Printed in U.S.A.

72-RT-3

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JUL 9 1984

Design Features and Performance Characteristics of the High Traction, Three-Axle Truck

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As a result of wheel-rail adhesion investigations, a locomotive truck design providing improved adhesion performance was developed and field tested. The improved traction was made possible by the ability of the truck to minimize the reduction of axle load on rail during operation. The purpose of this paper is to discuss the design features of the high traction, three-axle truck. This truck provides improved adhesion performance and better maintainability when compared to the more conventional trucks used on diesel-electric locomotives in the U. S. Results of predicted performance characteristics, and of laboratory and field tests are presented and compared to the more conventional SD type flexicoil truck.

Contributed by the Railroad Transportation Division of The American Society of Mechanical Engineers for presentation at the ASME-IEEE Joint Railroad Conference, Jacksonville, Florida, March 14-15, 1972. Manuscript received at ASME Headquarters, December 13, 1971.

Copies will be available until January 1, 1973.

ENGINEERING - PHYS. SCI.

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS, UNITED ENGINEERING CENTER, 345 EAST 47th STREET, NEW YORK, N.Y. 10017

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INTRODUCTION

With the increasing demands of Railroad Operations in the United States, as well as around the world during the past ten years, EMD has been extensively involved in the development of mechanical and electrical components to support the high performance requirements. To this end, significant improvements have been accomplished in a number of areas including the diesel engine, generators and traction motors, electrical controls, and the running gear—i.e., trucks or bogies.

Considerable EMD development and testing has been done on the running gear in the related fields of wheel-rail adhesion, curve negotiation mechanics, and truck design; some of this work has been published in ASME and other literature (1-8).[1] As a result, high adhesion efficiency, three-axle trucks were developed for domestic and export applications on EMD diesel-electric locomotives. The high traction, three-axle truck, Model HT-C, was designed to replace the SD type truck in locomotives starting in production January 1972 (Fig. 1).

1 Numbers in parentheses designate References at end of paper.

DEVELOPMENT BACKGROUND

The initial development at EMD of a high traction truck dates back to the early 1960's when engineering work was done on a lightweight export truck design for locomotive applications where stringent weight and size, high adhesion support, and limited wheel-rail loading requirements were among the primary aspects of consideration. In addition to these primary purposes for developing a high adhesion efficiency truck, it was considered essential to maintain the simplicity of design for ease of maintenance, and to improve component integrity for longer service life.

The first high traction truck was a Model "GL-C" which refers to general purpose, lightweight, three-axle truck arrangement. The GL-C was made available in 1964 for multiple gage applications covering a locomotive weight range of 156,000 to 210,000 lb. The GL-C truck was

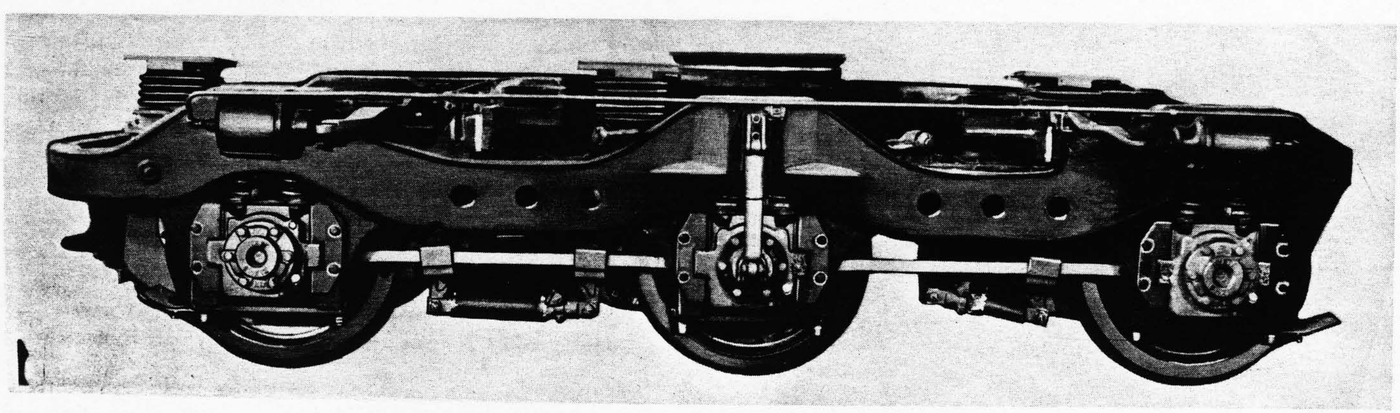


Fig. 1 High traction, three-axle truck model HT-C

used on 1500-hp GL-22C locomotives for Angola, Africa in 1966.

In 1964, an associate locomotive builder in Australia became interested in the same truck concept. With EMD's cooperation, this builder developed a high traction truck for 55,000-lb axle load and used it in 1966 and 1967 on 3000-hp GT-26C, six-axle locomotives for Australian Railroads. The reported operating performance of these locomotives in regard to support of adhesion was very encouraging.

