard Steinheimer; Nate Clark Jr.; William H. McKenzie.

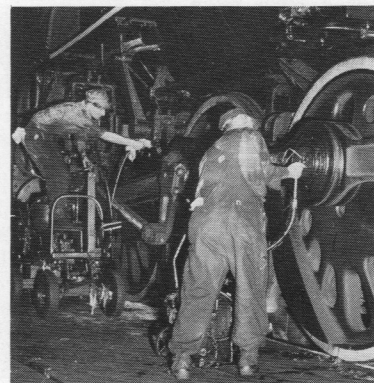
1944 operated the *Chief* without engine change between La Junta, Colo., and Los Angeles, 1234 miles; and the *Grand Canyon Limited* and the *Scout* without engine change between Kansas City and Los Angeles, 1788.7 miles. All these runs were made by Baldwin 4-8-4's.

Timekeeping and train-handling were excellent, but one has only to recall the army of men engaged in servicing steam to see why it was doomed. There was fuel-oil and coal and ash handling; fuel-oil heating; water treatment and water service; wayside facilities; large and small shops; and many other facets of steam-locomotive maintenance, all necessary to keep this thrilling

machine in revenue service and all requiring large labor forces. So when a less labor-intensive means of locomotion became available to the railroad industry, it quickly adopted it.

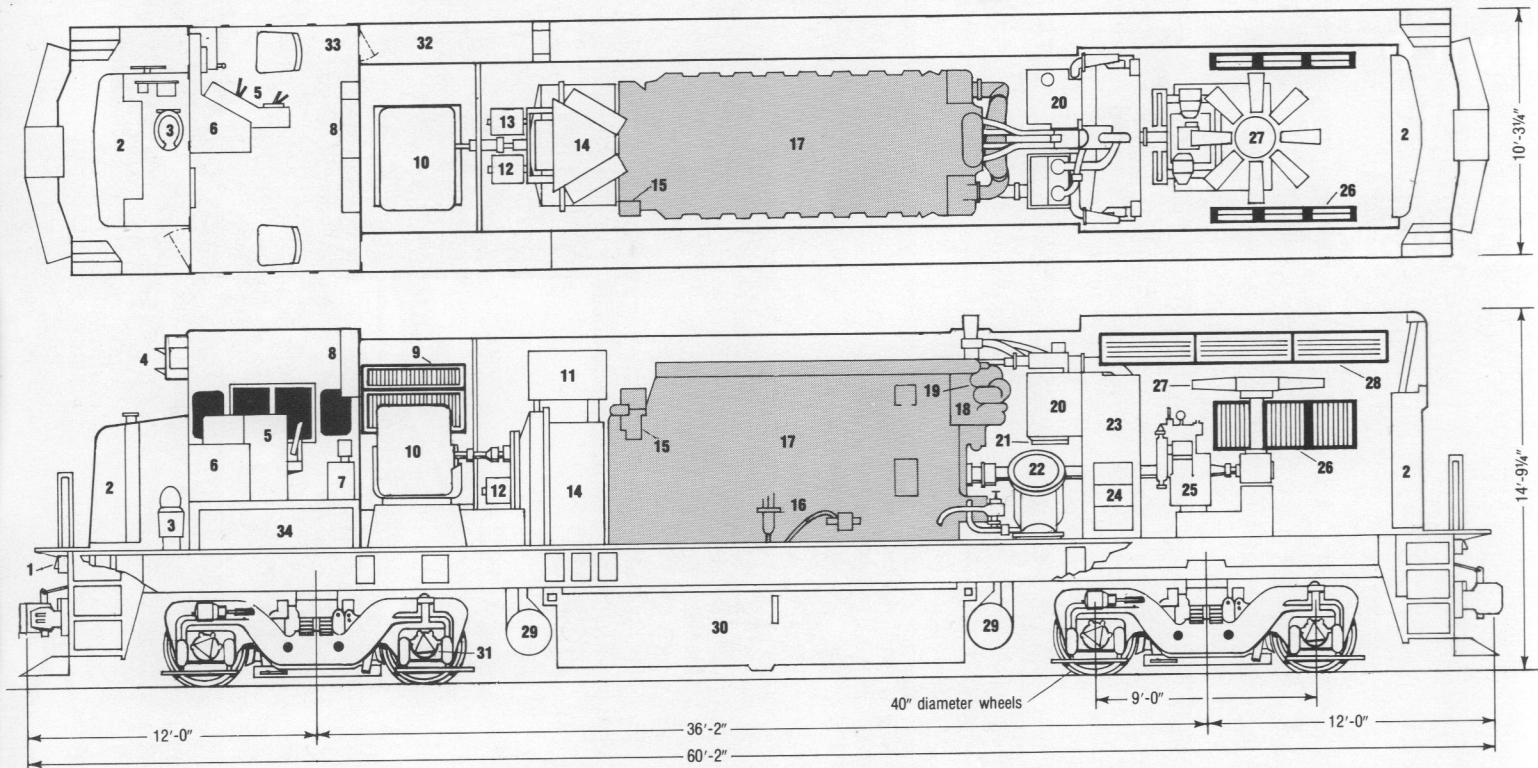
When a division or region of a railroad became fully dieselized, the trains moved much more uniformly over the road than they had with steam, primarily because of the diesel's constant power performance (to a large extent taken out of the hands of the individual engineman) and the elimination of fuel and water stops with the consequent loss of time in restarting.

Unfortunately, some roads ran their war-weary steam power into the ground in



Eugene Gianonne and John F. McBride.

- | | | | |
|---------------------------------|--------------------------------------|---|--|
| 1 Multiple-unit connectors | 10 Equipmeht blower | 19 Turbocharger | 28 Radiator |
| 2 Sand box | 11 Rectifier | 20 Cooling water storage tank | 29 Air reservoir |
| 3 Toilet (when furnished) | 12 Auxiliary generator | 21 Lube oil cooler | 30 Fuel tank |
| 4 Headlight and number boxes | 13 Exciter | 22 Lube oil filter | 31 Axle alternator (one per axle) |
| 5 Operating controls | 14 Traction generator | 23 Oil bath air filters | 32 Battery (right side) |
| 6 Cab heater | 15 Governor | 24 Engine primary air cleaners | 33 Air brake equipment (right side) |
| 7 Water cooler (when furnished) | 16 Fuel oil transfer pump and filter | 25 Air compressor | 34 Control equipment compartment (left side) |
| 8 Engine control panel | 17 Diesel engine | 26 Dynamic brake grids (when furnished) | |
| 9 Equipment air intake | 18 Intercooler | 27 Radiator fan | |



TODAY'S standard locomotive is a hood type road-switcher. This is a low-nose GE U36B—3600 h.p., four axles, all powered.

the last years, in anticipation of receiving new diesels. This situation can be illustrated by a verse attributed to the late Sid Winslow, sung to the tune of a well-known waltz:

*"It's three o'clock in the morning,
We've dragged the whole night through.
The old sow is still rolling,
It's more than I thought she'd do.
Soon the dawn will be breaking,
There will be breaking, too,
A lot more sorrow, tomorrow,
Railroad, to hell with you."*

The foregoing could have dealt with a wornout 2-8-2 on some impoverished road. But the railroad is a fascinating business, and I, as a onetime engineman, can say that after you got some rest you were eager to go back for more.

On the other hand, before dismissing steam, consider that a Chief Mechanical Officer of a large railroad once implied that it was a good thing the diesel freight locomotive was introduced in a multiple-unit consist because a number of the initial trips on his road were completed with only a couple of units still supplying traction. He had a point, but we both would agree that the diesel would have made it regardless.

It should be mentioned here that one of the great developments which advanced the diesel locomotive to its present state did not come from mechanical or electrical engineers but was the result of efforts by the major oil companies in producing improved diesel engine lubricating oils. When one thinks back to the days of original straight mineral oil, even with the best high-viscosity index oils, one remembers how the

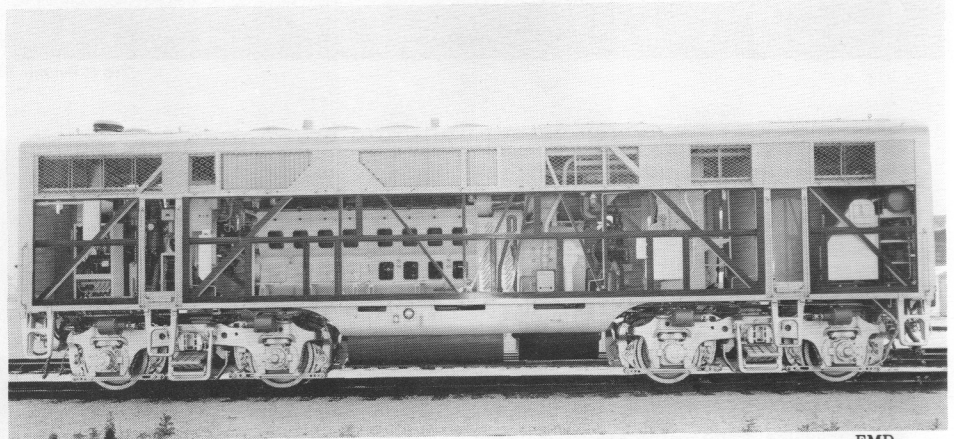
lube oil coolers would rapidly plug and cause the engines to run hot. This meant that a lot of cleaning and maintenance were needed to avoid the related road failures. Those indeed were difficult times. Today we have high-dispersant, high-detergent oils that keep the engine quite clean internally, and problems with the coolers are over.

What follows will deal only with Alco, Electro-Motive, and General Electric locomotives currently in use. You should be aware that all parts of this complex machine we call the diesel-electric locomotive cannot be covered in detail, and that some statements must be generalized in view of the many differences that exist among the

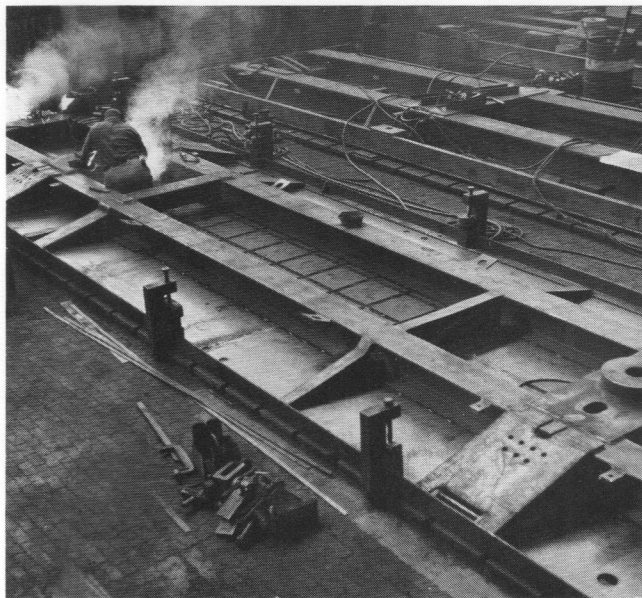
products of the several builders and the numerous requirements of the individual railroads.

We will deal with the hood type road-switcher, which—of either D.C. or A.C. electrical generation—represents most locomotives in use today. The essentials which comprise this locomotive can be divided as follows:

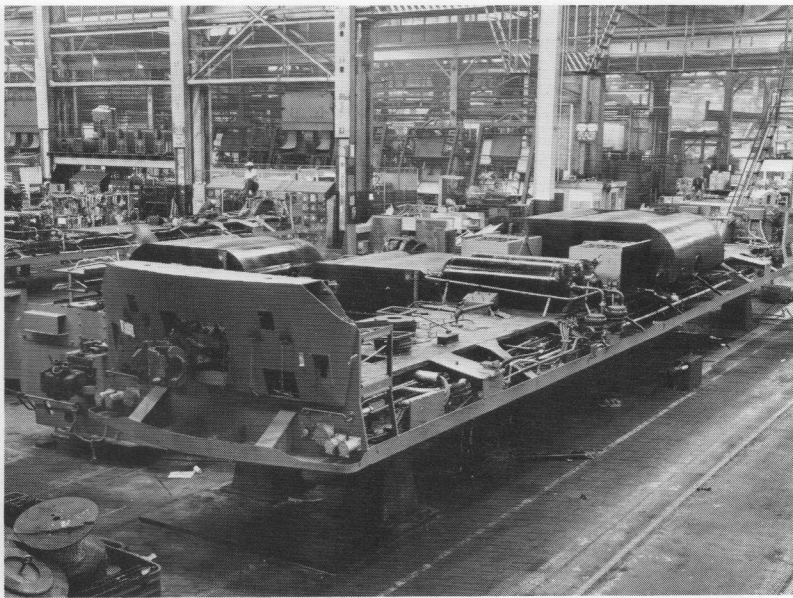
1. Underframe, including trucks
2. Traction motors and axle gearing
3. Diesel engine and . . .
4. Its cooling system
5. Its lubricating oil system
6. Its fuel supply system
7. Its air filtration system



ON carbody type units such as the EMD F (above), the carbody structure itself bore much of the framing load. On a hood type unit (right), the frame bears most of the load.



Robert Hale.



EMD.

UNDERFRAME main sills are evident on this GE (left). When building a locomotive, EMD begins with frame upside down (right).

8. Hood and operating cab
9. Braking system
10. Auxiliary power
11. Main generator or alternator
12. Control

The steam generator for train heating will not be covered, as this equipment is rapidly passing into history, nor will radio or remote control of mid-train locomotives be explained.

Finally, when all the items have been discussed, we will lead into "How the Locomotive Works," followed by comments on power, traction, and maintenance, and some general views.

1. UNDERFRAME AND TRUCKS

On a road-switcher underframe, the two *main sills* are generally of H-beam or similar built-up section set about 48 to 62 inches apart, and they run the full length of the locomotive. They are the chief load-carrying members. A heavy plate, usually the full width of the locomotive, spaces the sills and maintains the frame parallel. Today, frames are of all-welded construction.

About 12 or 13 feet from each end are the *body bolsters*, which are heavily fabricated cross members carrying the male center



Louis A. Marre.

UNDERFRAME will accept just so much stress, as this damaged SD45 illustrates.

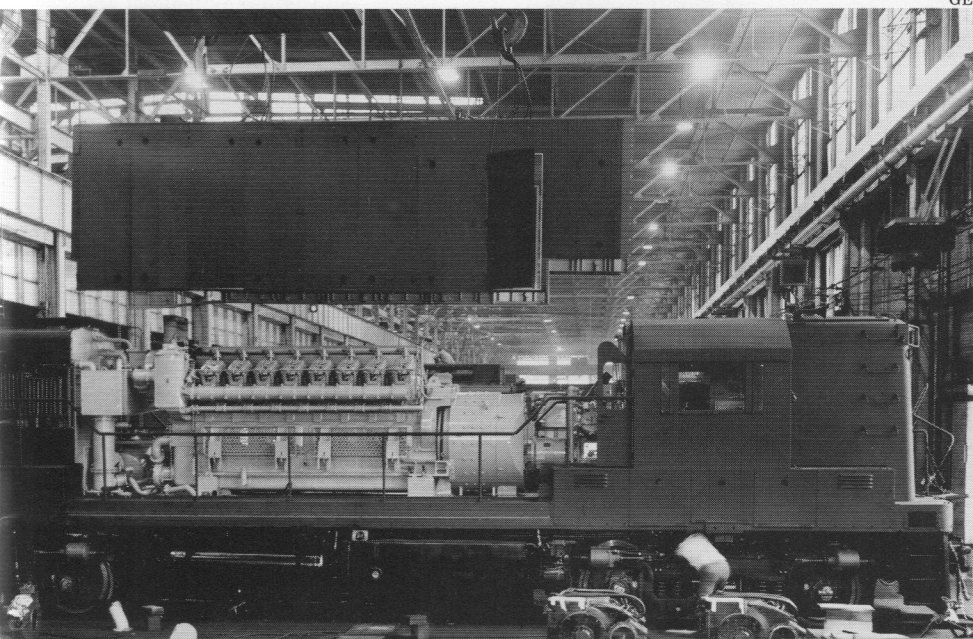
casting and the retaining lugs for the trucks. At the bolster extremities, where joined to the side sills, are the lugs and pads for the lifting of the locomotive by overhead cranes, or for raising it with jacks.

In recent designs of road-switchers, the side sills carry relatively little load. In the older carbody diesels such as the EMD E's

and F's and the Alco PA's, however, the sides of the carbody itself were framed up as a trussed girder, like a bridge, and these sides (plus the side sills and the top chord above the air intakes and radiator shutters, including the roof) carried a considerable portion of the framing load.

When built, the road-switcher underframe is cambered upward about $\frac{7}{8}$ inch at the midpoint of length instead of being straight. When the weight of the machinery is placed upon it, and with the passage of time, the locomotive frame becomes more level. In the course of many years of service, the underframe may sag slightly between trucks; often the frame even will turn down a bit at the ends owing to the strains of heavy traction and the buffing forces inflicted upon it.

The draft gear pockets, which fit between the main sills at each end of the frame, carry the draft arrangement. Draft gear today usually is composed of alternate laminations of rubber molded on steel plates. These laminated plates are compressed in the coupler yoke between a heavy cast steel follower at each end that bears against stop lugs in the pocket, to provide a shock-absorbant and resilient attachment for the coupler. The current draft gears are a great improvement over the metal friction gears



GE.

of the 1940's, but even so, the pocket, draft gears, and couplers remain high-maintenance items.

The coupler height at the center of the knuckle—a maximum of 34½ inches from the rail, with a minimum height of 31½ inches permitted—was fixed by an Act of Congress in 1893 (and amended in 1896) based on standards established by the railroads. Thus, when a locomotive is turned out of the shop with new wheels and full coupler height, it is intended that even after the wheels become worn out, the coupler height from rail still would be within regulations. However, in the real world this isn't necessarily so. Locomotives tend to get lower with the passage of time, primarily because the truck springs gradually lose their capacity, so sometimes it will be imperative to put shims under the coupler shank, or on top of the journal boxes under the equalizers, or even to put a liner between the truck center casting and the frame bolster, to raise the locomotive sufficiently to preserve the coupler height. The fact that the coupler horizontal center line is well below the pocket attachment to the main sills puts a severe strain on the sills, particularly in buffing owing to the eccentric loading.

A good underframe may determine the total life of a locomotive. The otherwise excellent EMD GP7, for example, unfortunately has a relatively light frame, and on my former railroad, the Belt Railway Company of Chicago, it will not survive in service as long as the older cow-and-calf TR4, which has side sills 4 inches thick.