Engineering and test work in the laboratory and the field were done in 1967 and 1968, which investigated weight transfer between axles and wheel-rail adhesion of a special 3600-hp SD-45 locomotive which was modified to have higher adhesion efficiency in one direction of operation compared to the opposite direction (4). The test results confirmed that the improved weight transfer in the one direction of operation supported a higher tractive effort in the same proportion as the reduction in weight transfer. This was necessary to determine if the other variables affecting tractive effort would nullify the expected improvement derived from low weight transfer.

In the United States, EMD had previously refrained from introducing a high traction truck due to standardization considerations which appeared to be of highest priority during the 1960's. Although this aspect is still a very imporatnt one, the pressing Railroad operating requirements and the test experience gained between 1966 and 1968 provided the incentive to develop and introduce the HT-C truck on American Railroads. Simultaneously, a second export three-axle truck (Model GH-C) using the same concept was developed for multiple gage applications in locomotives ranging in weight from 190,000 to 315,000 lb.

The designs of the HT-C and GH-C trucks were developed during the latter part of the 1960's. Early models of the HT-C truck were used on seven SD-45X experimental locomotives placed in service in 1970. A considerable amount of testing and experience has been gained on these experimental locomotives since their introduction. The export Model GH-C truck has been used since June 1971 on fifty 3 ft-6 in. gage, 2650 hp GT-26MC locomotives built by EMD for the South African Railways. A slightly modified version of the same truck will also be used on 80 locomotives to be built during 1972 for the Argentine Railways.

The following sections of this paper will present the design features of the HT-C truck and a summary of test results comparing the performance of the HT-C truck to that of the conventional, three-axle truck.

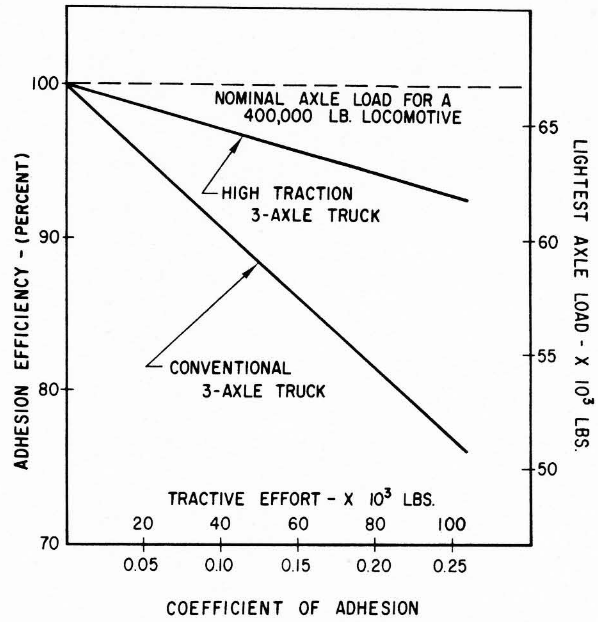


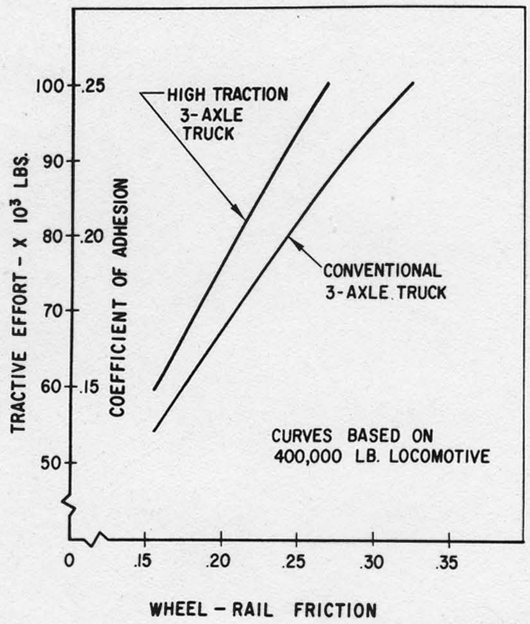
Fig. 2 Adhesion efficiency and axle load as a function of tractive effort for 400,000-lb locomotive

LOCOMOTIVE WEIGHT TRANSFER

The goal at the outset of the HT-C program was simple: design a highly reliable truck with improved traction capability which would adequately support a 420,000-lb locomotive under current operating conditions such as track profile. The HT-C design was developed using many of the concepts of the earlier traction export truck. During the development of the HT-C truck, every effort was made to retain interchangeability of parts with the domestic truck design.

To achieve the highest possible tractive capability from a locomotive, the truck must be designed to utilize the maximum amount of available weight for adhesion. If the power is equally distributed to each axle, which is common, then the weight at each axle should be kept as nearly equal as possible, since the lightest axle will determine the locomotive's pulling capacity as limited by wheel-rail adhesion. Control of the power supplied to individual axles can further affect the adhesion capability of a locomotive; however, that does not involve the truck design and, therefore, will not be discussed in this paper.

A large amount of weight transfer can occur between axles as a result of heavy tractive forces,



$$\text{Coefficient of adhesion} = \frac{\text{Locomotive Tractive Effort}}{\text{Locomotive weight}}$$

Fig. 3 Locomotive tractive effort and coefficient of adhesion as a function of wheel-rail friction

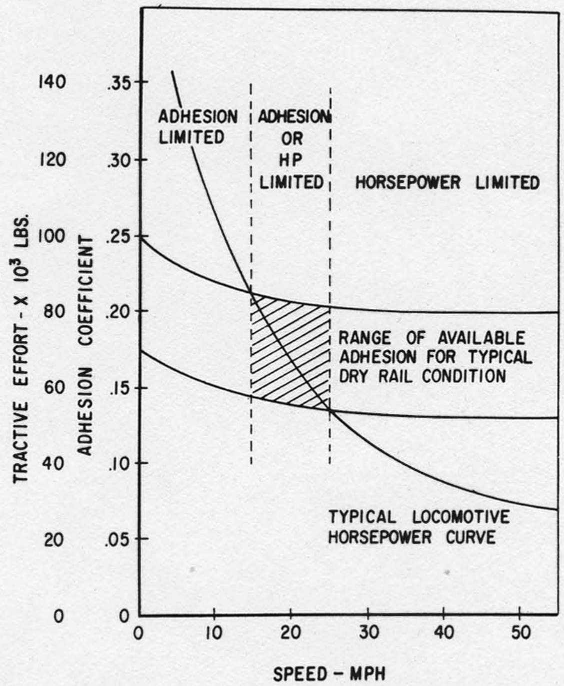


Fig. 4 Typical locomotive operating conditions: Sanded conditions will raise the band by 50 percent; wet or oily conditions will lower the band by 50 percent

Fig. 2. When accelerating from a stop, an automobile will "lift off" at the front wheels redistributing part of its weight to the rear wheels. This is also true of a locomotive, with three major differences.

1 In a locomotive with all driven axles, the wheels which get lighter are powered and will, therefore, tend to slip.

2 Significant weight transfer usually takes place for only a short time in an automobile. However, a locomotive operates for extended periods of time at high tractive effort; such conditions occur during acceleration and grade operation.

3 Since there are more than two reaction points (such as two axles on an automobile), the resultant distribution of weight transfer between axles depends on truck geometry and not merely the unloading and loading of the lead and trailing axles. (The phenomenon of weight transfer occurs during both driving and braking.)

PREDICTED ADHESION CAPABILITY

The ability of a truck to minimize weight transfer under traction is measured in terms of adhesion efficiency, the efficiency being equal to the ratio of minimum axle load for a specific tractive effort to the nominal static axle load.

Calculations have shown that the adhesive capacity of the HT-C truck would be 15 to 20 percent greater than existing six-wheel designs used domestically. For example, Fig. 2 shows that the SD truck, which is similar in adhesion performance to existing designs, offered 77 percent efficiency while the HT-C truck provides 93 percent efficiency at 25 percent adhesion demand. Thus, for a 400,000-lb locomotive, the lightest axle of a SD truck would be 51,000 lb compared to 61,000 lb for the HT-C truck. In essence, a locomotive pulling with a drawbar of 100,000 lb (25 percent adhesion) would require a coefficient of friction between the wheel and rail of 0.32 (i.e., 0.25/0.77) if equipped with the SD type trucks, and only 0.27 (i.e., 0.25/0.93) if equipped with the HT-C trucks. It is apparent that the conventional type truck would require a 21 percent higher friction coefficient at the wheel-rail interface than the new truck to prevent wheel slip under these heavy drawbar loads.

Fig. 3 shows that at a given value of wheel-rail friction, the HT-C truck can pull greater loads before slipping than the previous design. For example, at 0.25 available friction level, the HT-C would pull 93,000 lb before slipping, while the older SD would pull only 81,000 lb.