The end sills, which are welded to the



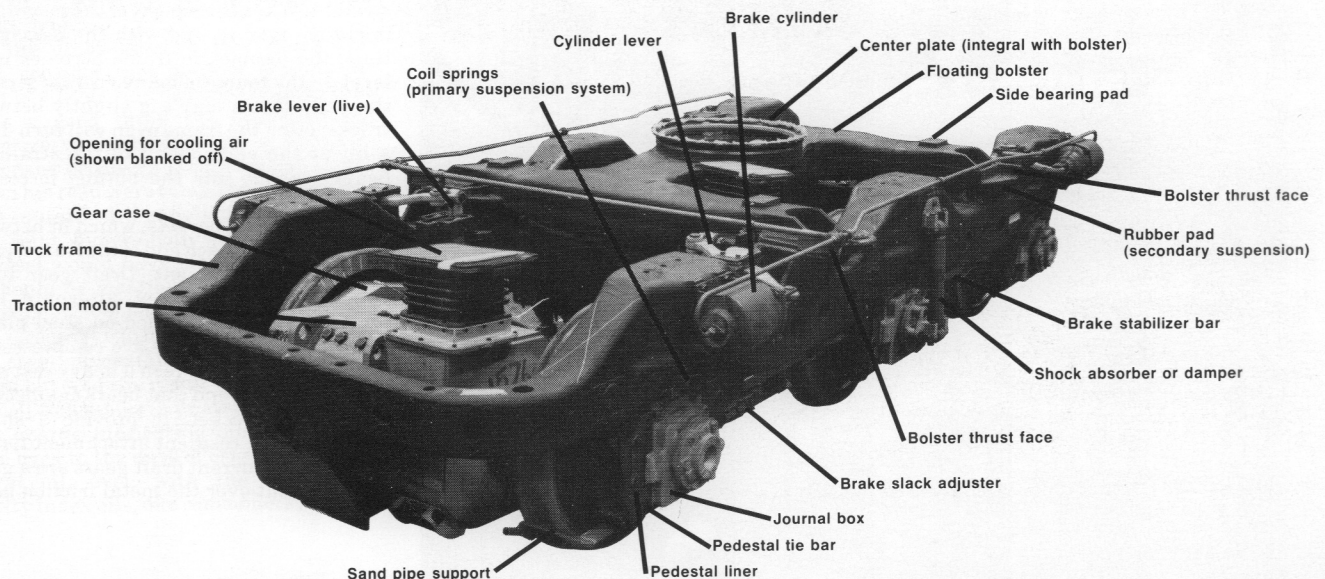
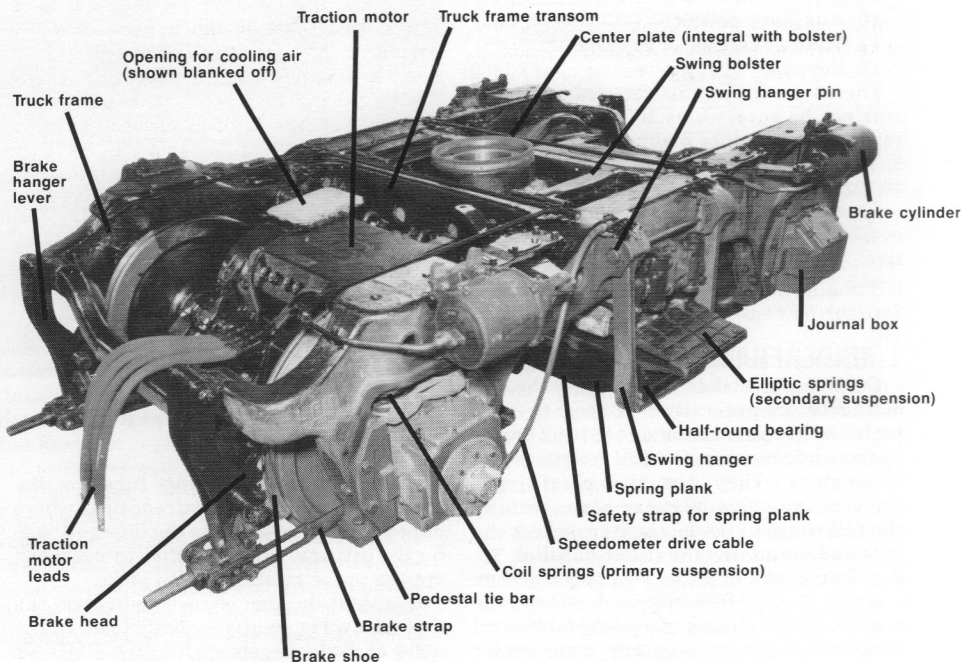
EMD.



Vernon L. Smith.

"LONG OVERDUE": ban on end footboards. Present on SW600, absent on MP15.

EMD TRUCKS: Two-axle, or "B" truck (right), as used under FT's, is virtually identical to that used under later F's and Geeps (GP7-GP20). Six-motor units today ride on the HTC truck (below).



longitudinal sills, are generally flat plates $\frac{3}{4}$ inch to $1\frac{1}{2}$ inches thick that carry the side steps, footboards, pilot, or snowplow. The familiar end footboards on diesels are to be gone from the American scene by October 1, 1979, by virtue of an FRA regulation, long overdue. Most railroads, in fact, have had rules prohibiting the use of end footboards for many years (many of you will recall the "Keep Off" stenciling on the end sills or pilot beams of steam locomotives). A number of recent locomotives have angled slots cut in the end sills near the outer edge of the plate; the purpose of these is to enable a satisfactory attachment of lifting cables to be made when rereiling the locomotive.

The underframe usually has the fuel tank suspended underneath. The attachments of the tank to the frame must be very strong, for the dynamics of the fuel weight, in spite of the numerous baffles in the tank, have brought many fastenings to grief.

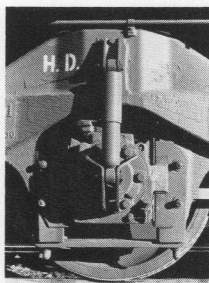
THE TRUCKS in use today, of the four- or six-wheel (or more) type, are of several designs, differing mainly in the method of springing and equalization. The truck frames are nearly always of cast steel, strongly designed so that they will stay square from the shocks received in service.

Most trucks have primary and secondary spring suspension. Before this is explained, note that the wheels, axles, and axle gears, together with the roller bearings and journal boxes plus about one-half the weight of the traction motor, are interposed between the rail and the first group of springs in the trucks. This means that all the foregoing items are unsprung weight and consequently take a hard beating from the jarring of the locomotive traveling over the steel rails.

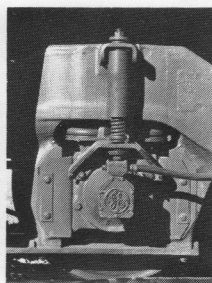
Forming the *primary suspension* are the coil springs that rest upon the top of the journal boxes and bear against the truck frame. In some designs, these coil springs are set in pockets carried by the side equalizers, with the top of the spring bearing against the underside of the top rail of the truck frame.

Before getting to secondary suspension, a bit of description will be necessary. The four-wheel road-switcher truck has a separate cast steel bolster incorporating the female center plate on its top surface. The bolster fits neatly between the two cross transoms of the truck that restrain its longitudinal movement but permit the bolster to slide about $2\frac{1}{4}$ inches from each side of the locomotive center line.

Each end of the bolster is supported on a set of elliptic springs or on composite rubber-steel pads, which in turn rest upon the transverse spring plank, a weldment or



R. Steinheimer.



Keith R. Tygum.

VERTICAL damping strut, or shock absorber, is found on many current trucks. EMD's is at left, GE's at right.

steel casting about 22 inches wide, 6 inches deep, and of a length suitable for the width of the truck frame.

The bolster, springs, and spring plank make up an assembly that is attached to the truck frame by swing links or hangers. The lower ends of these swing hangers can rotate in a half-round bearing on the underside of each end of the spring plank, and the upper ends of the hangers are pinned to brackets on the side of the truck frame or pinned to the transoms. The swing hangers are spread apart a greater distance at their lower pins than at the upper—thus the arrangement permits the bolster and its springing to move side to side as a cradle.

On entering a curve, the side movement of the bolster has the effect of shortening the swing hangers on one side, and this tends to lift the locomotive—or more accurately, presses harder on the springs on that side. This pressure acts to bring the truck back to its central position upon leaving the curve.

Springs or pads interposed between the bolster and spring plank form what is known as the *secondary suspension*.

On some recent trucks, the bolster rests

on composite steel and rubber pads attached to the truck frame, and no swing hangers are used, the rubber pads furnishing the necessary side movement in shear.

The object of permitting the truck bolster to move about $2\frac{1}{4}$ inches each side of center is to reduce the shock loads of a locomotive entering a curve at speed. It also permits the truck to better follow irregularities in the track without losing tractive adhesion owing to rigidity.

Two other designs of trucks merit mention. First is the EMD Flexicoil, which has the usual coil springs over the journal boxes but also has the truck swing bolster supported on tall, large-diameter, coil springs. The bolster can move sideways on the flexing or bending of these tall coil springs; again, these are the secondary suspension. This truck has an excellent record in carrying heavy locomotives over light-rail track without derailment and also appears to minimize wheel flange wear. This truck was discontinued by the builder, which cited excessive frame breakage problems in the four-wheel version and replaced the six-wheel Flexicoil with the HTC design that reduces the transfer of weight between axles.

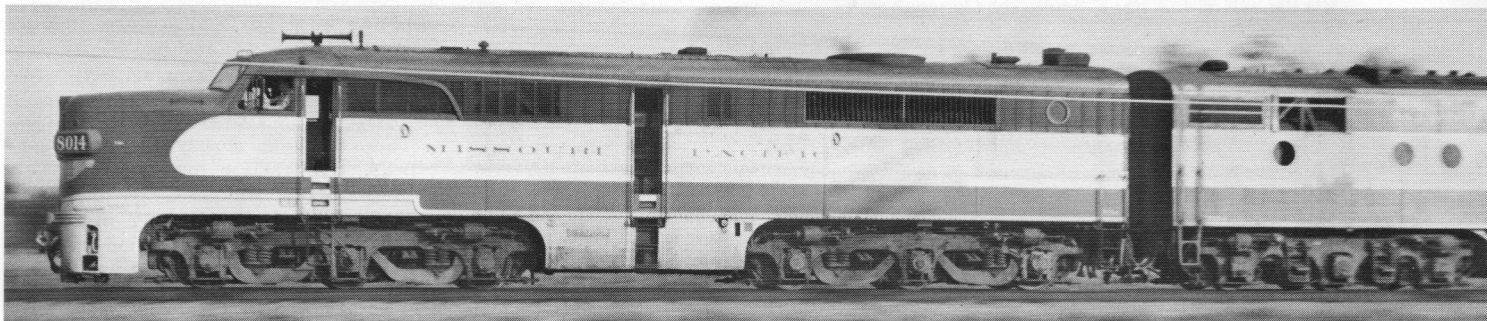
The second truck is the AAR type A seen on most switcher locomotives. This is a rigid-bolster truck having only primary suspension, provided by coil springs held in pockets on top of the two equalizers and the underside of the truck frame, working in conjunction with a long leaf spring set inside and between the equalizers whose ends rest on top of the journal boxes.

This truck is a rough rider and is not suitable for speeds much over 35 mph. On the Santa Fe, for which I worked, a diesel-electric switcher with AAR trucks could quickly put out of gauge a lightly laid branch line that previously had been operated successfully with old 2-6-2 steam locomotives. This made the strengthening



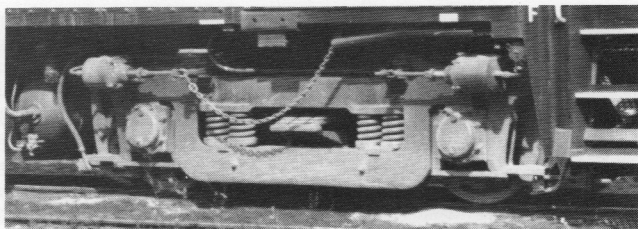
L&N.

MOST early switchers had AAR type A trucks; pre-1950 Alcos (left) had Blunts.



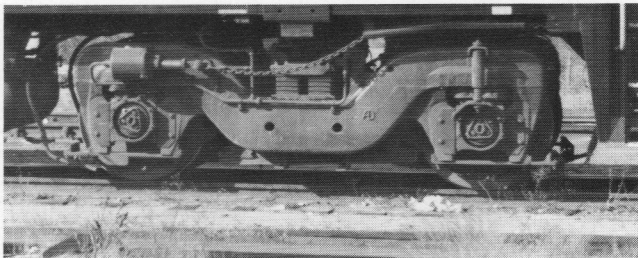
J. Parker Lamb.

PASSENGER-UNIT trucks, of A1A (center axle unpowered) configuration, rode quite well. Author says Alco PA's were best.



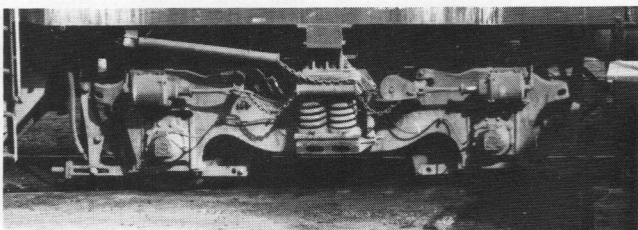
Louis A. Marre.

AAR TYPE B road truck under a General Electric U23B.



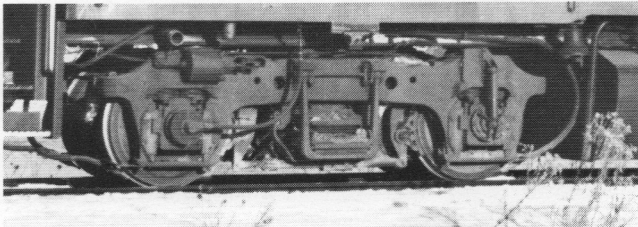
Warren Calloway.

NEWER GE floating bolster (FB-2) truck, now standard.



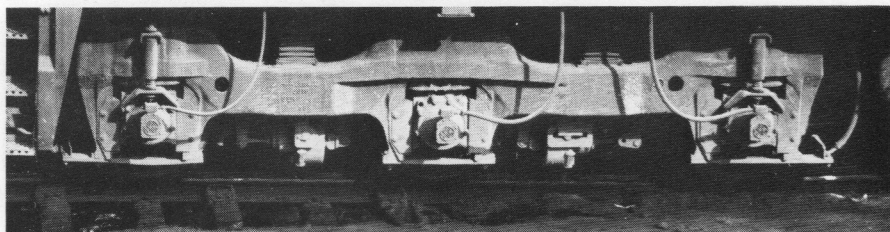
Jay Potter.

ALCO high-adhesion truck, introduced in 1967, under C430.



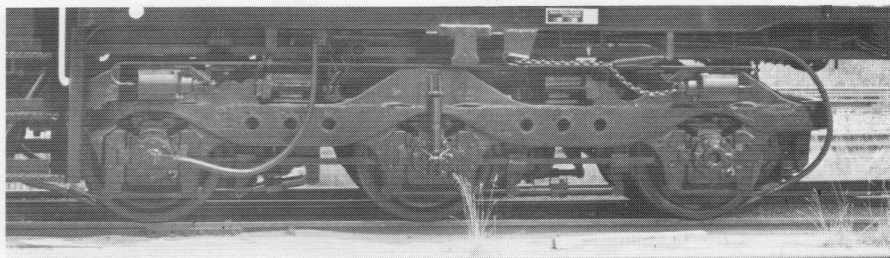
Ernest L. Novak.

DAMPING STRUT marks EMD's newer Blomberg M truck.



Jay Potter.

NEWER GE C-C's have truck by General Steel Castings or Adirondack (above).



Louis A. Marre.

HTC (high traction) truck replaced Flexicoil design on C-C EMD Dash Two models.

of track necessary for the diesels. This track punishment is inflicted because of the low center of gravity on a diesel—the heavy mass of the traction motors is concentrated in line with the axles, resulting in high lateral side forces on curves with the rigid bolster truck. The steam locomotive, on the other hand, with its high center of gravity, would sway on its springs when entering a curve.

Diesel trucks carry the brake cylinders and the brake rigging to force the brakeshoes against the wheels. With cast-iron shoes, the designed braking force (at 50 pounds brake cylinder pressure) will be about 58 to 85 per cent of the weight of the locomotive. Composition shoes are used for some services but are not suitable for hump power or slow-speed work. Interestingly, although the tractive effort of the locomotive rarely exceeds 35 per cent of its weight, the locomotive still can move on level track if the throttle is opened wide with the air brakes applied.

On the subject of trucks, I must mention that no locomotive rode better than the Alco PA, with its well-equalized 15-foot, 6-inch-wheelbase truck. These locomotives would go through a long lead crossover at high speed with remarkable smoothness. The center axles of these (and other passenger-locomotive) trucks were not motored, hence the designation A1A (letters for number of powered axles, numerals for unpowered ones).

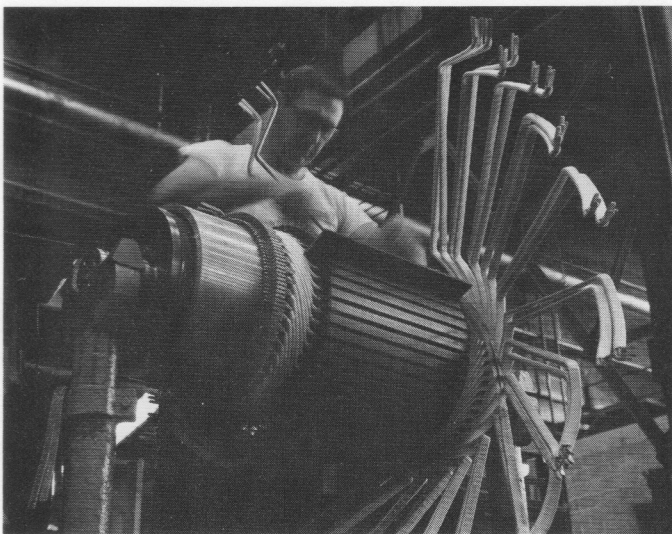
Many current production locomotives are equipped with six-wheel trucks with all three axles motored (C designation). The additional truck axle is often necessary to spread the weight of a reasonably powerful locomotive to permit its operation over lightly laid branch lines. The best example of this is the Milwaukee Road's custom-designed EMD SDL39 locomotive of 2300 h.p. and only about 247,000 pounds weight. The more usual reason, however, is to secure increased tractive effort in a heavy single unit by the use of two more motors, since ample horsepower is available from the modern diesel to supply six motors.

With respect to traction-motor inspection, four-axle locomotives (B-B) are easier to maintain, although recent six-axle (C-C) locomotives do have improved access to the center motor. Four-axle units are less subject to derailment, and when off the track they are not as difficult to rerail. More flange wear will usually occur on six-wheel trucks, particularly on the center pair of wheels. Where high-speed heavy tonnage trains are run with C-C locomotives, the track must be maintained to a high standard, especially with regard to being tightly to gauge. It is also desirable to maintain an accurate wheel-tread profile on these locomotives to avoid developing any tendency to "hunt," with consequent high lateral pressures on the rail heads.

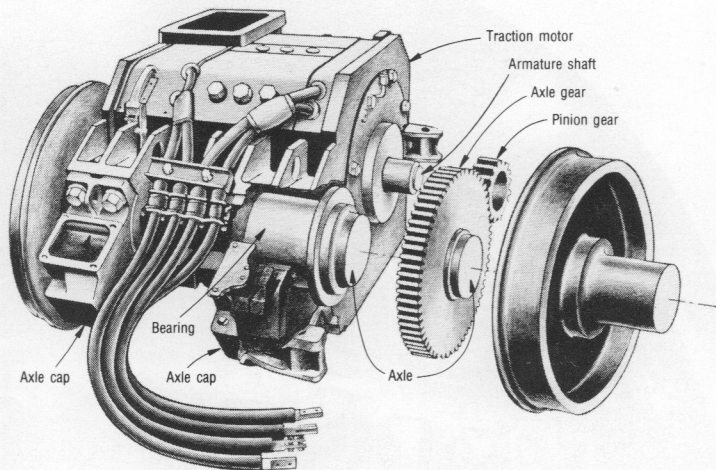
2. TRACTION MOTORS AND AXLE GEARING

These are items closely related with the trucks. The traction motors usually are supported on one end from the truck frame transom with a resilient laminated rubber-steel nose block placed between the motor lugs and the truck crossmember ledges. The other end of the motor is supported on the axle by two split bronze bearings that provide for wear.

A traction motor weighs from 6150 to 7100



Robert Hale.



ARMATURE WINDER positions preformed coils in slots of armature for traction motor (left). Traction-motor drawing (above) shows relationships of motor, gears, truck axle.

pounds; about half of this amount rests on the axle as unsprung weight. In service, shocks and jolts from the wheels passing over rough rail joints and frogs are transmitted to the motor, and it is a tribute to both EMD and GE (Alco used GE motors) that their motors can take this abuse at speeds as high as 100 mph and still not require excessive maintenance. Many of our foreign friends who employ motors entirely suspended on the truck frame in conjunction with complicated drives to the wheels, are amazed at our success in using axle-supported motors in our locomotives.

The four flexible cable leads of each traction motor are fitted with locking or bolted connectors to make the joint with the fixed cables beneath the locomotive's underframe. Once in a while, after a locomotive has been retrucked, some luckless electrician will connect one of the leads wrongly, and one pair of wheels will be turning in the opposite direction from the others. A check is always made on this before the locomotive leaves the shop.

Many switcher traction motors are cooled by air furnished from blowers above the underframe, the air being blown through a hollow passage in the frame center castings, thence through the hollow rigid bolster of the truck with a short flexible horizontal duct connection to the traction motor. These locomotives usually have the blowers mechanically driven from the main engine.

Road locomotives generally have a flexible duct, set vertically, connecting a blower air passage in the underframe with the top of the traction motor. These units have electrically driven blowers.

The traction motors are four-pole D.C. series-wound machines (the same current flows through the armature coils and field coils in series order) having a maximum permissive rotative speed of about 2500 rpm. This means that the motor must be geared to the axle in order to furnish the proper wheel revolutions for the rail speed desired.

FOR EMD's, gearing ranges are from a 65-tooth axle gear with a 12-tooth integral motor pinion (65:12) to a 58-tooth axle gear and a 19-tooth separable pinion (58:19). The first ratio provides a safe continuous speed, at full power, of about 8.2 mph and a top speed of 50 mph. The second ratio will give a continuous speed of about 14 mph at full

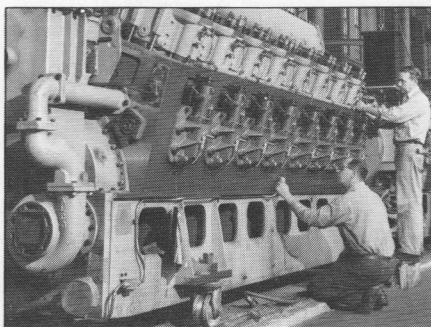
power and a top speed of 90 mph. The usual freight gearing is a 62:15 ratio with a top speed of 65 mph.

General Electric (and consequently, Alco) gear ratios range from 74:18 to 77:26, the latter with a maximum speed of 93 mph.

In high-speed times, Alco 2000 h.p. passenger units with a 58:25 gearing were good for 117 mph, and their EMD counterparts, the E7's, E8's, and E9's, were equally speedy with a 52:25 gearing.

What is the purpose of all these different gear ratios, when theoretically a passenger unit and a freight unit of the same horsepower should deliver the same-weight train over a district in the same length of time? After all, horsepower is just the rate of doing work, and all that is being done is moving a certain number of pounds over a measured distance in a specified time.

A couple of examples should help. Suppose the freight locomotive has a 65 mph gearing, but the train is very light and the horsepower available is sufficient to run at 85 mph. If this speed is reached, the traction motors are turning above their rated speed of rotation, and the centrifugal forces created may be great enough to throw the armature windings out of their laminations and destroy the motors.



Alco.

MORE TO COME

IN the second installment of "The Diesel from D to L," Vernon L. Smith discusses the diesel engine itself and some of its supporting systems—next month in **TRAINS**.

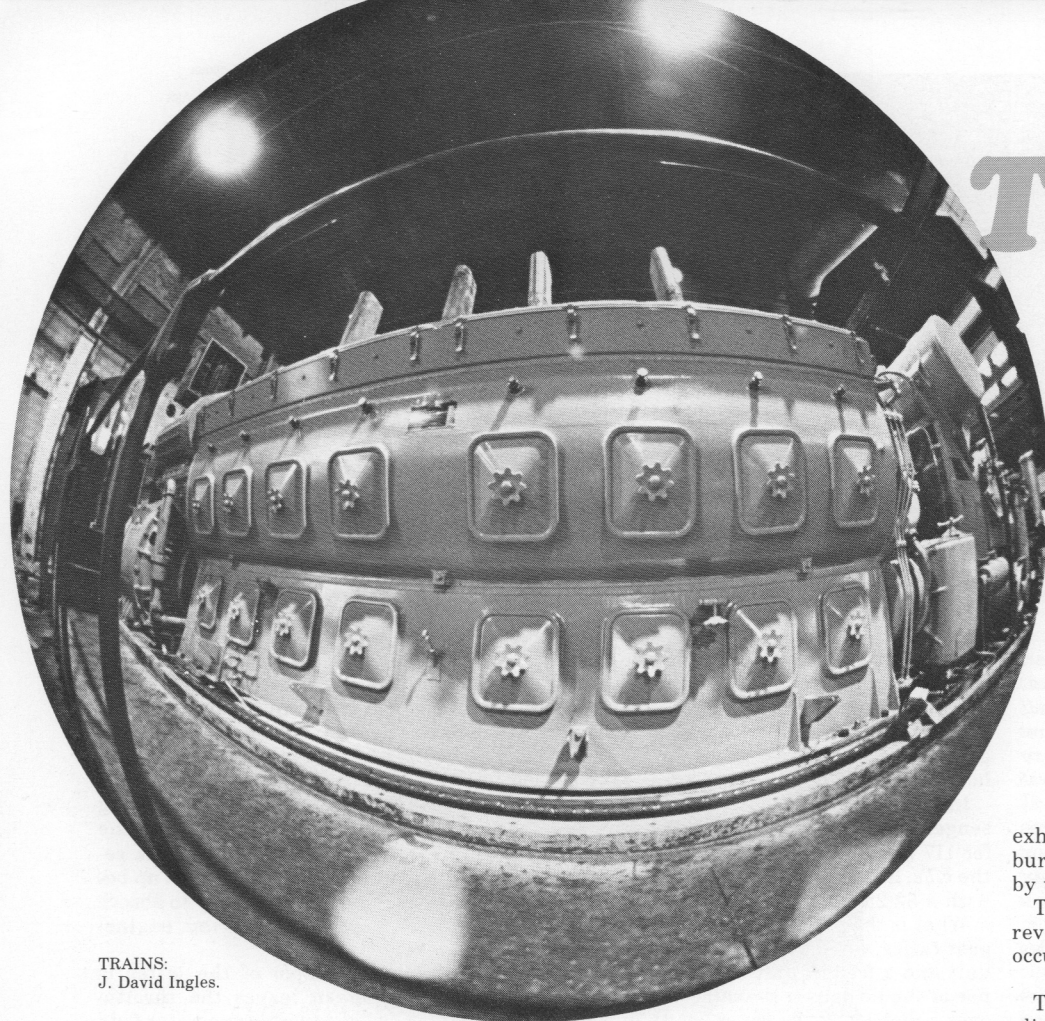
What of the passenger locomotive with, say, 90-mph gearing? This locomotive will have about 14 mph minimum speed in which it can operate continuously receiving full power from the diesel engine and generator. The passenger locomotive, if heavily loaded, may reach a long ascending grade and the speed will drop below the minimum of 14 mph; unless power is reduced, the traction motors will burn up because they are rotating too slowly to absorb all the energy produced by the engine-generator set.

The ultimate example of the latter is when an engineman leaves the throttle open a notch or two with the generator field switch in. With the locomotive standing still, either with the brakes set or with the train stalled without the wheels slipping, this will fry the motors very quickly. However, modern motors with improved insulation can take much abuse, and the rating for these motors can be extended over that permissible in the early 1940's.

A BRIEF WORD is in order on the wheels and axles, upon which so much of the safety of the locomotive and train depends. It may appear that the pair of wheels, a gear, and an axle are a simple thing; however, the vertical and lateral loads imposed, plus the traction and braking forces, together with the heating of the wheel tread and flange from heavy braking, create problems that are under continuous study and research. In fact, an organization known as the International Wheel Set Conference exists for investigating matters applying to this assembly alone. This is in addition to the Wheel Manufacturers' Institute and the Wheel and Axle Committee of the AAR.

The forged steel axle gear and the motor pinion are enclosed by a split two-part gear case containing a suitable lubricant. Gear cases are difficult to seal, particularly for high-speed service, and much engineering talent has been applied to this detail and more is needed.

Nearly all locomotives have roller-bearing journals. The bearings and boxes usually are of either Timken or Hyatt manufacture in the U.S. Timken's is grease-lubricated and Hyatt's is usually oil-lubricated. Journal boxes run quite warm in high-speed service during hot weather, with temperatures often reaching 155 degrees to 165 degrees F. **I**



TRAINS:
J. David Ingles.

THE DIE Cycles

The locomotive's

VERNON L. SMITH

I NOW that we have examined the underframe, trucks and traction motors of a diesel-electric locomotive, let us look at the diesel engine itself and some of the supporting systems the engine requires.

3. THE DIESEL ENGINE

The oil engine is of either the two-cycle or four-cycle type. EMD's is two-cycle, and the current model, introduced in 1965, is 645E, the number denoting the displacement in cubic inches per cylinder.

Alco and GE engines are of the four-cycle type. The model last produced by Alco and still used by Bombardier-MLW is known as the "251" series, the number indicating the month and year introduced (February 1951). General Electric's engine is known as the 7FDL. In the GE indexing system, the "7" stands for rotating mechanical equipment, the "F" indicates the size of the cylinder block (9-inch bore x 10½-inch stroke) and "DL" is for Diesel Locomotive. A suffix denoting the number of cylinders of a particular engine is often added.

The foregoing all are what is known as a "medium speed" engine, turning at from 800 to 1050 revolutions per minute at full power or speed and idling at 275 to 450 rpm, depending on the builder.

All diesel engines are provided with a shutdown mechanism to prevent damage to

the engine from overspeeding. It is set to function when the maximum designed rpm are exceeded by 90 to 120 revolutions, or 10 per cent over rated speed, and the centrifugal force device operates by cutting off the action of the individual fuel pumps that serve each cylinder. A reset is, of course, provided so the engine may be restarted.

FOUR CYCLE

The term "four-cycle engine" means that four strokes of the piston, covering two revolutions, are required to complete one set of events. These are:

Intake Stroke: The piston, upon descending in the cylinder, draws in air for combustion through the open *intake* valves in the cylinder head.

Compression Stroke: After bottom dead center is reached, the piston moves upward in the cylinder, compressing the air and raising its temperature because all the valves in the cylinder head are now closed.

Power Stroke: When the piston arrives near the top of the cylinder, and just before passing top dead center, fuel is admitted and burned because of the high compression temperature, forcing the piston downward. The expansion of the hot gases continues to a point near bottom dead center, when complete release of pressure occurs as the *exhaust* valves open.

Exhaust Stroke: During this stroke, the

exhaust valves are held open and the burned gases are driven out of the cylinder by the ascending piston.

To repeat, the crankshaft has made *two* revolutions, and *one* power stroke has occurred.

TWO CYCLE

The two-cycle engine, as the term implies, requires only *two* strokes or *one* revolution to accomplish the same series of events—which must be completed very rapidly. A two-cycle EMD engine turning at 900 rpm must scavenge the cylinder of burned gases and recharge with new air in about 1/50th of a second. Therefore, in order to make such an engine work, an external means of supplying a large volume of air *under pressure* must be provided in order to furnish sufficient combustion air during the short time interval that exists.

Here is the two-cycle sequence:

As the descending piston nears the lower end of the cylinder, it uncovers a row of ports which extend around the cylinder liner, through which scavenging air rushes into the cylinder, pushing upward any spent gases out through the four open *exhaust* valves in the cylinder head. The cylinder is then full of clean air.

Crankshaft rotation continues, and the piston and connecting rod reach and pass bottom dead center of the shaft. As the piston moves upward, it covers the ports while the exhaust valves are closed in the head, causing the piston to compress the air charge to a fraction of its original volume and raising the temperature to about 1000 degrees F.

Shortly before the piston reaches its top dead center, fuel is injected into the cylinder, where it is immediately ignited by the high temperature of compression and burns until the fuel charge is consumed. The burning charge rapidly builds up high pressure in the cylinder, forcing the piston downward on its power stroke.

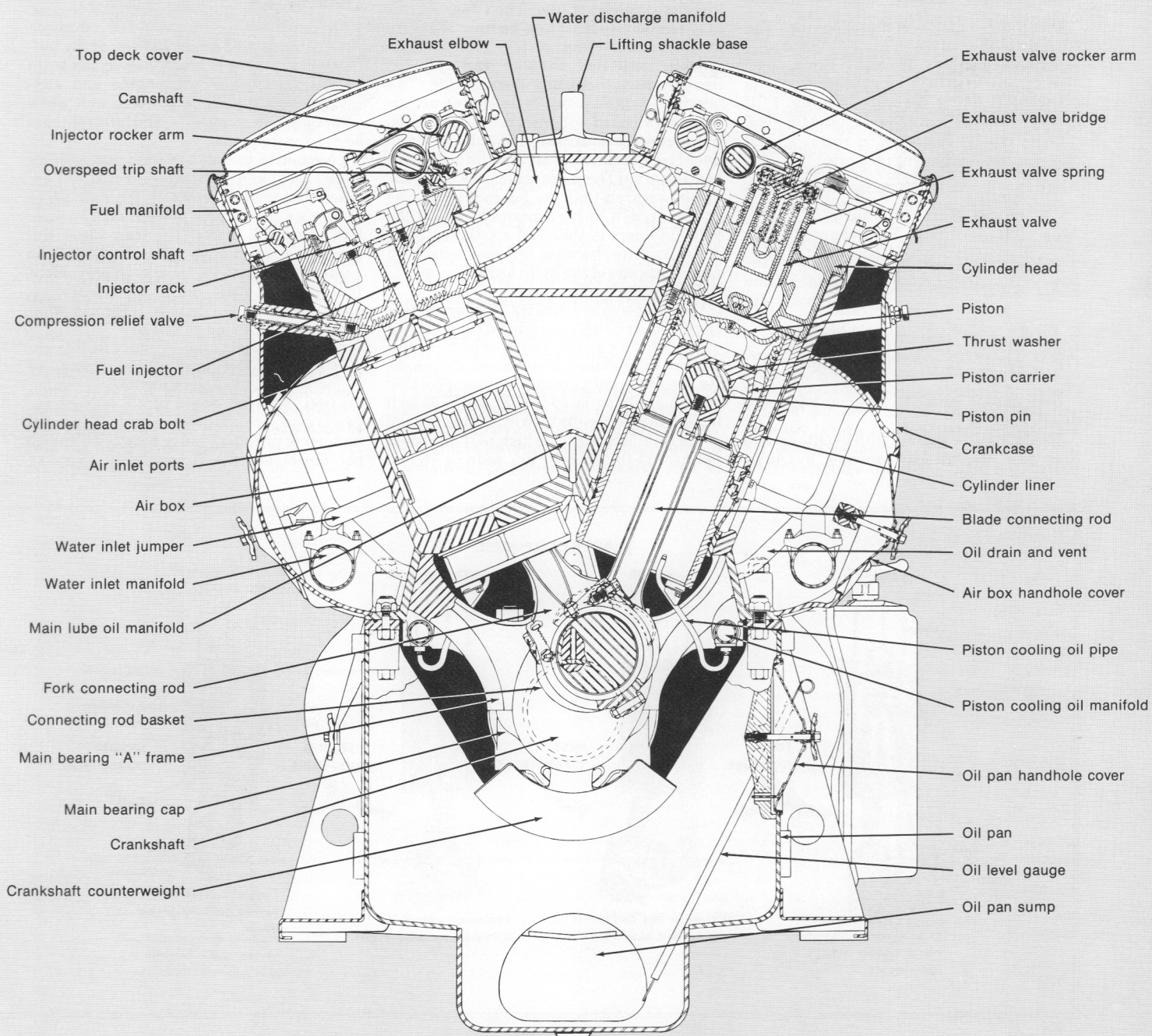
Again, before the piston approaches the end of its downward stroke, the exhaust valves open and release the spent gases to the exhaust manifold. The piston continues

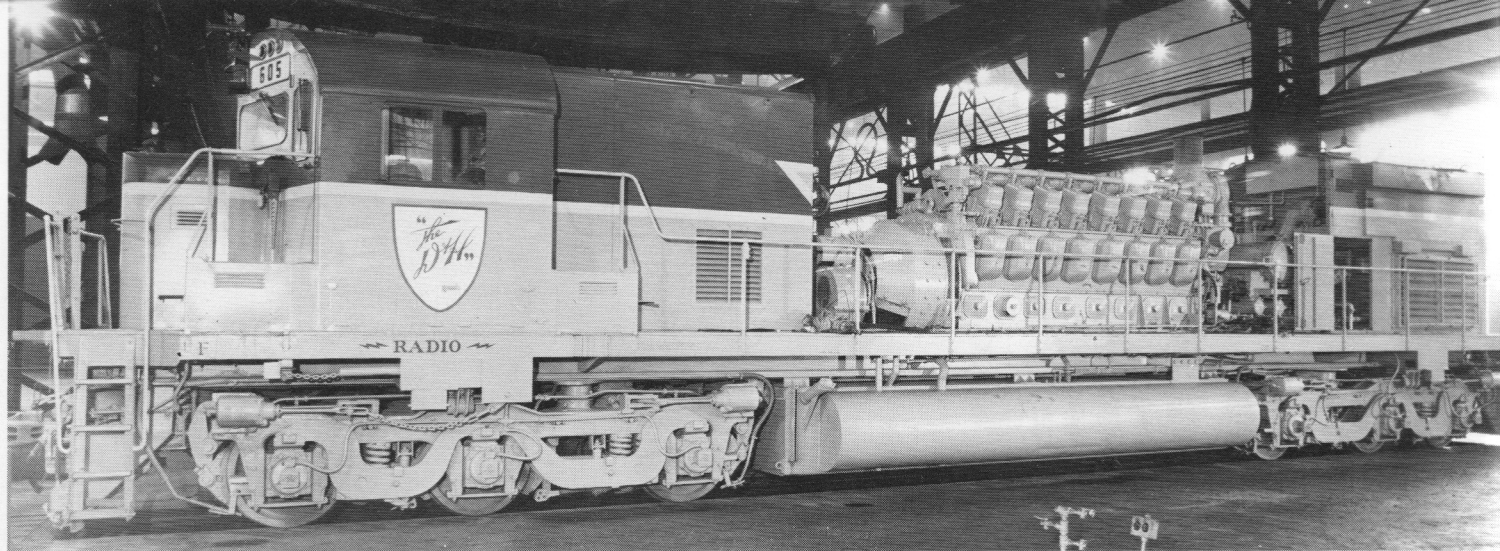
SEL from D to L-2

and cylinders

prime mover and its care and feeding

CROSS-SECTION of an Electro-Motive series 645E diesel engine, the prime mover found in the majority of newer American units.





Jim Shaughnessy.

to move downward, uncovering the ports in the cylinder liner, and the air under pressure enters the cylinder and forces out the remainder of the expanded exhaust gases. The cycle is ready to repeat.

On all three makes of diesel engines, the opening of the valves in the cylinder heads is accomplished by cams and rockers, operated by shafts driven by gearing from the crankshaft, fixing the valve timing. Stiff springs close the valves against the tappets.

Some typical compression ratios for 16-cylinder locomotive engines are:

Engine	model	Ratio	Remarks
Alco	251	12:1	Turbocharged (steel cap pistons)
EMD	645E	16:1	Normally aspirated (Roots blower)
EMD	645E	14.5:1	Turbocharged
GE	7FDL	12.7:1	Turbocharged

Both engine cycles have advantages and disadvantages.

The four-cycle engine, with events spread over two revolutions, provides a longer

ALCO 16-cylinder model 251 engine, freshly rebuilt and installed in a C628 locomotive (above) in the 1960's, and cutaway of an 8-cylinder version (right), illustrates the prime mover still utilized by Bombardier-MLW of Canada, an ex-Alco licensee.