A locomotive operating under normal running

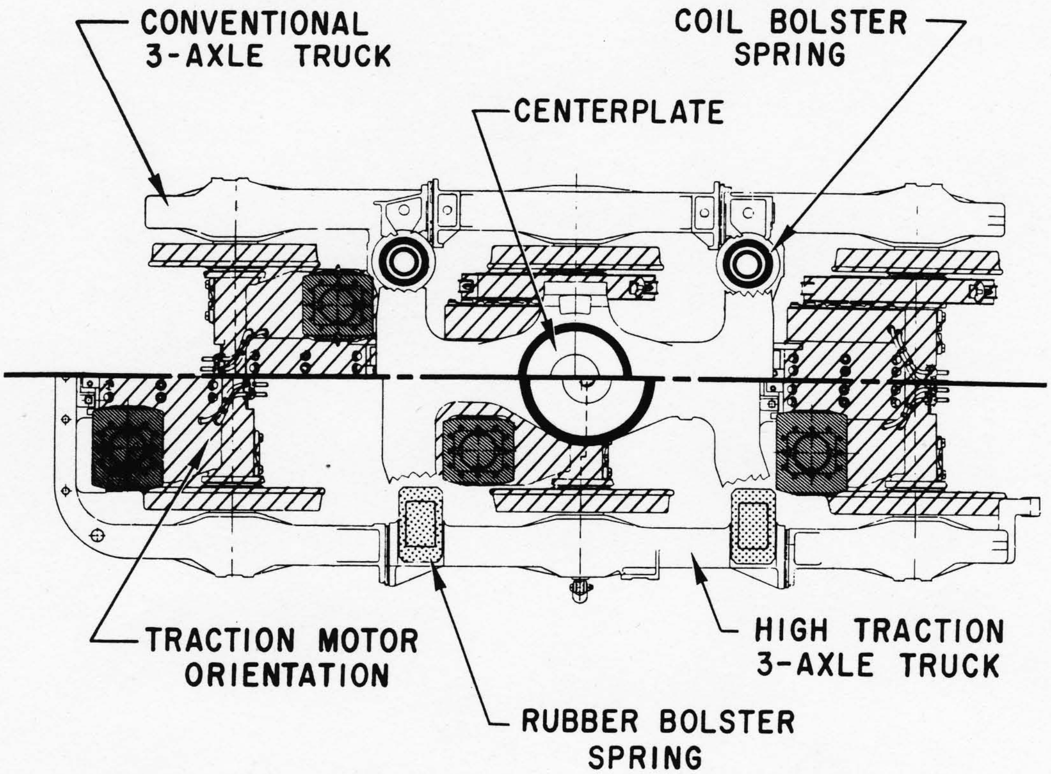


Fig. 5 Half-sections of the HT-C and Conventional three-axle trucks showing the major differences:
(a) Motor orientation
(b) Centerplate diameter
(c) Bolster suspension

conditions will encounter varying levels of tractive effort demand. The maximum locomotive tractive effort will either be limited by horsepower capacity or by the available wheel-to-rail adhesion as shown in Fig. 4. A tractive effort versus speed curve for a high horsepower locomotive has been drawn along with a band representing a range of available adhesion which the track will support under dry unsanded rail conditions. The upper limit is typical of the adhesion level attainable on slightly contaminated track with good rail joints, while the lower limit represents the available adhesion on moderately contaminated track with poor rail joints. Since the available coefficient of adhesion between the wheel and rail is a function of such things as atmospheric conditions, track contamination, and rail irregularities, this band will shift as indicated in Fig. 4.

For the conditions given in Fig. 4, at speeds below 15 mph, the usable tractive effort is adhesion limited, since the locomotive can develop more horsepower than the rail can support. However, at speeds above 25 mph, the delivered tractive effort is horsepower limited, because the locomotive cannot develop the horsepower that the rail can support. Between these speeds is a grey area where the locomotives may be adhesion or horsepower limited, depending upon the given wheel-to-rail conditions. In order to properly evaluate the adhesion capability of a truck, the testing must be done in the adhesion limited areas; if not, only the comparative locomotive horsepowers can be measured.

DESIGN FEATURES

The HT-C truck was designed for maximum performance under extreme driving and braking conditions by using specific truck geometry, component orientation, and suspension characteristics to reduce weight transfer between axles. This was accomplished while providing good riding qualities, overall simplicity of truck arrangement, and ease of maintenance.

The minimal weight transfer between axles, which provides the improved adhesion capability of the new truck, was achieved by using the following concepts, Fig. 5:

1 A relatively stiff secondary suspension between the bolster and truck frame, and a soft spring primary suspension between the truck frame and journal boxes: The secondary suspension is over 10 times stiffer than the primary, which tends to transmit a large portion of the moment reaction due to the driving forces to the carbody rather than to the wheels.

2 A large diameter centerplate between the truck bolster and the carbody underframe, to accept the large tractive reactions which result from the high traction design.

3 Traction motor orientation in one direction with each motor resting on a separate truck frame transom: This allows similar torque reactions at each axle which promotes equal axle loads.

4 Lower driving faces which contact at the trailing interfaces between the truck and bolster providing increased adhesive stability.

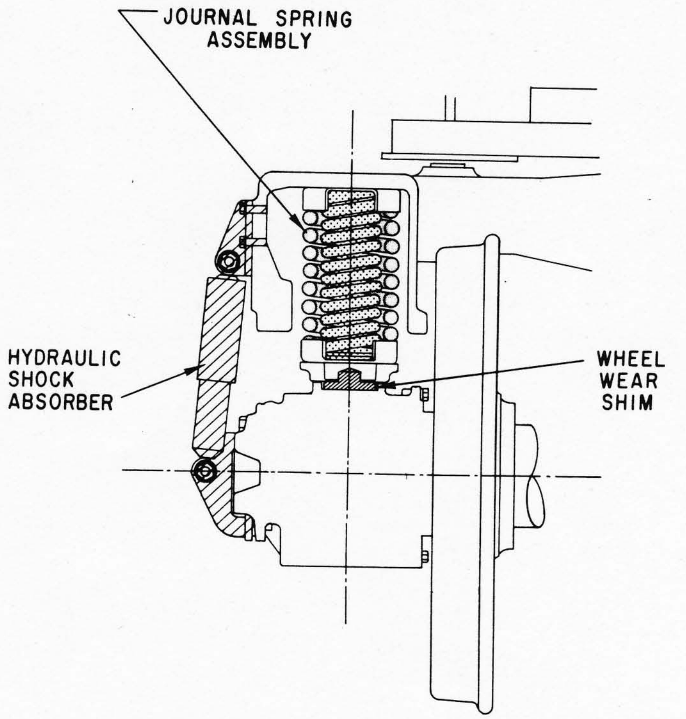


Fig. 6 Primary suspension system

Ease of Maintenance

It is important to stress the accomplishment of high adhesion efficiency with design simplicity in the new truck. This was essential in justifying the adoption of the new design for domestic application. Some foreign designs use traction bars between the truck and carbody, or axles which are interconnected by gears; these arrangements are cumbersome to maintain and more expensive to build.

Effort has been made to extend the service time between maintenance requirements on all truck component parts other than those expected to provide service for the life of the locomotive. One of the HT-C trucks from a prototype locomotive was completely dismantled after one year's service and 114,000 miles to inspect for possible problem areas, such as abnormal wear, stress fatigue, or deterioration of any kind. The truck was found to be in very good condition.

Suspension

Journal coil springs provide a softer primary suspension for the locomotive sprung mass which results in good riding qualities. These coil steel springs offer improved equalization when compared to the suspension of the previous three-axle truck. This is a result of the 38 percent higher static deflection at nominal wheel loads. The new journal springs will produce smaller wheel load variations at a given vertical rail irregularity which helps reduce wheel slip, as well as minimize the loading of truck components.

New rubber springs used at four locations between the truck frame and bolster perform a vital role in the high adhesion design. These springs have undergone an extensive development program in the laboratory and in actual field service. This secondary suspension provides about 5/8-in. static vertical deflection and allows 1 1/4 in. of lateral deflection between the carbody and truck frame. The rubber pads isolate track noise, and they also serve as a secondary damping medium for the suspension system.

The primary damping is provided by hydraulic shock absorbers which are accessibly located between the journal bearing and the truck frame at both ends of each center axle, Fig. 6. A simple but rugged adaptor bolts on the standard journal box to accept the lower mounting pin of the shock absorber. The top of the shock absorber is bolted to the center journal spring pocket. The primary damping system is designed to control undesirable resonant motions, such as bounce, body pitch, and roll. The shock absorbers maintain a stable and comfortable ride for safe operation at all speeds.

Wheels

The standard taper contour cast or wrought steel, 2 1/2-in. rim multiple wear wheels are basic on the truck, with cylindrical contours available and recommended for high-speed operation above 95 mph. The HT-C truck has been designed to accept a special 42-in. wheel which is presently undergoing field evaluation. Provision is made to maintain the same carbody and coupler height with any wheel size which may result from wheel wear. Shimming can be made at the journal suspension area to accomplish this feature, Fig. 6. The lack of proper shimming to compensate for wheel wear can result in unequal axle loads severe enough to completely overshadow the high adhesion features of this truck. (It should be noted that similar adhesion losses will occur with existing truck designs when wheels are mismatched.)

Brake Rigging

With one single exception, the brake rigging of the HT-C truck is identical to the SD type, three-axle truck. The hand brake is located on the outside of the truck frame at the left side of the No. 3 axle, rather than on the inside of the truck at the left side of the No. 4 axle. Single shoe (per wheel) brake rigging using composition brake shoes with screw-type slack adjusters is basic. Clasp brakes or pin-type slack adjusters are also available.

Journal Boxes

Many improvements have been incorporated into the journal box components to extend service periods. A new rear cover provides an improved labyrinth seal which extends intervals between necessary oil additions to three times compared with the older boxes. A new oil fill cup shortens the time required to inspect or maintain the oil level, as no tools are necessary for its removal or replacement. The journal box housing has been modified to provide improved support for the wear plates. High strength bolts and special lock-washers have eliminated the need for lockwiring both front and rear cover bolts. A modified front retainer ring provides improved oil flow to the thrust block bearing surface. Crowned rollers reduce the contact stresses between the rollers and races, thereby extending the service life. There is also an improved non-sticking rear cover gasket.

Truck Frame Strength

Structurally, the truck frame and bolster casting have been designed to adequately support a 420,000-lb locomotive for unlimited service under maximum driving and braking conditions while negotiating jointed track with a vertical loaded rail profile of 3 in. in one rail length. Static stress tests have been performed in the laboratory, and dynamic stress tests have been run under actual service conditions which have confirmed that the design criteria have been met.

LOCOMOTIVE APPLICATION CONSIDERATIONS

The three-axle high adhesion truck will not be interchangeable with any previous three-axle truck assembly. This is primarily due to the following differences between trucks:

1 Traction motor air duct locations
2 Centerplate diameter
3 Carbody-to-truck safety interlock systems
4 Overall truck dimensions.

Truck Weight

The truck assembly will weigh from 54,600 lb with single shoe brakes and a hollow bolster casting to 60,300 lb for clasp brakes and a solid bolster. The bare truck frame casting weighs approximately 11,400 lb, and the bolster is 4500 lb if hollow or 8200 lb if solid. The new truck assembly can weigh up to 1500 lb more than the older assembly.

Truck Dimensions

Wheelbase—overall-----------------163 3/8 in.
Axle 1 - 2 spacing----------------79 5/8 in.
Axle 2 - 3 spacing----------------83 3/4 in.

Truck Casting
Overall length----------------19 ft-1/8 in.[2]
Overall width----------------8 ft-4 3/4 in.
Overall height-------------------37 1/4 in.

Locomotive Application Considerations

Truck assembly
Overall length--------------19 ft-3 5/8 in.[3]
Overall width----------------9 ft-8 5/8 in.[4]
Overall height-------------------50 5/8 in.[5]

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[2] Single shoe brake design shown. Add 7 3/4 in. for clasp brake truck.