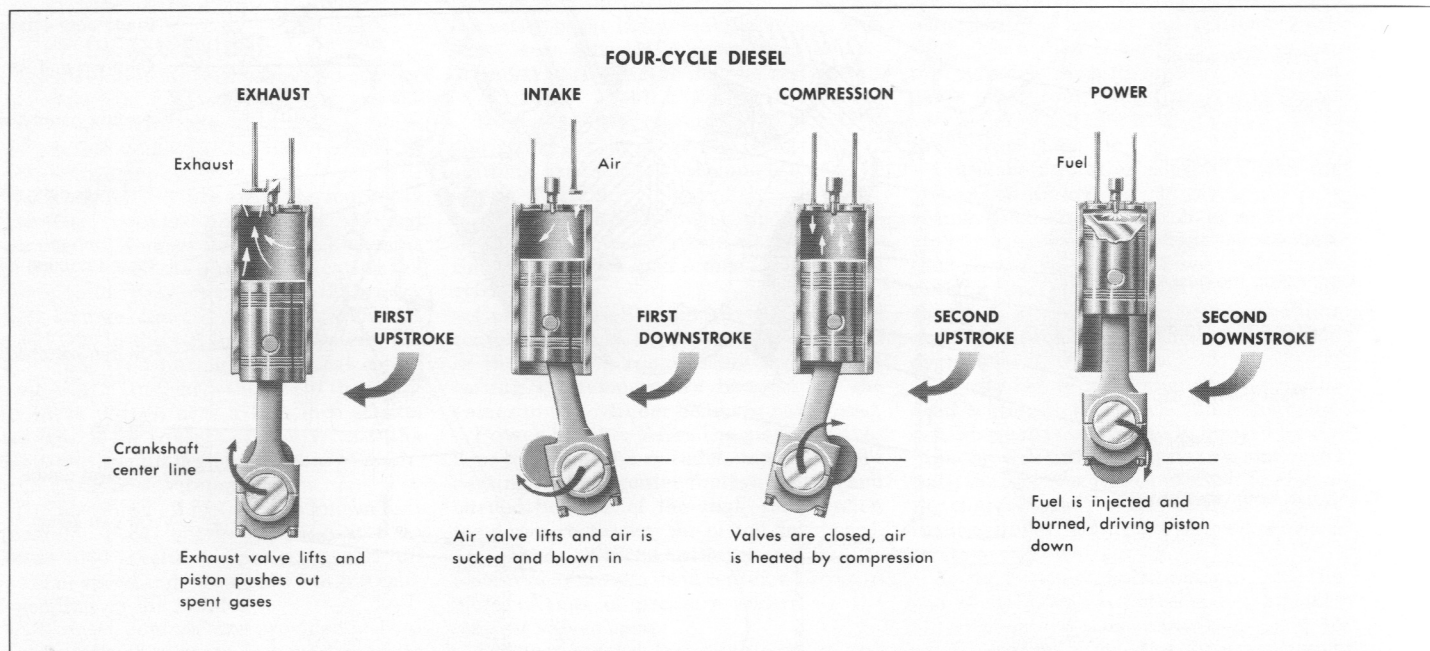
period of expansion and so is somewhat more economical of fuel. The two-cycle engine is easier to maintain because the compression rings and piston tops can be quickly inspected through the cylinder liner ports without any dismantling. The bearing loads on a two-cycle engine are always downward—there are no reversals, but require careful design in order to introduce large amounts of oil into the piston pin bearing area. There are other pros and cons, but be assured that the locomotive engine as produced in North America by any of the three builders is the most sophisticated of diesel engines, because railroad work here represents one of the more arduous applications of diesel power.

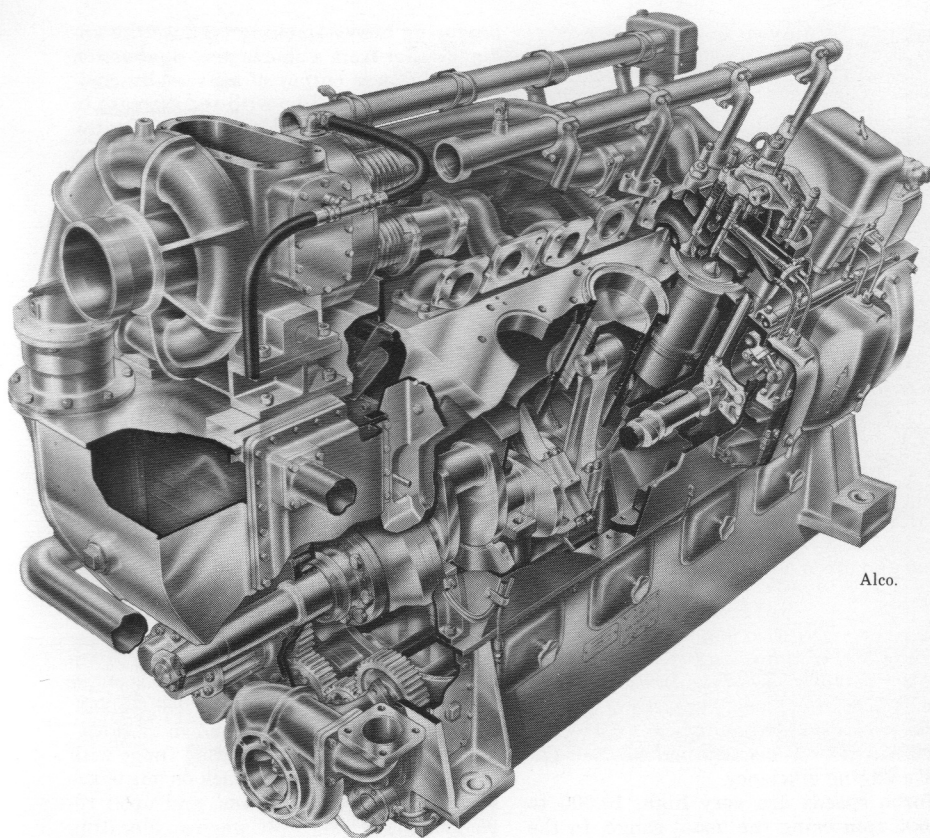
Consider some requisites. The locomotive engine must be able to respond rapidly from extremely low power requirements to full horsepower demand in a matter of seconds. Its weight, configuration, and supporting equipment must be such that it will fit well in, and can be maintained in, a cross section of the total locomotive which normally does not exceed 10 feet 6 inches wide by 16 feet

high. It is mounted on a framing of steel, which, though provided with springing, still does not entirely avoid the vibration from running on a steel roadway or the buffing and coupling shocks of day-to-day train operation. Further, the engine and auxiliaries are expected to perform well when subjected to the elements, and failures must be very infrequent.

Locomotive diesels are used successfully in riverboat and stationary service, but engines designed specifically for marine or land work never have made it on a locomotive. As E. W. Kettering, then Chief Engineer of Electro-Motive, said in 1951, "The engine has dictated every improvement that has been made. We, at Electro-Motive, have only done our best to interpret what the engine is trying to tell us."

Excluding the Alco 6-cylinder in-line engines in switchers, most all the oil engines in locomotive use today are of "V" configuration, with an angle of 45 degrees between the two cylinder banks. The total number of cylinders range between 8 and 20 per diesel engine. Accessibility to make





Alco.

rapid repairs is an important feature of the locomotive engine.

Each of the three builder's engines has its own distinctive sound, beat or rhythm. A smooth-running, responsive diesel engine is a source of satisfaction, and with a fast freight an engineman can begin to feel like a part of the rushing train. On the other hand, I can recall handling an excessively heavy train of petroleum coke on a stiff grade, working the throttle and sanders to avoid wheel slip, becoming concerned over possible damage to the traction motors, and then digging my feet into the cab floor to help the locomotive. Here, too, you can become part of the machine.

THE CYLINDER BLOCK for Alcos and EMD's is a fabricated steel weldment, while General Electric's is a special iron casting. The cylinder liners are of hard, close-grained cast iron for all engines. The liners may be plated or hardened initially by the builder, and when worn, they can be reclaimed by chrome-plating and finishing to original standard size. This is done to obtain additional service, a matter of importance to the railroad.

Cylinder heads are of cast iron, and since they are subjected to high temperatures in spite of extensive cooling, frequently many are found to be cracked when the engine is overhauled. To get this expensive part to

perform additional duty, many cracked heads are reclaimed by welding or other means.

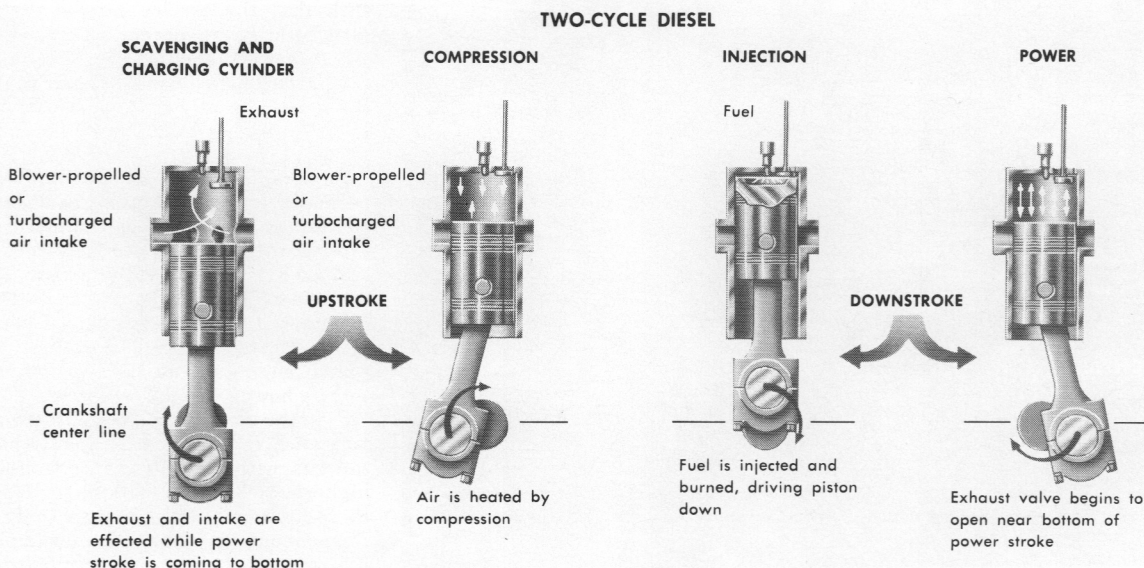
On an EMD engine, pistons are of cast iron; on Alco and General Electric engines, they are of an aluminum body with a steel cap. There are usually three or four compression rings above the piston pin, to seal against the burning gases; and one or two oil scraper rings (generally below the pin), to help return lubricating oil on the downward stroke so this oil will not enter the combustion space. The piston lives in a tough environment, and sometimes it will fail in service. If so, a heavy oil film at the stack or on the hood sometimes will give a warning, enabling the immediate removal of the defective piston from the engine. But if the piston breaks up and the connecting rod comes through the side of the engine, this becomes a costly repair.

The connecting rods and crankshaft are steel forgings, and their bearings are of the precision type, *i.e.*, no fitting or scraping is required to apply them.

These bearings have a thin layer of tin/lead/copper metal backed by a steel shell, which fits neatly into the bearing caps and the engine block or crankcase. Very little wear is permitted on the crankshaft and connecting rod bearings. The running clearance is about .007 inch (seven one-thousandths) new, and when the clearance increases by about six to nine one-thousandths, the bearing shells are removed and scrapped. Most roads, however, replace bearings on a time or mileage basis, depending on their own operating experience.

There is a damper, either of the mechanical or the fluid type, mounted on the free end of the crankshaft to control torsional vibration.

ENGINES are either normally aspirated or supercharged—or more accurately, turbocharged. EMD engines having gear-driven (Roots type) blowers supplying a large volume of combustion air at relatively low pressure (about 7 to 9 inches of mercury or 4 psi) are known as "normally aspirated," and EMD's engines up to the 2000 h.p. rating





MODEL RAILROADER: Jim Hediger.

EMD'S popular 2000 h.p. GP38-2 lacks turbocharger, often a high-maintenance item.

level are constructed to this arrangement.

The turbocharger is a useful adjunct to the diesel because its turbine utilizes some of the velocity energy in the exhaust gas (which otherwise would be wasted) to drive an impeller to supply combustion air under relatively high pressure to the engine.

Alco and General Electric four-cycle engines all are turbocharged, regardless of their horsepower. The higher-rated EMD engines are turbocharged, with the unique arrangement of having the charger mechanically driven from engine gearing through an overriding clutch until the exhaust energy builds up sufficiently to take over and drive the turbo without help from the engine gearing.

The EMD turbocharger puts out an air pressure of 15 to 18 pounds at full load, and these engines have been manufactured up to 3600 h.p. As you can see, with a turbo, power can be increased over normal aspiration by about 50 per cent simply by forcing in more air plus the additional quantity of fuel to be burned.

Most turbos consist of a single-stage turbine and a centrifugal blower mounted on a common shaft running on bearings carried

in a casing. On Alco and GE engines, the turbine end of the casing is water-cooled. The air delivered from the impeller wheel (blower) is frequently cooled by an after-cooler on its way to the engine cylinders to increase the air density and further improve engine efficiency.

Turbo speeds are very high, 10,000 to 17,600 rpm being the usual range. In the early 1940's turbos were frequently subject to failure, and I recall, unhappily, being alongside of an engine under load taking power readings when the turbo elected to break up, some of the blades rocketing out of the stack, fortunately without bursting the turbo casing.

As previously mentioned, Alco and GE engines are all turbocharged, depending entirely on exhaust gas pressure (this energy is almost free) to drive the turbo and producing an air pressure to the engine of about 18 to 26 pounds. Incidentally, the finely spaced blading in the turbo wheel breaks up any large pieces of hot carbon coming from the exhaust manifold, so the turbo also becomes a spark arrester.

High-altitude operation poses some problems for diesels with normal aspiration,

producing heavy smoking because the engines suffer from a shortage of combustion air. The power output of a normally aspirated engine will drop with the increase in altitude above sea level, and at 5000 feet the total loss in power is 8.2 per cent. However, with turbocharging, sufficient air can be rammed into the engine so that a high percentage of power can be maintained, and such engines successfully operate on railways at high altitudes.

ANYONE who has seen older Alcos at work knows they can lay down a heavy blanket of smoke, particularly when accelerating. This is from an early proprietary turbo and occurs before the exhaust pressure is sufficiently high to spin the turbo up to speed to supply adequate combustion air to the engine. In the trade it is called "turbo lag," and it was for this reason that EMD developed its mechanically driven turbo for low engine speeds, for when the exhaust gas pressure is built up sufficiently high, the turbo is released from the engine gearing and runs on gas pressure only.

In 1946, I was part of a Santa Fe group testing the three-unit Alco passenger locomotive No. 51 (Alco serial No. 75000), prototype of what became known as "PA's." One day we decided to go to San Diego with the two cab units back to back on one of the scheduled passenger trains, and upon returning in the afternoon, when accelerating from a slack (slowdown) in Los Angeles, we were given a citation for smoke production. This was a little embarrassing, because at that time our oil-fired 3700-class steam locomotives still were working some of the *San Diegan* trains and were arriving and departing almost smokelessly. Our Mechanical Officer was not a man to be easily dismayed with No. 51, though, and he said, "We will wait and take her out of Los Angeles at night."

Alco was a pioneer in introducing turbocharging in America, for it was an early licensee of Buchi (Switzerland). The current Alco turbocharger (homebuilt at Auburn, N. Y.) is greatly improved over the old design we had on the Santa Fe PA's.

All machinery has some disadvantages, and turbochargers can be high-maintenance items. If the power requirements of a railroad (using EMD locomotives) are such that the service can be performed satisfactorily by normally aspirated engines, that is the route to go. Many roads do not have shop facilities to repair turbos, so the repairs usually are done by the builder on a repair-and-return basis.

FUEL CONSUMPTION for EMD's two-cycle normally aspirated engine is about .390 pounds per brake horsepower hour, and the rate for the turbocharged version is about .365 pounds bhp/h, depending on speed of rotation. The average diesel locomotive consumes 1.6 gallons of fuel oil per mile, according to national statistics, and a switch engine burns 11 to 14 gallons per service hour.

Like the steam locomotive, the diesel is very much a "heat" engine, and the hotter it can run without getting into trouble, the higher efficiency it will have. However, there are limits to temperature that certain components can absorb. For example, the limit for piston crowns is about 500 degrees F. This is established by the ability of the lubricating oil to remove this heat and still

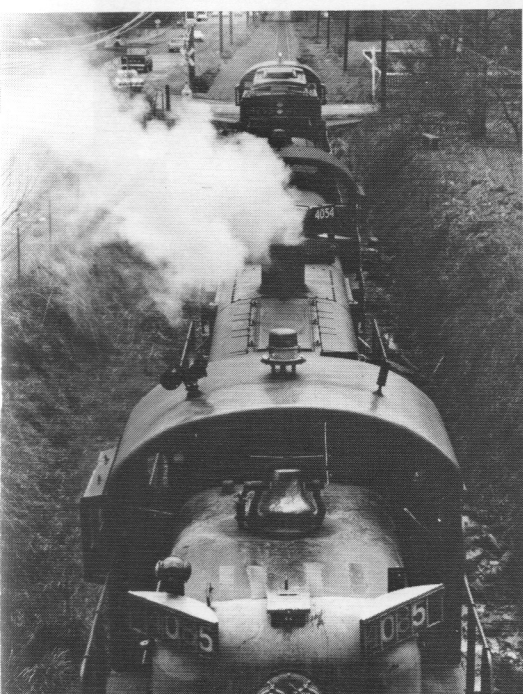


David Oroszi.

PRODUCTS of Alco, EMD, and GE show compatibility on a Conrail freight in Ohio.



Leo Caloia.



James Pettinari.

OLDER ALCOS are renowned for pouring out the smoke when accelerating. The malady is known as "turbo lag," illustrated at left by an RS3 and above by a PA. Author remembers Santa Fe being issued a smoke citation in Los Angeles for a PA's production. Smoke from the stack on the GP40 below indicates the turbocharger has suffered a failure.

maintain sufficient film strength so the sliding parts will not "seize." Also, there must be adequate capacity in the water cooling system to withdraw this heat from the hot oil at the heat exchanger, so the lubricant can make another pass at lubricating the engine, in addition to cooling the cylinder jacket water.

It is easy for me to appreciate the heat that a diesel produces, and that it is exposed to, by recalling Santa Fe trips of long ago in the summer through the Tehachapi tunnels in California, with four-unit consists of EMD F7's handling heavy drags out of Bakersfield. Upon looking back from the lead cab, one could see shimmering waves of heat radiating off the carbody. In the tunnels, the temperature in the last unit could be almost unbearable. It was not uncommon to hear the alarm bells ring, indicating that one of the trailing units had overheated and shut down.



William Gerhardt.

HEAT that a diesel-electric is exposed to, and produces, was shown to author by Santa Fe F7's on the Tehachapi line.

4. WATER COOLING SYSTEM

As noted earlier, a large portion of the energy in the fuel is rejected, in the form of heat, by the engine into the water and oil systems. Both the water and oil temperatures must be kept within a specified range. On a turbocharged engine, the water temperature returning to the engine will be about 175 degrees Fahrenheit and oil temperature about 20 degrees higher. The three major locomotive builders (Alco, EMD, and GE) each have different features in their cooling systems, but all have a water storage tank and a circulating pump or pumps that are driven from the main engine. In all modern locomotives, the cooling system is pressurized.

In general, the sequence of water flow is from the storage or expansion tank to the centrifugal pump, which forces water into the engine headers; then around the cylinder liners, the water flowing upward, cooling the heads; and then out to the radiators for giving up the heat. The cooled water from the radiators flows back through the oil cooler, to bring the oil temperature down. The water then returns, via the storage tank, to the pump for another cycle. There are other circuits from the pump which cool the turbocharger (on Alcos and GE's) and pass water through the aftercoolers to cool the combustion air. In cold weather, it is common to circulate hot water from the en-



John Uckley.



MoPac.

JUST like an automobile, EMD switchers have their radiator fans up front.

gine through radiating core heaters for heating the enginemen's cab, although some locomotives use electric cab heaters.

The EMD engine differs in that the cylinder liners have hollow walls, with the cooling water circulating within them on its way upward to the cylinder heads.

Radiators are subjected to vibration, and also the tin in the solder tends to migrate out of the tube fastenings so that after 10 or 12 years life a radiator generally will require replacement.

The control of the water temperature can be accomplished by different methods. On an EMD MP15, a multipurpose switcher-style locomotive with a constant-running mechanically driven cooling fan, the temperature control switch arranges to open or close the shutters to modulate the flow of air through the radiators and thus regulate engine temperature.

Most recent EMD road locomotives have electrically driven cooling fans located just above the radiators. These fans draw air through openings in the side of the hood and discharge the air upward. The several fans are energized in sequence order by the temperature switches, which are arranged with different settings to maintain the desired cooling.

The Alco Century series road locomotives have radiators associated with thermostatically controlled shutters, with one large cooling fan below the radiators. This fan is mounted on a vertical shaft, connected through a right-angle gear box, to rotate with the engine crankshaft. Interposed between the gear box and the engine is an eddy current (magnetic) clutch, and the temperature switches electrically control the strength of the clutch field current. This means that when the engine is running cool, a weak field allows slipping of the clutch to reduce fan speed, causing the engine to warm up—and vice versa.

General Electric has a novel system employing eight thermostatic valves, set vertically, each having a temperature-sensitive bulb at the top. When no cooling is needed, these valves pass circulated water directly to the storage tank. However, an increase in water temperature causes expansion of the bulbs, forcing the thermostatic valves downward to open. These valves act as pilots, causing the water flow to get under and lift up one or two large

piston-type valves. The piston valves route the water into one or both radiator sections, depending on the amount of cooling required by the load carried by the engine. Fans located below the radiators are also part of the system.

The newer General Electric locomotives have fluidic cooling controls to reduce maintenance requirements. Basically, the fluid amplifier is a device to control the main flow with a control jet of much smaller power, and in conjunction with a thermostatic valve to sense water temperature, plus two pilot and two diverting valves, permits or prevents cooling water from flowing to the radiators.

Nearly all diesel engines are arranged to shut down, or drop to a reduced or idle speed, in the event that cooling water is low or the cooling water temperature exceeds a predetermined value. On occasion, radiator shutters will stick shut or a temperature switch will malfunction; with the resulting rise in water temperature, the engine will reduce to idle speed or shut down to prevent damage by seizure of the pistons.

Treated water is required in the cooling system to reduce corrosion damage. Borate compounds are commonly used at the rate of .75 oz. to 1.25 oz. per gallon of water to maintain a Ph of 8.5 minimum. Other good water treatments are also available.

The engine system will hold about 225 to 350 gallons of water, depending on the type of unit. On most modern locomotives, water will drain from the radiators automatically to prevent their freezing when the engine is to be shut down.

An antifreeze solution for winter protection is seldom, if ever, used in railroad locomotives. Although the cost would be prohibitive, the chief reason for this nonusage is the possibility of the ethylene-glycol from a small water leak getting into the crankcase lubricating oil. The resulting rapid deterioration of the oil from this contamination would very likely cause destruction of the engine bearings. The engine lubricating oil will tolerate some plain water but not the ethylene-glycol mix. The use of alcohol with a pressurized cooling system would present a fire hazard.

It has been reported recently that chemical companies are endeavoring to develop an antifreeze solution suitable for locomotives.

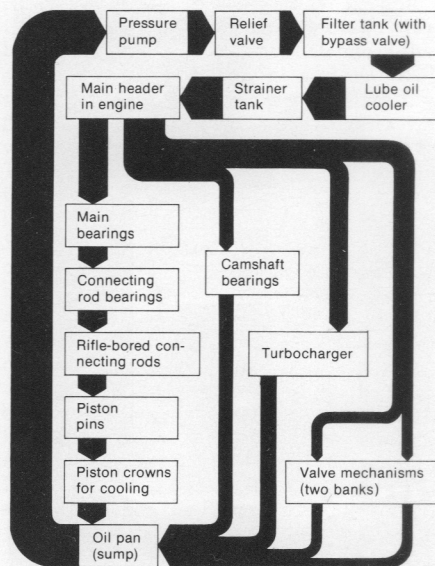
5. LUBRICATING OIL SYSTEMS

The engine lubricating oil system provides pressure lubrication to all the bearings and working parts within the diesel engine. In addition, this system has the important function of carrying away from the working parts heat which has been produced by friction and the combustion process. The pressure circulating pump is always driven from the main engine.

The system is closed. The sequence of flow for the systems of the three major builders is illustrated on the accompanying diagrams. The sequence starts with the engine oil pan, or sump, where most of the oil is contained.

The modern Alco engine with steel-capped pistons will have an oil pressure of from 55 to 85 pounds per square inch (psi) at full engine speed. The Alco locomotive also has a separate pump taking oil from the header, pressurizing this oil to drive a hydraulic fan motor that ventilates the generator compartment. The oil exhausted from the fan motor returns to the strainer tank.

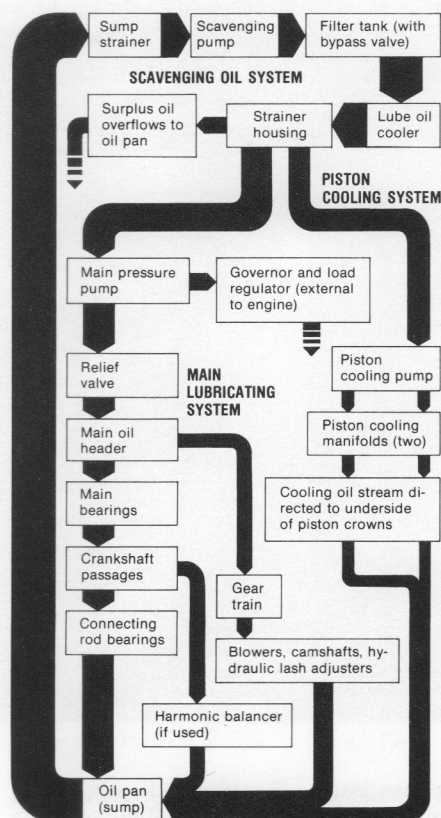
The Electro-Motive engine has a combination of three separate systems, each with its own engine-driven pump.



The lubricating oil system of a 16-cylinder engine holds about 250 gallons on an Alco or EMD and about 380 gallons on a General Electric. Unless contaminated by a water leak or for other reasons, the engine oil is only changed on an annual basis or on information furnished by spectrographic analysis. The oil drained from crankcases is usually re-refined and is then the equivalent of new oil for reuse. On modern locomotives, the oil consumption is about one-half of 1 per cent (.005) of the fuel consumed in gallons, depending on the service.

The General Electric oil system is of the full-flow type without any bypass valves; therefore, the GE engine will automatically shut down if the filters become very dirty and offer excessive resistance to flow. Bypass valves are used by the other builders and are arranged to open in the event the filters become clogged and will allow the engine to continue running. The oil pressure on a GE at full throttle is about 44 pounds psi varying with the temperature.

Since hot oil filters best, all builders ar-



task was completed, I am sure most of the residents were up before their appointed time.

One of the most important protective devices for the diesel engine is incorporated in all lube oil systems, the low-oil-pressure shutdown. When an oil pump fails, or perhaps a pipe breaks, or a particle of debris gets under a pressure-regulating valve, this device is intended to stop the engine before any bearing damage occurs.

Oil leaks are one of the routine items that plague the locomotive maintenance officer. Since the oil and water are on opposite surfaces of the tubes in the coolers or heat exchangers, a leak here puts oil into the water system because the oil pressure is the greater. This has the effect of reducing the heat transfer, at liners and cylinder heads, to the cooling water until corrective measures are taken and the water system cleaned.

6. FUEL SYSTEMS

All locomotives have a motor-driven pump which draws the fuel from the tank and brings it, via filters and regulating valves, at about 35 to 45 pounds pressure, to either a fuel injection pump (Alco or GE) or to a unit injector (EMD). These latter devices develop the very high pressure necessary (3000 psi on EMD unit injector, 3600 psi on Alco or GE nozzles) to force the fuel into each individual cylinder, where the liquid is atomized by the design of the multi-hole nozzle. The excess fuel in the injection pumps and nozzles over that required by the load, is returned to the tank.

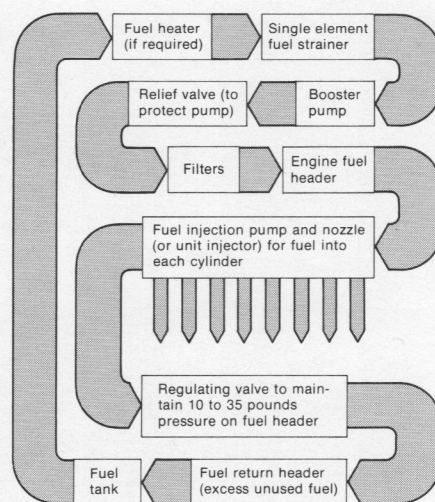
The fuel pumps or unit injectors are actuated by rockers and cams, the latter which are integral with camshafts driven and timed by the engine gear train. Please note that the fuel pumps have a constant stroke. The amount of fuel delivered to the cylinders is varied by partially rotating the pump plunger as it is moved up and down by the cams. The pump plunger has a helical groove cut in to its periphery, and the degree the plunger is rotated regulates the quantity of fuel trapped between the inlet and outlet ports that will be delivered with each stroke. The arc of rotation is controlled by the governor through appropriate linkage.

The fuel enters the cylinder when the pressure on the fuel oil in the pump overcomes the set, predetermined, spring pressure of the nozzle.

For its diet, the diesel engine is fairly tolerant of liquid fuels (remember, Rudolph Diesel planned to burn coal!). However, many maintenance problems are created—chiefly by wear—when fuel varies greatly from the usual specification. A typical specification for No. 2 diesel fuel includes, among other properties, a 45-50 Cetane, 0.3-0.5 per cent maximum sulphur content, and a minimum flash point of 150 degrees Fahrenheit. The fuel needs certain additives to prevent injector sticking in summer, and northern railroads are very interested in pour points, which will indicate if the waxes in the fuel will solidify and prevent fuel passage through filters in cold weather, causing engines to shut down.

The quality and characteristics of fuel and lube oils are a very extensive, and sometimes controversial, subject, which we shall exclude here.

The excess fuel that is pumped, mentioned above, performs several useful functions: it lubricates the fuel pumps or injec-



tors; it cools them, particularly the unit injector in its hot location in the center of the cylinder head; and, heated, in returning to the tank, it reduces the waxing tendency problems in cold weather.

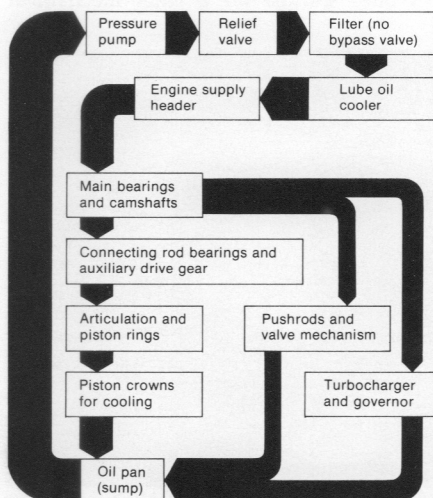
The fuel tank is provided with a drain valve so that accumulated water can be drawn off below the fuel as necessary. This water may come from a number of sources: pipelines, tank cars, fixed facilities, or condensate which forms on the inside of the tank from air entering the fuel tank vents.

7. AIR FILTRATION SYSTEM

Most modern locomotives have two air filtration systems. One system cleanses the combustion air for the engine, and the other provides a supply of clean air for cooling the main generator, for pressurizing the electrical control compartment to keep dirt out, and for cooling the traction motors.

The engine air filtration system must be maintained clean for free flow. For instance, black smoke from the exhaust stacks of an otherwise good engine generally indicates that the air filters need cleaning, or replacement, because the engine is starving for combustion air.

The system serving the engine combustion air may be a combination of inertial, oil bath, or paper filters. The paper filters are quite expensive per engine set, and therefore the usual practice is to periodically check the pressure drop through them with a manometer. When a depression of 18 inches of water is reached (on a normally aspirated engine, 14 on turbocharged), the filters are considered plugged with dirt and are replaced. I



MORE TO COME

IN the third installment of The Diesel from D to L, Vernon L. Smith explains the braking and electrical systems of a diesel-electric unit, and breaks down the weight, by components, of a road-switcher. Next month in TRAINS.

LOCOMOTIVES exit tunnel atop Blue Ridge and start descending. Their train will be going uphill and downgrade at once, requiring precise control.

THE DIESEL from D to L-3

Stopping and starting

All about the braking system and the "electric" in diesel-electric

VERNON L. SMITH

I SO FAR in our examination of the diesel-electric locomotive, we have studied the underbody components plus the diesel engine itself and its supporting systems. Now, we'll look at the enginemen's cab, braking system, and electrical systems. Remember that we are considering mainly the hood style road-switcher, which is the overwhelmingly dominant type of locomotive in service today, and that we are generalizing to allow for the differences in the products of the three builders (EMD, GE, and Alco/MLW) and individual railroad specifications.

Before we proceed, let us break down a locomotive by component weights. As the example, I chose a particular favorite, the Electro-Motive GP38-2 built for my former employer, Belt Railway Company of Chicago. The only atypical aspect of BRC's GP38-2's is the heavy ballast; these units are used in pairs in Clearing Yard and on transfer runs, and the greater-than-normal weight is advantageous in gaining addi-

tional traction for these heavy, slow-speed trains.

The weights break down approximately as follows (in pounds):

Underframe	46,500
Trucks (2) with traction motors (4)	80,000
Engine, 16-cylinder 645E (with manifold)	35,000
Main alternator	16,000
Auxiliary generator and blower	1,000
Air compressor	2,400
Long hood (equipped)	19,000
Inertial filter and hatch	4,700
Short hood and operating cab	12,000
Batteries	3,000
Fuel tank (empty)	6,440
Miscellaneous items, including ballast	28,060
Supplies (fuel, lube oil, water, sand)	27,900
Total	282,000

Dividing the total weight by the four axles yields a rail load under each axle of 70,500 pounds—about the limit on 40-

inch-diameter wheels. Many roads cannot accept such high loads, and the common figure for a substantial number of railroads is 62,500. In fact, builder specifications list a GP38-2 fully loaded at the corresponding total of 250,000 pounds. An SD40-2 (six axles) typically weighs 368,000 pounds, or 61,000-plus per axle. General Electric and Alco locomotive weights are comparable.

8. HOOD AND OPERATING CAB

The long hood protects the equipment from dirt and moisture and also provides useful support for many items including radiators, air filters, sandboxes, and headlights. On the sides of the hood are hinged doors with two latches, one high and one low, and the maintenance of these door latches, particularly on road units, is a significant expense item. You often see road units operating with hood doors flapping open, which negates the clean, pressurized air systems found on many modern units. On switchers, door hinges and hinge pins also are an expense item, for they have a relatively short life owing to vibration.

I once worked for a chief mechanical



MODEL RAILROADER: Jim Hediger.

POPULAR road models of today, EMD GP38-2 (left) and SD40-2 (right), typically weigh 250,000 and 358,000 pounds respectively.



Robert E. Abernethy.

officer who stated that the diesel engine ought to run satisfactorily without an enclosure and be steam-gunned for cleaning like the steam locomotive was. He may have been right, for all the diesel-electric's supporting auxiliaries would have been more rugged, and a better (although more expensive) locomotive might have been the result.

The short hood, or nose, carries the front sandboxes, some air-brake equipment (on certain designs), and usually the radio. Strong collision posts, generally in the form of heavy flanged gussets, are built into the nose. These, together with the horizontal depth of the nose (about 50 to 81 inches, depending on builder) provide some measure of protection for the enginemen.

Regarding the headlights, it is interesting to note that each of the two sealed-beam lamps which make up a headlight is of 200,000 candlepower—a vast improvement over the old headlights of the 1940's that required much attention in focusing to obtain a satisfactory beam of light.

The operating cab provides shelter for the enginemen and houses the controls. No further comment is necessary without in-

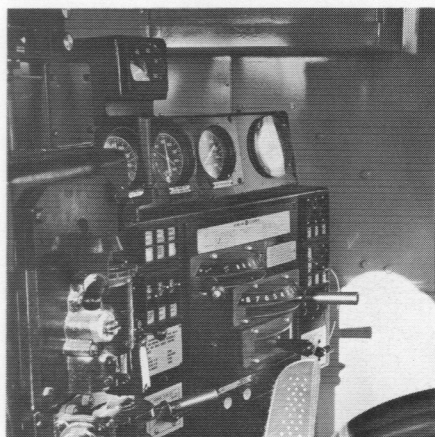
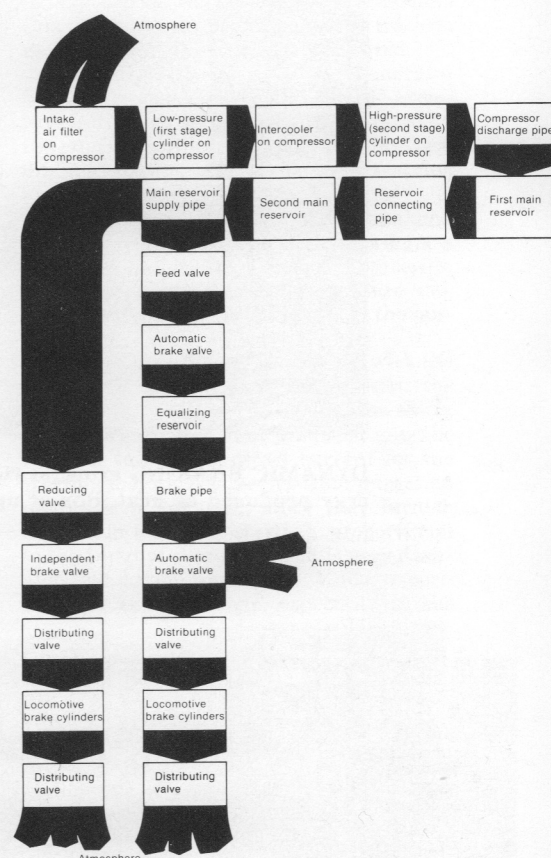
dulging in details of furnishings, except to say that today's diesel cabs are a far cry from some steam-locomotive cabs. After diesels came to my road, one of our former steam enginemen—who on summer days would wash the steam cab and tender deck down with a hose—got a bucket of water and sloshed down the diesel's cab floor and front face of the control compartment. It was pointed out to him that his knowledge of electricity would rapidly go from A to Zap if he continued the practice. Amenities on today's diesel cabs now even include air conditioners, which southwestern roads specify.

9. BRAKING SYSTEMS

The locomotive air brake has been well-covered elsewhere, so we will not attempt to describe it in detail. The accompanying "tree diagram," however, illustrates the system's flow.

You will observe that there are two branches from the main reservoir supply pipe. One is the independent brake system; this controls the brake on the locomotive alone. The other is the automatic brake system; this controls the brake throughout the entire train, including the locomotive. The locomotive ("independent") brake may be released at any time with the train ("automatic") brake remaining applied. This is a feature necessary to avoid damage to the locomotive wheels during heavy braking, for the braking ratio of the locomotive is much greater than that of the freight cars (whose braking ratio may be as low as 20 per cent of the loaded weight of the car).

The brake system currently employed is known as the 26-L schedule. Development of the 26-L provided an important step forward in smooth train-handling, since now both the independent and automatic brake valves are of the self-lapping type. This means that the amount of braking exerted is determined merely by the position of the brake handle and can be increased simply by advancing the handle position to any point. The pressure in the brake cylinders is



Ernest L. Novak.

CONTROL stands are standardized.

held constant until released. The 26-L brake schedule is also economical to maintain.

The air for braking and other purposes is generally produced by a three-cylinder, two-stage air compressor, either air-cooled or water-cooled. Current practice is water-cooled, with the compressor driven directly from the diesel engine.