[3] Distance shown for sander guide to end transom. Add 10 in. for clasp brake assembly.

[4] Add 5 in. at outside hand brake crossover lever.

[5] Height shown to top of bolster with 1/2 variable supplies. Add 3 1/8 in. when standing free.

LABORATORY AND FIELD WEIGHT TRANSFER TESTS

In July 1970, a prototype SD-45X locomotive built with the HT-C truck was available for experimental work. It was a six-axle diesel electric locomotive rated at 4200 hp and weighing 398,000 lb, or slightly more than 66,000 lb per axle. In order to determine the increased adhesive capacity of the HT-C truck, a series of laboratory

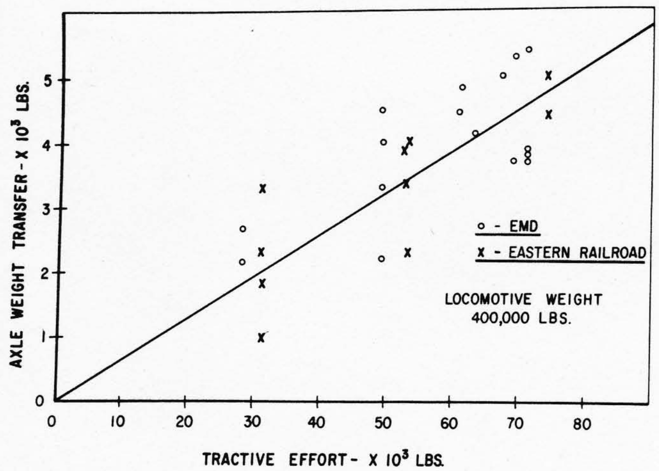

Fig. 7 Experimental weight transfer for the leading and trailing axles of the HT-C truck summarized from EMD and field tests

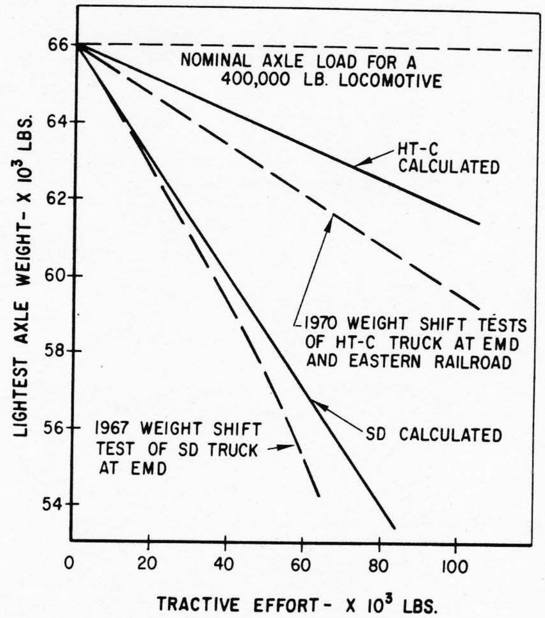

Fig. 8 Comparison of experimental and calculated axle weight transfer versus locomotive tractive effort for the HT-C and conventional three-axle trucks

and field tests were conducted on this unit. Static weight transfer tests were performed at EMD and on an Eastern Railroad. Then in early 1971, adhesion tests comparing the HT-C truck to the conventional SD truck were completed on a Midwestern Railroad. The results of these tests confirmed the practical value of the high adhesion design concept which, in turn, led to the adoption of the HT-C truck in the 1972 SD model locomotive.

The initial testing of the HT-C truck took place at EMD to establish a relationship between the weight transfer at each axle to the tractive effort of the locomotive. This was accomplished by recording the following quantities:

1 Change in wheel load
2 Generator current.

Track load cells were used to monitor the individual wheel loads by locating the axle to be tested directly over the load cells. Since locomotive tractive effort is a function of main generator current, the current was measured by placing a shunt in series with the main generator.

In this stationary test, the locomotive was held in place by blocks welded to the rail and by application of the brakes to the truck which was not to be tested. As the tractive effort increased, the change in wheel loads occurred, and the resultant axle loads were recorded on an oscillograph. Under the conditions involved, a locomotive tractive effort of 74,000 lb, equivalent to a coefficient of adhesion of 0.18, was usually developed before the wheels started to slip. The axle weight transfer was measured in both the forward and reverse direction of travel.

Static weight transfer tests were also run on an Eastern Railroad as part of the first road test of the SD-45X locomotive. The unit was taken to an electronic scale where individual axle weights could be measured. Again, the tractive effort was determined as a function of the main generator current. The locomotive was held stationary by braking the remaining units in the consist. As in the previous tests, no braking was applied to the truck being tested. The total axle load was recorded for each axle with the locomotive being powered in both forward and reverse directions for throttle positions 2, 3, and 4. A maximum locomotive tractive effort of 77,500 lb was delivered before the braking force of the consist was overcome and the locomotive started to move.

The results of the laboratory and field weight transfer tests were summarized, and Fig. 7 was developed. The data points represent the change in axle load (in absolute value) for the end axles (No. 1 or No. 6) in either the forward or reverse direction as a function of tractive effort. The end axles were chosen, since they exhibit the largest change in axle load, and the adhesive capacity of the locomotive is related to the lightest axle. Since the scatter of data was between 2000 and 3000 lb, or 3 to 4 percent of the nominal axle load (66,000 lb), the accuracy and repeatability of the results were considered to be very good.