The compressed air, at 130 to 140 psi, goes to the main reservoirs for storage and use. Automatic blowdown valves are provided to get rid of the moisture which would freeze in the brake apparatus in cold weather. A governor is necessary to load and unload the compressor to suit the air requirements, since the compressor crankshaft rotates constantly at engine speed.

Under Federal Railroad Administration regulations, the compressor must start loading (producing air) when air pressure in the reservoirs drops to within 15 pounds above the brake-pipe pressure used by the individual railroad. Brake-pipe pressure, as established by the feed-valve setting on the locomotive, is between 70 and 90 psi, and this is the pressure that normally passes through the brake hoses to the cars.

After the locomotive has been placed on a train, the air-brake system of the cars is charged. This operation would take considerable time with the locomotive standing and the compressor turning at only the idling speed of the diesel engine, so it is usual for the engineman to open the generator field breaker, which prevents electric current from being produced for propulsion. It does, however, allow the engine to respond to the throttle. The throttle lever is brought out to the 4th or 5th notch

("run 4" or "run 5"), speeding up the engine, and the air compressor then about doubles its air production. Hence the term "pumping air."

Incidentally, throttle positions higher than 4 or 5 are seldom used when the engine is turning the unloaded electric generator, because of possible vibration damage.

MOST locomotives have Service Safety Control, a "dead man" feature. If the locomotive brakes are in release (off) position and the engineman removes his foot from the "dead man" pedal, he will receive a warning whistle. If action is not taken to again place his foot on the pedal or apply the engine brake within about 6 seconds, the brake will be set as a service application on the entire train; excitation will be removed from the generator; and the diesel engine speed will be reduced to idle. Recovery of the system can be accomplished by placing the throttle in idle, depressing the foot pedal, and going to suppression, lap (depending on type of brake equipment), or emergency position of the automatic-brake valve, then waiting a prescribed time interval, or until the "P.C." (pneumatic control) light goes out. The automatic-brake handle is then placed in running position. Some railroads will specify a different procedure.

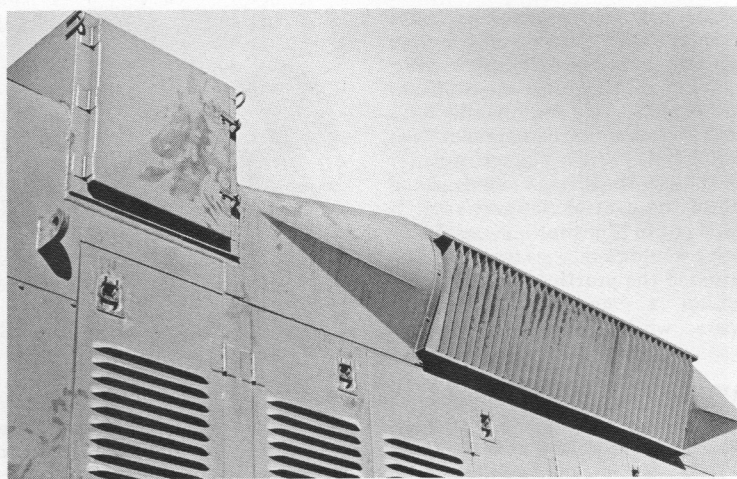
Air is also used to power a number of devices. Among these other air operations: to blow the whistle, to ring the bell, to release the sand from its boxes to the rail, and to actuate the window wipers. On older-model locomotives, air, rather than electricity, provided the control.

DYNAMIC BRAKING is a feature now found on many road locomotives. Initially, it was used solely in hilly or mountainous regions, but now, with advances in technology, roads in relatively flat country with undulating profiles can utilize it.

When desiring the use of dynamic braking, the engineman places the throttle in idle position; after waiting 10 seconds or more, he moves his selector lever on the control stand from POWER to OFF, and, after waiting another 10 seconds, to BRAKE. Electric circuitry is connected to the traction motors that will furnish excitation to these motors, making them generators. The kinetic energy of the train is then rotating these temporary generators (which now offer resistance to rotation), and the electrical energy produced is directed to the braking grids, where it is dissipated in the form of heat. The resistance to rotation controls the speed of the train. (The grids are the externally visible feature that enable an observer to determine if a unit is equipped with dynamic braking.)

The throttle lever now has a new function in regulating the amount of braking effort required, because the throttle lever may be advanced smoothly, without notching, to the desired level of braking.

Several features have to be incorporated to make this all work. Fan operation must be provided to cool the dynamic-braking grids (a big electric toaster) to avoid melting down the elements, and the traction-motor blowers must be operating at increased speed to cool the motors. Newer locomotives are arranged to limit the amount of energy forced into the grids. Further, the dynamic and air brakes must be interlocked, or the engine air brakes released, to avoid sliding the locomotive wheels in the event both brakes are applied together in a heavy application. The engineman also has a warning light to assist him in not exceeding the maximum amount of braking permitted. Maximum braking ef-



Lee Langum.

DYNAMIC BRAKING grids (at right on this GP9) dissipate the energy produced as heat. Box at upper left houses paper air filters.



John C. Lucas.

BY looks of the brake-shoe smoke, dynamic braking alone wasn't enough to hold this train on the 1.22 per cent grade.



Richard Steinheimer.

SMOKE from braking swirls around mid-train helper in the Sierra. Three units are from SP, UP, by EMD, GE.

fort with the dynamic braking occurs somewhere between 19 and 25 mph, depending on design. On extended-range designs, a more recent innovation, dynamic braking can be effective at speeds as low as 9 mph.

The whine of dynamic-braking fans is unmistakable, and well-remembered—I can still recall the sound of Santa Fe F7's descending eastbound from Flagstaff, Ariz.

If only ordinary tread braking with brake shoes was employed on a stiff descending grade, the heat generated would have to be absorbed by the wheels of the locomotive and cars. In some instances, this air braking alone would require a stop at the foot of a long grade for wheel-cooling. Wheel life is much shortened by wear, and in some instances by thermal cracking from heat concentrated at the treads. With dynamic braking, this heat is dissipated through the grids.

In the days of steam on the Santa Fe, a 3800-class 2-10-2 descending Cajon Pass would have a low cloud of blue smoke extending along the entire train, caused by brake shoes heating the wheel treads and by oil burning off the wheel plates. This scene was repeated at the foot of every grade in the U.S. where train speeds were held in check with set-up retainers and heavy air-brake applications.

10. AUXILIARY POWER

The locomotive is provided with a set of batteries to supply electricity (64-volt to 72-volt direct current) for engine starting, control excitation, lighting, and other low-voltage needs. A heavy knife switch connects the battery to the low-voltage circuits. The battery is kept charged, through a voltage regulator, by an auxiliary generator driven from the engine.

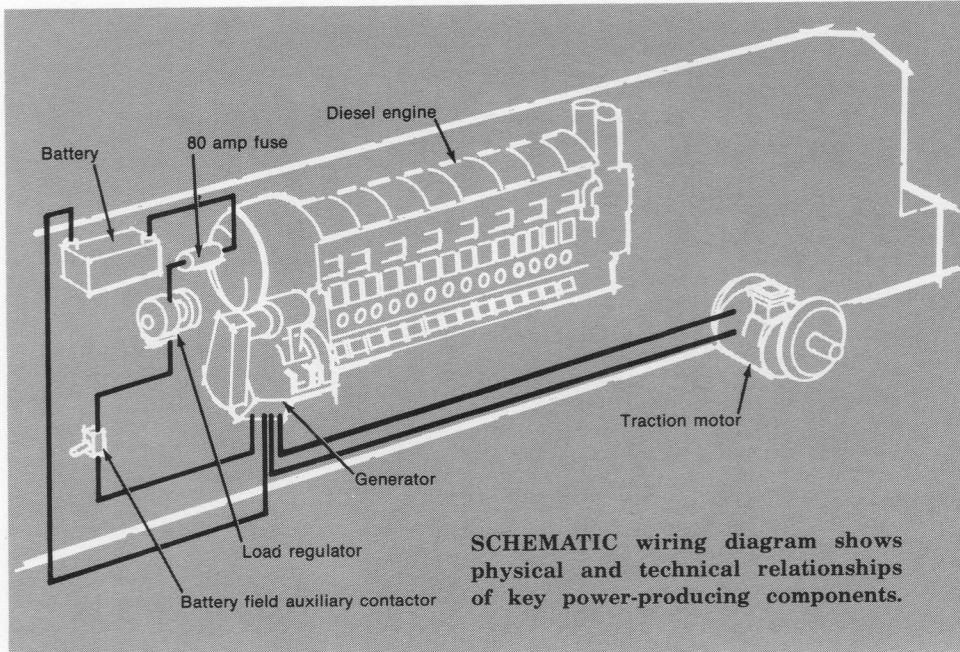
The Alco Century series locomotive has in addition an exciter generator—a separate machine, gear-driven from a common gearbox, with an auxiliary generator. Its purpose, as the name implies, is to furnish current for main generator excitation. General Electric locomotives also have a separate gear-driven exciter.

The batteries ordinarily are arranged in eight trays, each containing four cells, with a total capacity of about 426 ampere hours at the 8-hour discharge rate. Recently, batteries have been offered which have four of the eight trays combined into a single unit; this has advantages and disadvantages over the ordinary arrangement.

A set of batteries weighs about 3000 to 3200 pounds and, with proper maintenance, has a life of 10 years or better.

The battery charging contactor, which connects the auxiliary generator to the battery, is controlled by a reverse current relay that opens the circuit to prevent the battery from trying to motor the auxiliary generator when the engine is stopped. Normally, the battery loafs while the engine is running, but when cranking a cold diesel the current demand is the equivalent of a dead short across the battery terminals and the cranking circuit is usually fused for 400 amps.

SINCE the batteries furnish the starting power, we will now review the engine-starting procedure. In the cab, the reverser must be on center, control breakers in, throttle closed, isolation switch in "idle" or "start" position, and fuel pump switch in. Next, if the engine has been shut down for 4



SCHEMATIC wiring diagram shows physical and technical relationships of key power-producing components.

hours or more, it is required practice to drain out any water which might have leaked from the head-to-liner seals (or from a cracked head) or that might be laying on top of the pistons. On an EMD, such drainage is accomplished by opening each cylinder flash cock; on an Alco or GE, equivalent cylinder drain plugs are opened. Since water is nearly incompressible, failure to do this can result in a bent connecting rod or other damage. If the engine is a known leaker, it must be barred over (rotated) manually to force out any accumulated water from the cylinders. If the engine has been shut down for a shorter time, the flash cocks or drains can be opened and the start switch turned quickly, for a single revolution of the engine, after which the drains should be closed.

Now we are ready to crank the engine. The starting switch usually is located near the engine governor alongside a lever mounted on the engine that is connected with the fuel pumps. First, depending on the make of locomotive, the start switch is turned to RESET, FUEL PUMP START, or FUEL PRIME to start the fuel pump and build up fuel pressure in the system.

Second, the switch is turned to ENGINE START and held there for 15 seconds; the engine must start within that time or something has been overlooked, such as the low-water reset button or a similar protective device. The lever on the engine that is connected to the fuel pumps may be pushed in or pulled out (depending on engine design) to supply additional fuel to assist the start.

When the starting switch is turned to ENGINE START, it energizes a relay to bring in the heavy starting contactors which connect the battery with the motoring winding in the D.C. generator or the starting motors on an A.C. locomotive (more on this later).

Third, with the engine running, the engine oil pressure must be checked to verify that it has come up properly and that supporting equipment such as the crankcase exhauster is operating. The newly started engine should not be expected to go to work under load until the water temperature has reached at least 140 degrees Fahrenheit.

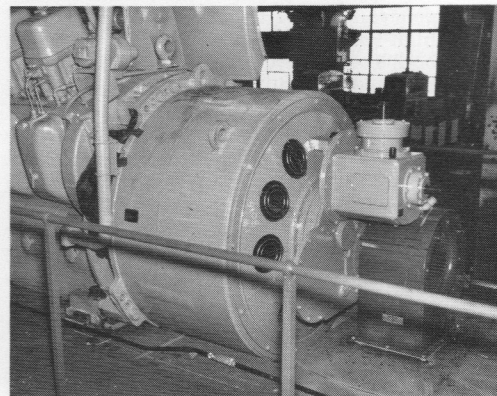
11. MAIN GENERATOR OR ALTERNATOR

The main generator or alternator receives the power of the diesel at relatively *constant* speed and *torque*, and it transmits this power at *variable torque* to the traction motors to suit the rail speed required.

On a D.C. locomotive, the generator frame carries the field coils, and the armature is directly connected to, and rotated by, the engine through a flexible coupling, producing direct current for the traction motors.

The generator also has an additional and separate winding in the fields, making it a motor. When energized from the batteries, this winding will rotate the armature and, consequently, the diesel engine, for the purpose of starting the engine.

The A.C. locomotive is arranged with the stator in the alternator frame, with the rotor directly coupled to the engine shaft. The alternating current produced must be rectified to produce direct current for the traction motors. D.C. series-wound traction motors still are used, since they furnish maximum torque at starting, proportional to the input of current, which is very desirable for locomotive work. Much experimenting is being done, especially in the



Alco.

ALTERNATOR on a C630 unit, mounted just forward of the diesel engine.

United States and Germany, to produce A.C. traction motors that will have the favorable characteristics of D.C. motors. When this work is successful, simple motors without brushes, and hence commutator maintenance, will become available.

It is not practical to introduce a starting winding in an alternator; therefore, two starting motors geared to the engine flywheel, arranged to disengage automatically when the engine fires, are necessary to crank the engine.

The output of the generator or alternator is determined by its speed of armature rotation and by the amount of excitation current fed to its field windings. This excitation current may come from batteries, from a winding in the generator itself, from a separate exciter, or from a combination of these.

As the voltage generated and sent on to the traction motors goes up, the amperage goes down—and vice-versa; one is traded for the other. Voltage is the unit of pressure, and amperage is the rate of flow.

The above may be observed from the following formula (neglecting all losses):

$$\text{Volts} \times \text{amperes} = \frac{\text{Watts}}{746} = \text{Horsepower.}$$

Since the horsepower of the diesel is fixed for each engine speed (throttle-notch setting), the volts and amperes must vary within the horsepower available.

The characteristic curves representing the engine and the generator are of interest. On the accompanying graph (below right), the generator or traction motor curve (broken line) and the power output curve of the diesel engine (solid line) are superimposed. It will be observed that at only two points do the curves match in the locomotive speed range. Therefore, it is up to the excitation system to control the generator voltage to meet the engine output. The other graph shows how the excitation control furnishes the right amount of current flow to provide a constant engine load. Excessive excitation current will overload the engine, causing it to lose speed (bog down), smoke heavily, and decelerate the train. The effect is somewhat like driving fast in your sports car and downshifting from high gear to low, then letting the clutch snap out. The curves (below) are for D.C. generators. The A.C. alternator curve is steeper and may not intersect the engine power curve at the lower point within the voltage limit of the machine.

12. CONTROL

The locomotive normally has two separate electrical systems: the control system, generally at 64 to 72 volts D.C.; and the high-voltage system for traction, which on both D.C. and A.C. locomotives varies between 600 and 1250 volts, depending on the

speed of generator or alternator rotation and the amount of excitation furnished to the fields. Many locomotives also have a third system, in which another alternator also directly connected to the engine shaft is employed to operate cooling fans, blower motors, and static exciters with A.C. current. This arrangement has an advantage in that the speed of the fans and blowers varies directly with the engine speed and its load requirements.

Locomotives having dynamic braking incorporate a fourth system (D.C.) to provide this form of braking.

All locomotive electrical circuits are closed systems, unlike an automobile wherein the current return (or negative) is through the frame and body and only the positive side is wired. An insulation failure on a locomotive, whereby a circuit grounds to the frame or other metal, will cause undesired operation or lack of function in the various components on the low-voltage side.

The high-voltage power circuits are arranged with a protective ground relay having a sensitive coil connected to the locomotive frame. A leak of current, caused by poor insulation or a moisture path, from any of the power circuits to the frame will be sensed, and the ground relay will trip, removing power production from the generator, returning the engine to idle, and providing a warning indication to the engineman or shopman. Hence the term "ground relay," encountered in train operation describing a locomotive problem.

AMONG other features on the locomotive worthy of study is multiple-unit control, or m.u. Virtually all hood-type road locomotives are arranged to m.u. This capability means that nearly all control functions are connected into a number of wires running the length of the locomotive and terminating in a receptacle(s) at each end. These receptacles usually have 27 pins, or contacts, although it is common to use only 24 or 25, leaving a couple of wires for spares. A portable jumper cable—with heads on each end having female contacts, to mate with the receptacle pins—is installed to electrically connect the individual locomotive units.

Through suitable breakers and relays, the connected locomotive units will respond to in unison to commands made by the engineman on the unit in control (usually, but not always, the lead unit). Ten units can be operated together if need be; I'm told that when 15 units are connected, the control voltage at the far end is low and the operation of the 15th unit may be fuzzy and unreliable. In any event, most railroads would not want to concentrate this amount of weight over their bridges or fills.



Ken Kraemer.

JUMPER CABLE is installed between locomotives to electrically connect them.

As arranged, any unit in an m.u.'ed consist can be isolated—that is, a unit may be taken off the line insofar as producing power is concerned, and the remainder still will respond to the unit in control.

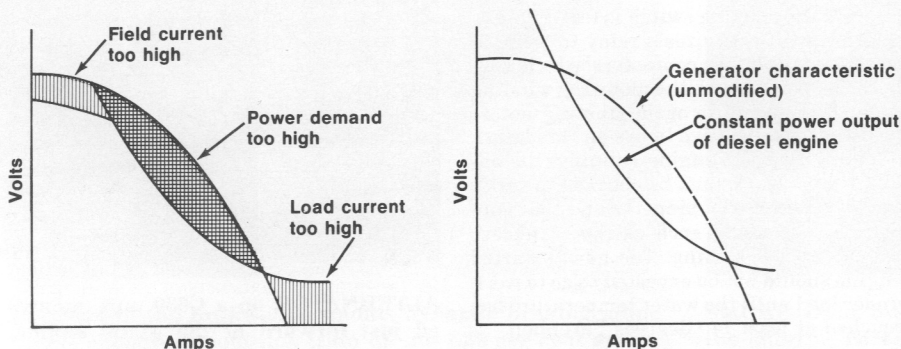
Changing control from the unit on one end of a multiple-unit consist to the operating cab of the unit on the other end requires some care on the part of the operator in correctly positioning electrical switches or breakers, as well as air-brake apparatus on the unit being given up and the setting up of the new unit to take control.

Older locomotives are equipped with pneumatically operated contactors and reversers to change the motor connections to suit the speed and load demanded, as well as to alter the direction of travel. Most modern locomotives have electromagnetically operated contactors and reversers, which eliminates the problem of frozen control air in winter that is frequently experienced with pneumatically operated devices.

SOME LOCOMOTIVES have the following four steps of motor connections to avoid overloading of the generator and to obtain the traffic characteristics necessary. The sequence is known as "transition," and the steps are: Series-Parallel; Series-Parallel-Shunt; Parallel; Parallel Shunt.

Transition is necessary because as the rail speed increases and the traction motors rotate faster, they create back electromotive force (BEMF), or resistance to current flow, causing the main-generator voltage to rise. If the generator voltage output were unlimited, the motors could remain in series at all times and electrical current would continue to be forced into them.

On all locomotives produced today, transition is made automatically, but in the days of, say, the earlier EMD FT's, the engineman would manually move his transition lever to effect the change of motor connections on the basis of rail speed and the observance of the position of the pointer on his transition meter (an ammeter that mea-



tures traction-motor current). This arrangement was not completely satisfactory, since damage to the electrical equipment would occur if "backward" transition was not made correctly when locomotive speed fell off when climbing a grade. A detailed examination of the automatic four-step system is useful in clarifying the foregoing remarks.

Let us consider then the steps of "forward" transition on a four-motor locomotive with 65-mph gearing:

Series-Parallel: As the term implies, there are two circuits in parallel, each having two traction motors connected in series within the circuit. Each motor within a circuit receives full current (amperage) but only one-half of the generator voltage. Stated another way, on a four-motor locomotive, one-half the current and one-half the voltage reaches each motor.

This connection provides the required high torque to start the train and is used from 0 to 20 mph.

Series-Parallel Shunt: As the train speed increases, the generator voltage rises and the current decreases until the shunting contactors close, diverting ("shunting") some of the current away from the motor fields to allow more current to flow through the armatures, permitting motor speed to increase. High starting torque is no longer required. The speed is now about 20 to 30 mph.

Parallel: All the motors now are connected in parallel, so the full generator voltage, over four separate paths, may be impressed on each of the motors individually, forcing current to flow and the train speed to increase. Parallel connections are for speeds of 30 to 53 mph.

Parallel Shunt: The back electromotive force from the motors builds up once more with the increase of speed, and it is necessary to shunt the traction-motor fields again to increase the current flow in the armatures to allow the locomotive to increase speed. This change will let the full power to be used, up to the locomotive's maximum (65 mph on our example unit).

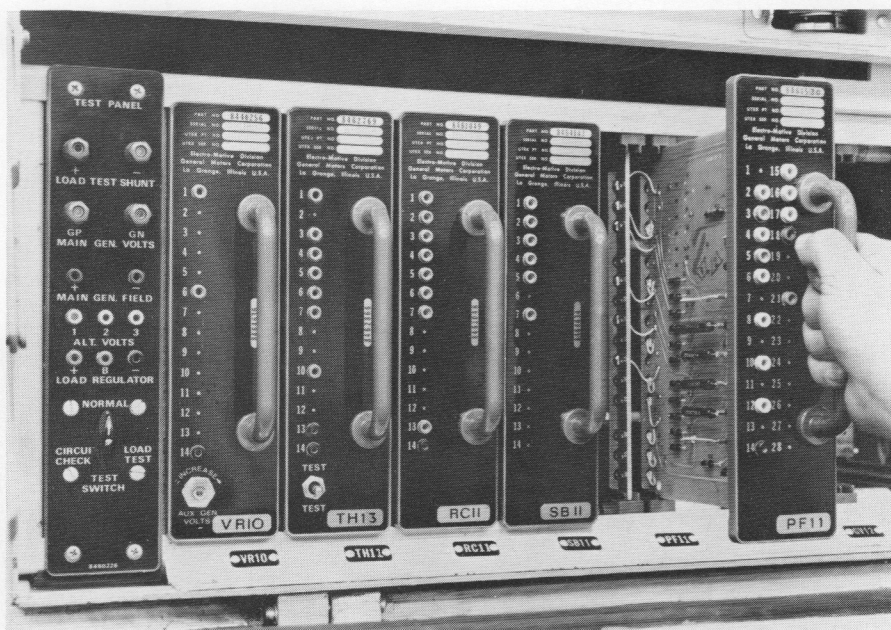
When a grade is reached and train speed decreases, "backward transition" must be made in the reverse order—parallel shunt to parallel to series-parallel shunt to series-parallel, depending on how low a speed is reached. This is necessary because as the speed reduces, the back electromotive force of the motors decreases, and the current flowing from the generator would exceed its rating, overheating it.

Forward transition is made automatically by relays working on the increase in voltage; backward transition is made by relays working on the the increase in amperage, or by loss of voltage dropping out the forward transition relay.

A forestalling feature is provided that lets the engineman hold the motor connections at any desired step. For example, when a number of very short but steep grades are ascended and descended, it is not always desirable for changes in transition to take place in combination with the train's slack action.

A typical Alco Century-series locomotive has motor connections as follows: Series-Parallel; Series-Parallel Shunt (with 15 steps of field weakening); Parallel; Parallel Shunt (with 7 steps of field weakening).

The shunting steps are carried out automatically by a shunt controller responding



EMD.

ADVANTAGE of modules in electrical panel is they can be replaced individually.

to generator current. Since General Electric supplied Alco with virtually all its electrical control equipment and traction motors, it is not surprising that the above system was adopted by GE on its own locomotives.

Many modern locomotives with A.C. generation have fixed connections with all motors in parallel, an arrangement that simplifies control and reduces slippage of the wheels when starting heavy trains.

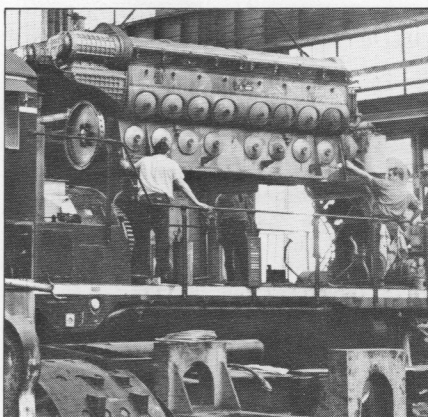
THE STATIC CONTROL of present production locomotives—wherein the control circuitry is on removable cards, divided by function—has proven to be highly successful. This was a development essentially by the builders, General Electric and Electro-Motive, rather than the railroads. Static control with diodes and transistors was a matter of concern to many me-

chanical-department men (myself included) when first introduced, but this control system has been very reliable in the railroad environment.

A locomotive with static control has in its electrical compartment 13 to 19 removable cards, or modules, each controlling a separate function of the locomotive. These cards slide into position in guides, and the inner ends have contacts to mate with the various circuits. The cards have printed or wired circuits and carry the numerous resistors, diodes, transistors, and so forth required for the function performed.

The individual modules control specific operations such as dynamic braking, excitation, field shunting, generator voltage, and wheel slip. The big advantage of the system is that when a malfunction occurs, for example in the wheel-slip circuit, that particular module can be withdrawn and a good spare module slipped into place, thus quickly returning the locomotive to service. The defective module then can be repaired at convenience in the shop or returned to the maker for correction. Inasmuch as extensive test equipment is needed to check out the sensitive modules, many railroads elect to have the manufacturer repair and calibrate the defective ones on a "repair and return" basis. To realize the complexity of the subject, consider that the description, troubleshooting, and repair of modules is covered in a large manual about 1½ inches thick, supplied by the manufacturer.

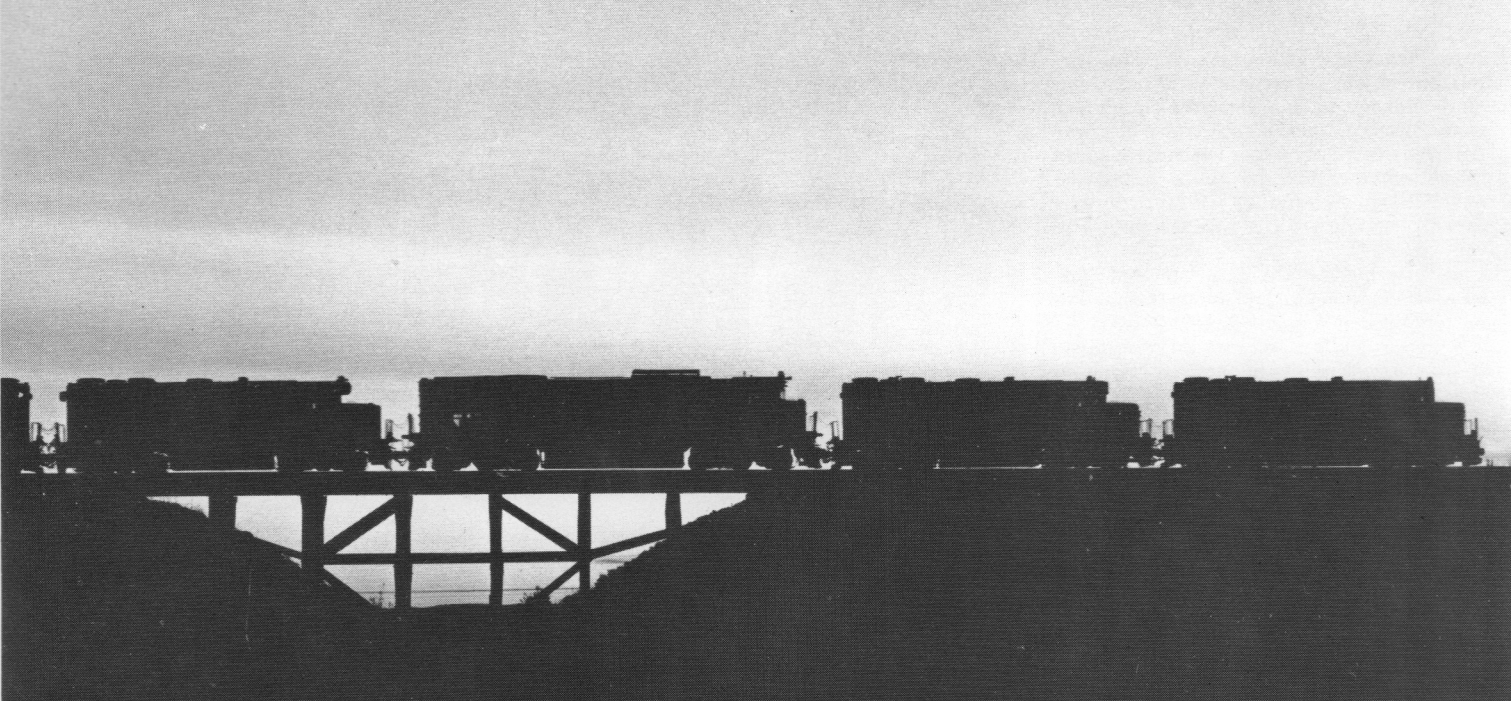
Excessive provisions for protection in control has occurred in the past in some locomotive models. I remember the first post-World War II Alco 2000 h.p. passenger units, later popularly designated PA's, which were placed in service in 1946 on the Santa Fe. They had a legion of protective devices, ostensibly to avoid any heavy damage to the electrical system in case of malfunction. However, we had so many shutdowns and road failures owing to these items being overprotective, that after 10 or 12 of these devices and relays were removed, the locomotives then went on to render good service. So today, apparently, simplicity still can be a virtue. **I**



Gary W. Dolzall.

IN CONCLUSION

NEXT MONTH we put all the foregoing together to make the locomotive work, and Author Vernon L. Smith comments on purchasing and maintaining diesels.



THE DIESEL from D to L-4

Magnets, mathematics, and maintenance

EMD GP35's and Alco C636 work together at Tenino, Wash., on BN/WP run-through freight. Dale Sanders photo.

How the locomotive works—and how to keep it running

VERNON L. SMITH

I NOW that we have covered the numerous components of the diesel-electric locomotive, we will endeavor to tie all the foregoing together and show the interrelation between the diesel engine and the electrical systems. A prerequisite, though, is a refresher on magnetism and how electric current is produced.

There are two types of magnets: permanent and temporary. An example of the permanent type is the common horseshoe magnet with its invisible lines of force between the ends—its magnetic field—and its ability to pick up small pieces of steel. The other type, the temporary magnet, is of interest to us because of its many applications in the locomotive. A temporary magnet is made by wrapping a coil of insulated wire around a soft iron bar and passing current through the wire. Invisible lines of force are created and will travel from one end of the bar to the other, creating a mag-

netic field that will last as long as current passes through the wire coil.

The basics of a diesel-electric locomotive are simple. The purpose of the diesel engine is to revolve the armature of the main generator. The armature can be easily turned, with practically no effort, when the field coils of the generator are not excited, but excitation—or passage of current through the field coils—makes each coil a temporary magnet.

A magnet attracts iron or steel because a magnet has two poles, designated North and South, and there is a continual flow of invisible lines of force between them. If these lines of force are cut by a material that will conduct electricity, that conductor will generate electricity.

On a locomotive generator, therefore, if the field pieces (coils of wire wound around an iron core) are energized by an excitation current, making a magnet of each one, and we alternate by having one a North pole and the next a South pole, and so on, all around the inside of the generator frame, we will

literally fill the space inside the generator with invisible lines of force, depending on how much excitation is applied.

If there is no excitation current, there will be no lines of force and consequently no load on the diesel engine. With full excitation, there are innumerable lines of force that produce a heavy load on the engine—because the armature of the main generator must turn within the generator frame, cutting the lines of force. Increasing the excitation increases the number of lines of force flowing between the poles, and the greater number offers more opposition to being cut, and hence requires more power from the engine.

On a D.C. (direct-current) locomotive, the electricity generated is conducted through brushes resting on the generator commutator and then by suitable cabling to the power contactors, reverser, and traction motors.

On an A.C. (alternating-current) locomotive, the three-phase current generated comes directly through leads off the stator

windings and is rectified by two banks of air-cooled silicon diodes into direct current for use by the traction motors.

THROTTLE control is complex, so to simplify the explanation, only the system of EMD, the largest builder, will be described. When the engineman opens the throttle, which generally is arranged for eight engine speeds plus the idle and shutdown positions, he is looking for a certain rail speed in miles per hour to suit the situation. At this point, we must acquaint ourselves with the engine governor.

The governor unit is gear-driven from the engine and includes, within its complex mechanism, an oil pump to perform functions hydraulically together with a miniature flyball governor.

The notch-by-notch information from the throttle position on the control stand is transmitted by low-voltage circuits to the top of the governor, where certain combinations of energized solenoids act on a triangular plate and through linkage and valving transmits a specific force to compress the speeder spring. The lower end of this coil spring rests on a thrust bearing that in turn bears on the arms of the miniature flyball governor that is rotated by the engine. Within the governor column is a rotating bushing, connecting with several ports, and inside the bushing is a vertical pilot valve which will admit or drain oil, under pressure, from below the power piston. The power piston hydraulically moves linkage that in turn moves the injector or fuel pump racks to partially rotate the fuel pump plungers, admitting the desired amount of fuel to the cylinders and maintaining the selected engine speed.

Let's assume that the engineman wishes to increase power. This action increases the tension on top of the speeder spring, causing the pilot valve to move downward and admitting additional oil under the power piston to furnish the engine with more fuel. As the engine speeds up, the centrifugal force causes the flyweights to move outward; their arms press against the speeder spring, raising the pilot valve. The pilot valve will drain sufficient oil from under the power piston to hold the engine speed at the balancing point.

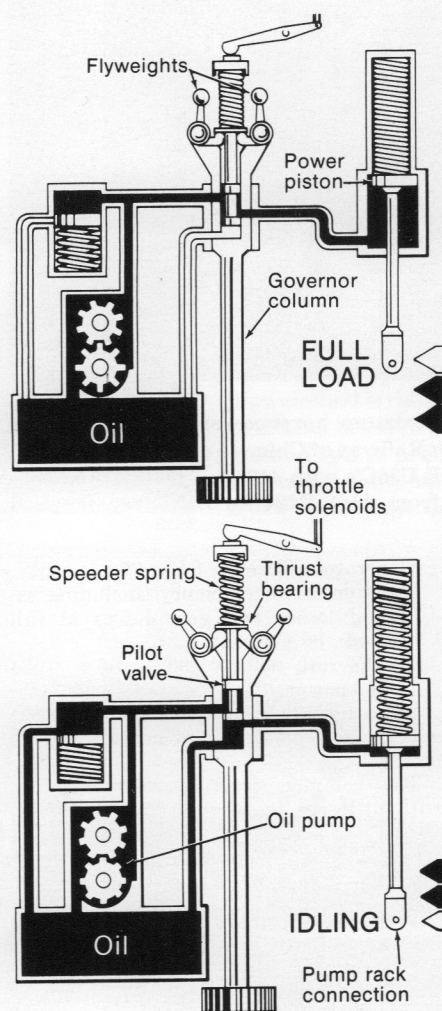
It should be noted here that for any throttle notch, the diesel engine speed (rpm) will be the same whether the locomotive is moving only itself or handling a heavy train. This is to say, the torque developed by the engine is automatically adjusted to the load. This is accomplished as follows:

Concurrently with positioning of the fuel racks, the governor is also engaged in positioning the load regulator. The load regulator is essentially a hydraulic vane motor, receiving engine lubricating oil under various pressures through another pilot valve in the governor, to move a brush arm across the face of a rheostat. This rheostat controls the amount of excitation current flowing to the main generator fields, which in turn regulates the electrical output of the generator. If much excitation is given the main generator, the engine speed would go down owing to the electrical load produced, but there the power piston portion of the governor acts to move the fuel racks on the injection pumps, increasing the amount of fuel admitted so the engine speed will be maintained for the selected throttle setting. Conversely, if the electrical load is reduced,

less fuel is admitted to the engine. The governor incorporates a number of other features including dashpots so that all movements are made smoothly. Another function performed by the governor is providing maximum fuel limits for each engine speed. If all the foregoing had to be accomplished manually, we might need as an engineman a skilled octopus who, if fortunate, would have an arm left to reach for the whistle.

Now that sufficient electricity has been generated to suit all loads, the current produced is carried in heavy cables to the traction motors, passing through their field windings and armature in series. This current also passes through the heavy contacts and connections of the reverser.

In principle, accomplishing the reversal of locomotive direction is a simple matter. When the engineman moves the reverse lever from forward position on the control stand to reverse position, the control current energizes magnet valves to rotate a drum or finger-type reverser (or, on late-model locomotives, energized electric switches). When the reverser drum is caused to rotate from one position to the other, it changes the order of connections to the traction-motor fields. Since the flow of current in the fields is reversed, the motors will turn in the opposite direction and the locomotive will go in that direction.



GOVERNOR is illustrated in the full load (top) and idling (above) positions.

In supplying tractive effort, wheel slipping frequently occurs, not only at starting but even at high speeds (60 to 70 mph), and much thought and effort has been expended by electrical engineers in devising methods or circuitry to overcome this problem.

Originally, a system was developed wherein when one pair of wheels slipped, its particular traction motor would, of course, speed up and receive more current than the other motor to which it was mated. This would cause a relay to pick up owing to the difference in electrical potential between the two motors. The relay contacts would serve to remove the excitation from the main generator, to reduce power to overcome slipping; when slipping stopped, power was automatically restored. The engineman also received a warning light or buzzer signal from another contact on the same relay so he could reduce throttle if continued slipping persisted. A four-axle locomotive would have two wheel-slip relays, each covering two motors.

This system had several disadvantages. Time would be consumed in having all the above take place, and precious train speed would be lost, with stalling possible if the train was on a critical grade.

Modern static systems perform a similar function much faster, and they sometimes automatically provide sand to the slipping pair of wheels if slipping continues after three seconds.

Alco and General Electric locomotives have small electric generators, mounted on the journal-box covers on the left side of the locomotive, driven from the end of each axle. The speed of rotation of each axle is measured at all times by the current produced by these little generators, and when one axle increases in speed by a predetermined amount, its signal output works to automatically vary the power to obtain the maximum traction for the adhesion available.

On some early General Electrics, a light brake application was made to the wheels of the slipping axles, followed by automatic application of sand and then by reduction of power.

In connection with improved traction, in recent years mechanical engineers have contributed to a better truck design with a center plate location nearer the horizontal center line through the wheels, an improved method of hanging the traction motors to compensate for their torque, and other means to reduce the transfer of locomotive weight from one axle to another that may occur when starting heavy trains. The lightest loaded axle will, of course, be the one to slip.

HEAT, POWER, AND TRACTIVE FORCE

Where does the heat in a gallon of diesel fuel go? This varies with different engines, but some typical figures are:

	Per cent
Exhaust heat out of stack	31.0
Cooling water heat (dissipated at radiators)	19.0
Lubricating oil	7.0
Unaccounted for (mostly radiation off engine and machine friction)	9.5
Useful work	33.5
	100.0

The foregoing "useful work" applies only to the prime mover. It must be remembered



Steve Patterson.



John E. Gruber.