The calculated and experimental weight transfer curves for the conventional SD truck and the HT-C truck are shown in Fig. 8. The experimental data compared closely to the calculated weight transfer for both the HT-C and SD trucks. At 60,000-lb tractive effort, the measured weight transfer was 1.9 percent greater than calculated for the HT-C truck and 3.1 percent greater for the SD truck. This increase was due to the friction developed between the journal box and the pedestal liners, which is present to a greater degree in a static test than under actual dynamic operating conditions.

The improved performance of the HT-C truck is made evident by the difference in weight transfer between the two trucks. Thus, at any given tractive effort, the HT-C truck effectively produces a higher adhesive weight locomotive. This means that a locomotive with an HT-C truck can deliver the same tractive effort at a lower locomotive weight; conversely, at the same locomotive weight, the HT-C truck requires a lower available coefficient of friction between the wheel and rail to maintain a given tractive effort, resulting in a lower slip risk.

ADHESION TESTS

To develop data on the effectiveness of the HT-C truck, adhesion tests were performed on a Mid-Western Railroad to compare the SD-45X locomotive to the SD-45 locomotive under simulated operating conditions. The SD-45 locomotive was the same unit which had been used during adhesion tests conducted in 1967, and it weighed 397,000 lb, virtually the same weight as the SD-45X. The SD-45 was a six-axle diesel electric locomotive rated at 3600 hp and was equipped with conventional SD type trucks. Both units were thoroughly checked to insure that they were operating properly and were producing the rated horsepower.

A consist comprised of the two SD locomotives, the EMD Test Car, and two dynamic brake units operated as a test train at two different test sites. The first location contained level tangent track, which was primarily welded rail. The second test site had different degree curves constructed with jointed rail.

Since the purpose of these tests was to verify the improved performance of the HT-C truck, a primary objective was to maintain similar operating conditions between the two locomotives, especially the available coefficient of friction between the wheel and rail. Therefore, numerous test runs were made over the same section of track by each unit. An attempt was made to conduct tests on each locomotive within a few hours to minimize the variation in rail surface due to such things as weather conditions, time of day, and passing trains. (For example, a passing train could cause the track to become oily, and a 50 percent loss in available friction would result.)

The remainder of the consist provided the dynamic braking load, simulating the train load, for the unit in power. This braking load was controlled from the Test Car and was adjusted according to the testing conditions. Hump control (variable throttle control) was installed on each locomotive, so that maximum tractive effort could be applied at the wheels at all times. Initial testing was conducted without wheel-slip protection; however, it was soon found that wheel slip occurred too frequently and wheel overspeed increased beyond control. Manually regulating the power was too slow; therefore, to prevent damage to the traction motors and the wheels, the wheel slip systems were used. Both units were equipped with similar IDAC wheel slip systems, and the automatic application of sand by the IDAC system was deliberately prevented.

By combining the IDAC with the variable throttle control, it was possible to operate at maximum tractive effort. The variable throttle control could establish a level of tractive effort about which the IDAC could modulate. The maximum tractive effort was obtained by increasing the power to the motors until small wheel slips occurred. At this point, IDAC reduced this power, and by watching the traction motor amperes, it was possible to determine the frequency and magnitude of the reduction. After the slip was corrected, small amounts of additional power were applied to the traction motors until it was obvious that IDAC was in continuous operation and the maximum tractive level had been reached.

Numerous tests were run with each locomotive under varying operating conditions:

1 Stop to 18 mph: Full dynamic brakes and air brakes were applied on the load units. Power was gradually applied by the test unit to prevent gross slip and to get the test train moving. As the variable throttle control was being operated to obtain the maximum tractive effort, the braking force was slowly reduced to build up the speed of the consist.

2 18 to 2 mph: With the consist traveling 18 mph and the test locomotive at maximum throttle, the dynamic braking load was slowly applied to

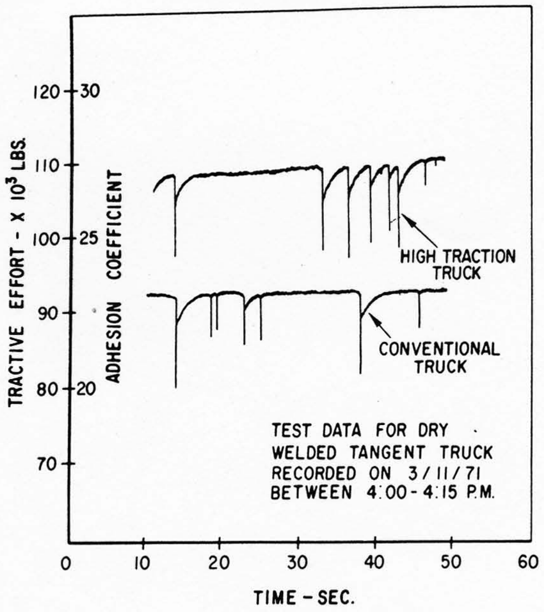

Fig. 9 Actual test traces comparing the HT-C truck to the conventional truck under adhesion-limited conditions—maximum tractive effort versus time for constant speed—5 mph

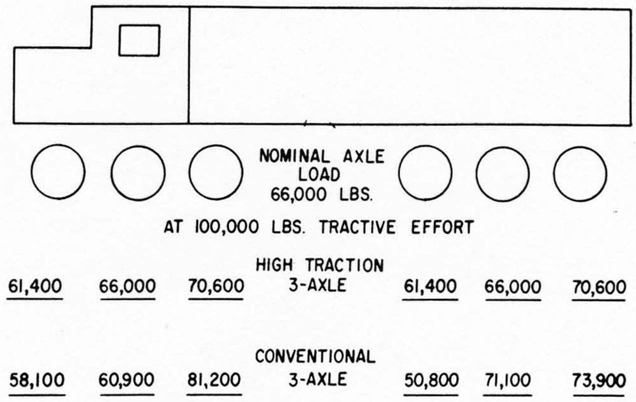

Fig. 10 Axle load distribution for a 400,000-lb locomotive at 25 percent tractive effort

decrease the train speed. Once under 10 mph, the air brakes were used to bring the consist down to 2 mph. While reducing the speed, the variable throttle control was adjusted to maintain maximum power to the wheels without gross slip.

3 Constant speed—5, 10, 15 mph: With the throttle control at the maximum level of tractive effort without gross slip correction, the braking load was adjusted to maintain a constant speed.

The data was recorded on an X-Y plotter located in the EMD Test Car—a fully equipped mobile laboratory containing modern data acquisition and recording instrumentation. The first two testing procedures resulted in tractive effort versus speed curves, while the last procedure provided tractive effort versus time plots at a known constant speed. Since one end of the Test Car had a calibrated drawbar, the tractive effort of the SD-45X was measured directly in drawbar pull, as well as from the main generator current. The tractive effort of the SD-45 was determined from the main generator current. The individual axle speeds of the SD-45X, the train speed, and the track profile were recorded for each test run on an oscillograph record.

Table 1 is a summary of the results obtained on tangent track. The level of the maximum available coefficient of friction was low for dry welded rail; however, it may have been slightly contaminated. The relative values of adhesion between the SD-45X and SD-45 may be considered typical for operation when both locomotives were limited by adhesion and not by the rated horsepower. The HT-C constantly provided 12 to 24 percent higher adhesion than the SD truck, which confirmed the theoretical calculations shown in Fig. 3. At 8 mph, the SD-45X developed 83,000-lb tractive effort, while the

Table 1 Summary of Adhesion Limited Test Data Under Dry Welded Rail Conditions on Tangent Track

	SD-45X With HT-C Truck		SD-45 With Conventional Truck	
Miles per hour	Tractive effort (lb)	Adhesion coefficient (percent)	Tractive effort (lb)	Adhesion coefficient (percent)
8	83,100	20.8	73,900	18.5
10	83,000	20.7	71,700	17.9
12	82,900	20.7	69,500	17.4
14	82,800	20.7	67,300	16.8
16	82,000	20.5	65,100	16.3

SD-45 could deliver only 74,000 lb; this represents a 12 percent increase in drawbar pull. Under conditions in which a conventional three-axle truck can deliver 74,000-lb tractive effort, the predicted value for the HT-C truck is 83,800 or a 13 percent increase in drawbar pull.

A sample of the actual test data for tractive effort versus time at a constant speed of 5 mph is shown in Fig. 9. The available adhesion during this test run was very high, and test results above 7 mph would have been affected by horsepower limitations. However, at 5 mph, both locomotives could deliver the horsepower necessary to develop the maximum tractive effort that the rail could support. The HT-C truck provided 16 percent greater tractive effort than the conventional truck. These test results confirm the validity of the theoretical calculations and the predicted increase in adhesion capability.

One method of checking these test results can be made by using Fig. 2. A conventional truck developing 93,000-lb tractive effort requires a coefficient of friction between the wheel and rail of 0.29 (COF--AD/AE), and at 180,000-lb tractive effort, the HT-C requires a coefficient of friction of 0.29. Thus, both trucks were developing the expected tractive effort for the given track condition.

CONCLUSIONS

It has been shown that the HT-C truck offers improved adhesion capability over the more conventional SD flexicoil truck or other domestic three-axle trucks. Calculations and field evaluations have shown an improvement in the range of 10 to 20 percent. This means that a locomotive with HT-C trucks requires a lower coefficient of friction at the rail or needs less total locomotive weight to produce the same tractive effort than the previous three-axle truck. This also means that the slip risk of a locomotive equipped with high traction trucks should be lower than a locomotive having the same weight but using the conventional design.

An additional benefit of the low weight transfer is the lower maximum axle loads on rails during operation at high tractive effort, Fig. 10. Furthermore, the soft primary suspension provides reduced wheel-rail load variation and lower twisting moments on the truck castings during operation. These aspects are significant in that they offer improved reliability of performance on present commonly encountered track condition.

ACKNOWLEDGMENT

The experimental data presented in this article are the results of tests conducted with the cooperation of our customer railroads in the field, and EMD Experimental Test Instrumentation and Field Engineering Sections. The authors also wish to express their appreciation to L. Buchholz and his group for preparation of the illustrations and to L. F. Koci for his continued advice and encouragement in supporting this work.

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