SANTA FE subjects its road diesels to maximum horsepower loading for long periods with few throttle changes, while Belt Railway of Chicago drags long trains at slow speeds across many switches. Top, GE U36C's with 4190-ton train 119 at Ibis, Calif.; above, Pullman Junction as seen from Alco C424 on BRC transfer run.

that auxiliaries such as the air compressor, cooling fans, auxiliary generator, and blowers are drawing power from the engine, and depending on the size of the engine and number of fans operating, this can amount to 7 or 8 per cent of the engine output.

The horsepower rating for North American locomotives refers to the horsepower that is available to the generator for traction purposes. Thus, the engine of a GP38-2, a nominal 2000 h.p. locomotive, is actually putting out about 2225 h.p. to cover auxiliary and traction requirements. European locomotives are rated differently, usually specifying the total diesel engine output.

All systems of power transmission from the engine to the rail wheels incur efficiency losses; this is true for mechanical, hydraulic, or electric drives.

Since the diesel-electric locomotive has electrical transmission, and our example locomotive is rated at 2000 h.p. into the generator, let us see what we get at the rail for traction:

Generator efficiency, 94 to 95 per cent
Traction motor efficiency (including cable losses and gear losses at full speed), 86 per cent

At the rail: $2000 \times .95 \times .86 = 1634$ horsepower

Carrying this further, we can figure out what our locomotive can be expected to haul.

The common tractive-effort formula, without losses, is:

$$\frac{\text{Horsepower} \times 375}{\text{Speed in mph}} = \text{tractive effort in pounds}$$

To make the formula usable by correcting for losses:

$$\frac{\frac{1634 \text{ rail h.p.}}{2000 \text{ h.p. rating}} \times 375}{\text{Rated horsepower} \times 306} = \frac{\text{Actual tractive effort in pounds}}{\text{Speed in mph}}$$

With this formula, a curve can be plotted for the tractive effort at all speeds. When the rolling resistance of the locomotive and cars for a particular speed are added to the grade and curve resistance of the track, plus some correction for cold weather or other factors, the trailing tons hauled ("tonnage rating") can be determined with reasonable accuracy. However, adverse situations such as mist or light rain, oil on the rails from freight-car journal boxes or wet leaves, rusty rail, high winds, etc., can make a shambles of the calculation. Good judgment on the part of mechanical and operating officers in rating locomotives for a given territory is also necessary, particularly in heavy drag service. The computer, you see, is only an electronic box; it does not know unless it is told, for example, that on a rainy, blustery night, gusts of wind can blow sand off the rails on a high embankment, causing a train to stall.

SOME COMMENTS ON MAINTENANCE

Although many locomotive maintenance practices are the same on the individual railroads, requirements differ greatly in some respects owing to variances in traffic density, scheduled speeds and loads, the effect of nature (climatic conditions), terrain or territory traversed, and track conditions, especially in regard to curvature and surface.

To illustrate, consider differences in two roads of my employ. The Santa Fe, with its long-distance high-speed service, subjects the road diesel engine to maximum horsepower loading for long periods of time. Consequently, there is wear on pistons, cylinder liners, bearings, running gear, and the like, as the locomotive sails across the desert with few throttle changes or contactor movements.

The Belt Railway Company of Chicago, on the other hand, drags long trains at low speeds across hundreds of switches and through perhaps 30 junctions with other roads, jarring over interlocking plants. In doing so, the engineman repeatedly closes or opens the throttle, dropping out or bringing in contactors, severely testing the diodes on the A.C. locomotives, and generally subjecting the electrical system to high wear.

While on the subject of dragging trains, let me emphasize the importance of traction sand. On a road like the BRC, where tonnage trains usually are in the hands of only one or two heavy units, the sand applied to the rails may reach 1¼ pounds per minute for the leading wheels in order to maintain adhesion. The use of sand has drawbacks because it contributes to the wear of motor support bearings and other components (and it also makes the signal and track departments unhappy). The Belt Railway often uses 9 to 10 tons of sand per month per locomotive, and you would think that with all this sand put down over the years that the railway would be completely on fills!

Most road trains that require high horsepower to make the schedule will have sufficient units on the train to provide more than enough adhesive weight so that in through service sand is not often needed, except for emergency braking.

The diesel-electric locomotive has a sand box capacity of from 28 to 56 cubic feet, usually equally divided at each end of the unit. Most modern locomotives have elec-

tropneumatic sanding. The engineman's sander lever actually operates an electrical switch which energizes solenoid valves that admit air pressure to nozzles in the sand traps, forcing the sand through pipes to the rail.

LOCOMOTIVE wheel life is determined by many factors, among them high speed, hard braking, sharp curves, heavy axle loads, and sand usage. The life of a wheel set ranges from 12 to 42 months, or 200,000 to 400,000 miles, depending on the service. A wheel can be turned, or remachined, twice in this interval before being scrapped.

A desirable feature of diesel-electric locomotives is that wheel sizes within a truck need not be held extremely close—

they can vary $\frac{3}{4}$ inch in diameter between wheel sets without problems with wheel-slip control. It is not uncommon for the leading wheels of a unit to wear more than the others, for they guide the locomotive and usually get more abrasive sanding. Contrast this with a diesel-hydraulic locomotive having all axles connected by Cardan shafts. On these units the diameter of individual wheel sets must be maintained to within one millimeter of each other to avoid short service life of drive shafts.

THE three most costly locomotive problems are the loss of these items: the main engine crankshaft through bearing failure; the main generator from mechanical or electrical breakdown; and fire, either in the

fuel system or electrical system. The first two require the lifting out of the engine and/or generator from the locomotive frame; the latter, if in the electrical compartment, may entail several weeks of work to rewire. Consequently, much effort and inspection is made to prevent these failures.

Cleanliness is a must for all electrical apparatus in order to attain reliable operation and prevent fires or other damage. Running with dirty traction motors that are loaded with carbon brush dust, or wet with engine oil seeping down from the underframe, or have neglected, rough commutators and such, will only lead to flashovers and road delays.

The high capital investment in a locomotive means that down time can be expen-

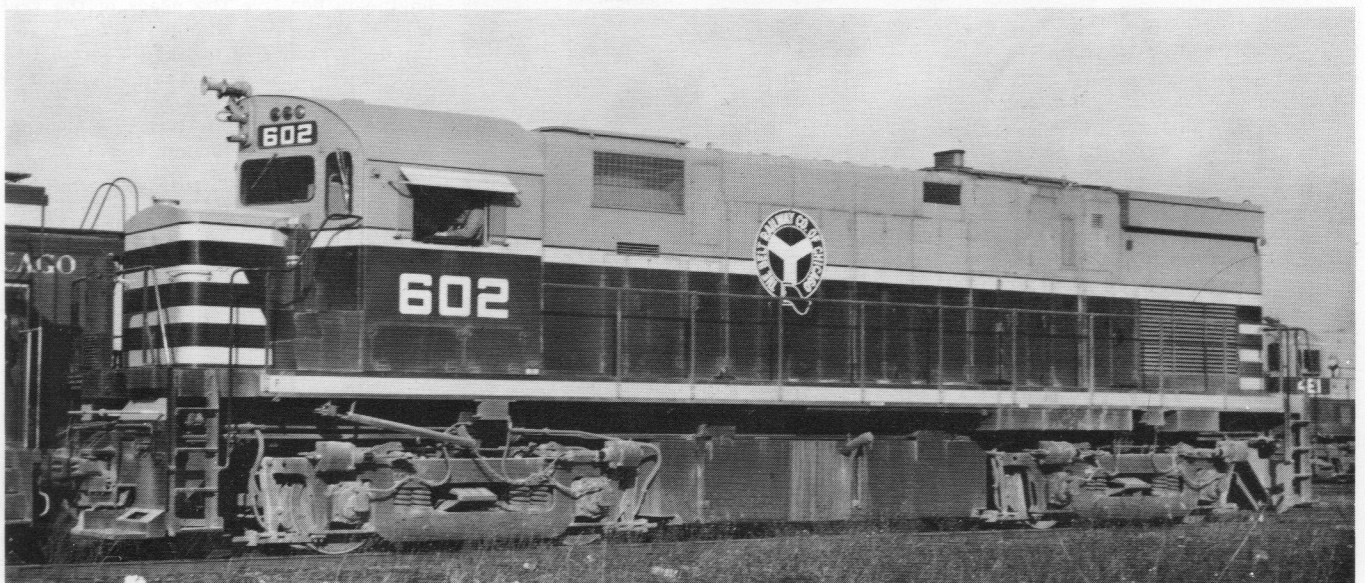


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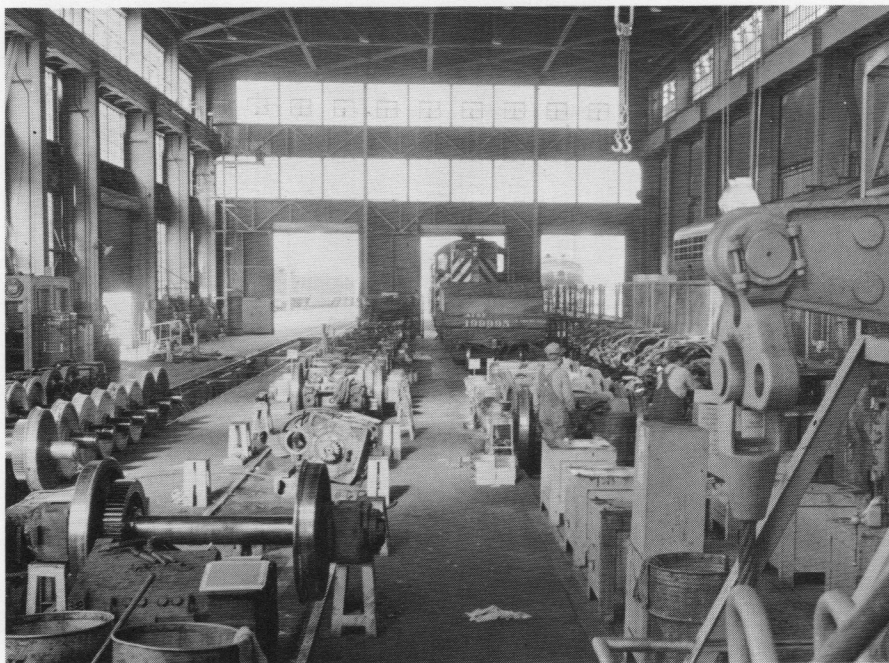


Ronald N. Johnson.

SAND can be put into locomotives in several ways. Most common method is running pressurized sand through pipes from an overhead tower (left). On some short lines, the informal manual method still is practiced (above). There are disadvantages in overusing sand, as evidenced by the encrusted wheels and truck frames on this BRC Alco C424 transfer unit (below).



Vernon L. Smith.



Donald Sims.

WHEELS last from 1 to 4 years, depending on locomotive usage, and can be remachined twice during their lives. The trend will be toward larger wheel diameter.

sive, and so most railroads endeavor to maintain about 90 per cent availability of the fleet for traffic purposes. This includes locomotives out of service because of wreck repairs, generally caused by operating department mishaps. In this connection, railroads which saved their old boiler shop machinery usually are in a good position to fabricate carbody and underframe components needed to restore a locomotive following a wreck. Some of the steel plate items, particularly for older locomotives, are hard to come by from the builders.

Since the diesel-electric locomotive has interchangeable working parts, much of the repair work may be done on an advance or production-line basis. On most roads, trucks, engines, engine parts, and motors may be swapped among several locomotives undergoing heavy repairs. This means that when a locomotive leaves the heavy repair

shop it may have only the underframe, hoods, and operating cab with which it arrived.

The integrity of the underframe in many cases may determine the life of that particular locomotive. Corrosion of the framing structure is responsible for much of the shop expense when rebuilding old locomotives.

Since the underframe carries the builder's serial number, this is what designates the locomotive. The concept is not new; English railways did this with steam power. The Great Western had a series of standard boilers that were regularly exchanged in the works between locomotives in the class to expedite their heavy repairs and return to service quickly.

A good repair schedule is important, but the real key to running locomotives economically is the right attitude, plus conscientious inspection and quality work on the

part of supervision and mechanics. Cleanliness is also imperative in diesel engine repairs, and thorough workmanship is a necessity for successful diesel engine operation. Most of the diesel's working parts are buried, rather than visible as on a steam locomotive, and a careless oversight of a small detail can destroy the engine.

Someone once said that about 70,000 separate pieces make up the diesel-electric locomotive, and when the locomotive is completely dismantled and the parts are spread out on the shop floor or occupying space on the work benches, it appears to be an understatement.

PURCHASE AND SPECIFYING OF LOCOMOTIVES

The numerous standard designs currently offered by the three builders, EMD, GE, and MLW-Alco (Bombardier) are adequate for the needs of the domestic market, but most roads require some modification of the basic locomotive in order to obtain the maximum benefits from it.

The cost of modifications may be very little for units in some services. However, the cost of modifications required by a few roads range up to about 15 to 18 per cent of the price of the basic locomotive. The modifications are legion; some are important components such as dynamic braking, 12-tooth motor pinions, large fuel tanks, special hump control and the like, and there are minor items such as number boxes, headlights, pilots, and snowplows.

Many railroads will prepare a specification listing all requirements as a supplement to the builder's specification for the basic locomotive. The railroad's specification will frequently spell out problem areas which have been experienced on locomotives of a previous order (for example, strengthened draft gear pockets to be provided on the new order when an earlier design gave trouble). Since the railroad lives with the locomotive long after the two-year or 250,000-mile warranty has expired, the owner's experience is a valuable asset to the design group of the locomotive builder.

Successful locomotive manufacturers maintain a strong field engineering force to assist the customer roads in overcoming maintenance problems. At the same time, the feedback from the problem areas, particularly with new designs, help the design engineers perceive the needs of the real world. My views changed when I left the design office to manage a locomotive department—the gain of say, 2 per cent in efficiency from a not totally reliable device became subordinate to having a dependable, possibly less efficient, locomotive for the 11:30 p.m. hotshot.

The EMD GP7 and Alco RS1 models were excellent examples of when operating experience dictated the direction that freight locomotive design was to take. The improved accessibility, through the hood side doors, straight off the shop ramps, instead of working within the confines of the streamlined carbody, brought the covered-wagon diesel to an end on many roads. Ease of cleaning of hood-type units was also a factor.

Regarding the life of locomotives, when the number of new locomotives constructed in a normal year is taken against the number of locomotives retired, it will be found that the average age of the national fleet is about 24.1 years. Switching loco-



Steve Forrest.

FIRE from mechanical or electrical breakdown is one of the three most costly locomotive problems. Others are the loss of engine crankshaft or main generator.



Blair Kooistra.

IMPROVED accessibility, through side doors on hood type units instead of within confined carbody, doomed the "covered wagons."

RAILROADS with suitable shop facilities or work forces fight inflation by rebuilding older locomotives instead of buying new.

tives generally have a longer life than that, and mainline, high-mileage road units have a somewhat shorter life. A few are withdrawn in as short a period of time as 16 or 17 years.

Most of the high-maintenance locomotive models introduced in the late 1940's or early 1950's are gone. Some of their repair requirements on exhaust manifolds and cylinder heads were so costly that it was economic to retire these units in 12 or 13 years.

When a class of locomotives becomes old or is reaching the end of its economic life, it is customary to cannibalize the worst or damaged units for parts to reduce the cost of keeping the remainder in service.

With inflation, the cost of new locomotives has risen sharply, and much rebuilding of older locomotives is being done, some by the builders but most by independent firms or those railroads with suitable shop facilities and work forces. In many cases, the rebuilt locomotive is upgraded to modern standards.

WHAT of the future? I, who spent the first part of my career with steam traction and who had a real affection for this type of power, have developed equal affection and interest for the diesel-electric locomotive. This power will certainly be predominant for many more years. It will be much improved, perhaps with larger wheels that permit more powerful traction motors; and, the trend to less maintenance requirements will continue, to the benefit of the railroads.

With respect to the railroads themselves, the dark cloud is the spectre of nationalization of the private companies, which I hope will never come. With nationalization, though, I would expect to see electrification of some principal main lines, with governmental funding providing the large capital investment. I



TRAINS: J. David Ingles.

ABOUT THE AUTHOR

VERNON L. SMITH is a career railroadman whose "entire working life has been spent with the design, construction, maintenance, and operation of locomotives and rolling stock." He retired in 1976 from the Belt Railway Company of Chicago after serving as its Chief of Motive Power for 22 years. Born in Virginia, Minn., in 1911, Smith went firing ore-company steam locomotives at age 16 after graduation from high school; three years later, he went on the engineers' extra board. He acquired an education in Mechanical Engineering at the University of Minnesota and was employed by Differential Steel Car Co. (now Difco, Inc.) and the Lima Locomotive Works. Lima later transferred him to the Franklin Railway Supply Company to assist in engineering poppet-valve gears to suit American service. "Since Lima did not show much interest in diesel traction, I joined the Santa Fe," says Smith of his job change in 1944. He served Santa Fe first as Assistant Engineer of Tests and wound up as its Acting General Supervisor of Diesel Engines—System. At recommendation of the Santa Fe as part owner of BRC, he joined the Belt Railway in 1953. "I still maintain a keen interest in locomotive history and progress, and presently I do some railway consulting work," he reports. He and his wife Olive reside in suburban Chicago.





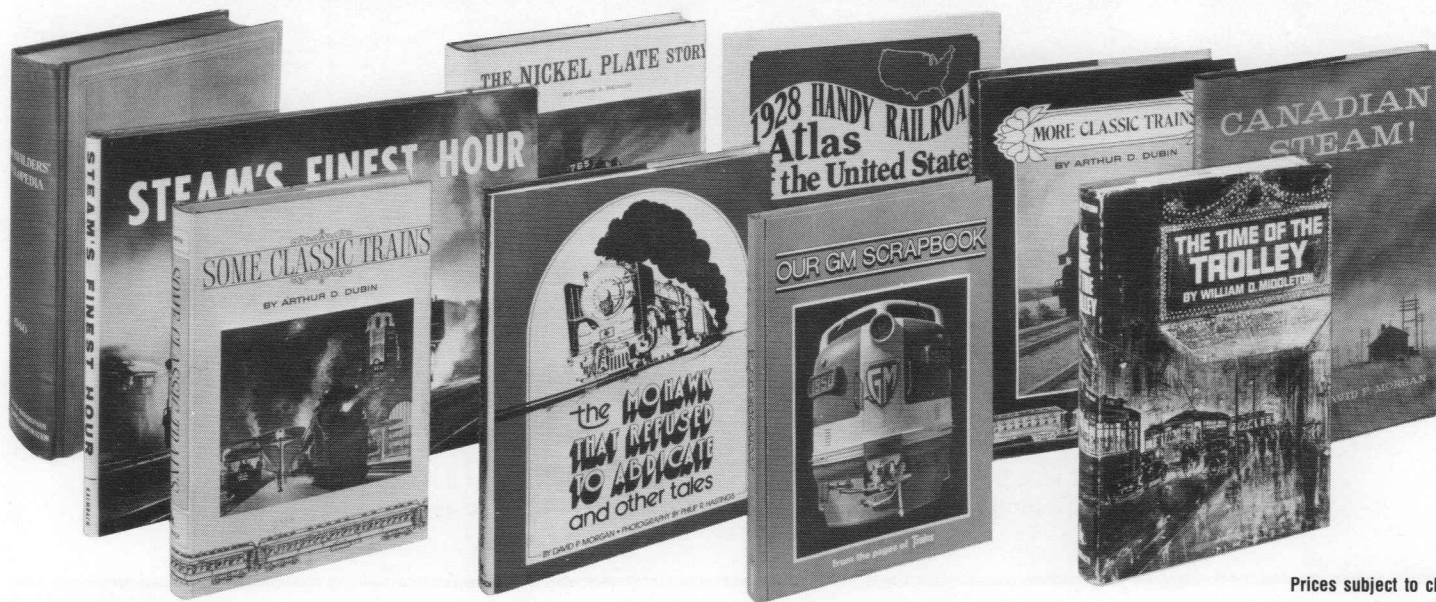
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