

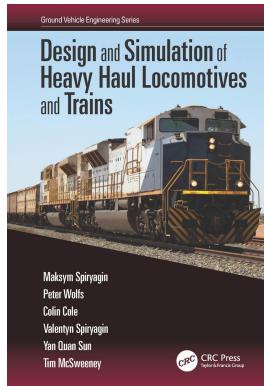
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Design and Simulation of Heavy Haul Locomotives and Trains

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Design of Mechanical Systems of Locomotives

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3 Design of Mechanical Systems of Locomotives

3.1 CLASSIFICATION OF MAIN COMPONENTS

From the standpoint of modern locomotives, their mechanical systems can be seen as a set of unified design elements consisting of the following main assemblies and components:

- The locomotive car body with a main structural frame that transmits traction and dynamic forces, and on which are located the main power plant units and various units that undertake the overall monitoring and management of the locomotive's performance and movement. These include the traction transmission control, braking, cooling, ventilation, oil, water and fire protection systems, plus auxiliary equipment and safety devices. This leads to the division of the body and underbody spaces into the relevant areas and compartments needed for the protection of the equipment and the locomotive crew from the effects of various hazards arising from the operation of the locomotive. The layout is designed to create a safe and comfortable working environment for the crew and locomotive maintainers.
- Bogies (referred to as trucks in North America) which, for a locomotive, are an assembly comprising wheelsets, bearings, a frame, a bolster or transom, brake rigging, springs and connecting components used to support the locomotive and capable of rotation in the horizontal plane to provide guidance along the track. Modern locomotive bogies are designed to improve curving performance by means of the reduction of dynamic interaction between the running gear and track. Early locomotives and wagons were designed without any bogies, with all wheelsets fixed in a rigid frame or directly attached to the car body. The development of large railway transport networks with massively increased freight volumes required rail vehicle manufacturers to increase the capacity of locomotive power plants and improve their traction performance, inevitably seeing an increase in the weight of locomotives. This subsequently resulted in locomotives that reached and exceeded the permissible limit of the vertical load that could safely be supported on the track structure. As a result, the number of wheelsets carrying locomotives had to be increased, along with locomotive dimensions, causing difficulties with stability of locomotives when traversing tightly curved track sections and problems with the force interactions between locomotives and track. One of the solutions to address these problems was the separation of the rigid rail vehicle superstructure and those parts that provide guidance along the track, which led to the creation of the modern design of a railway

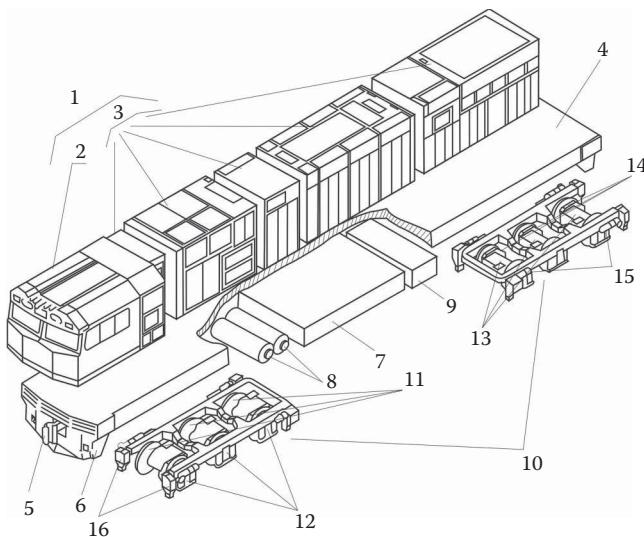


FIGURE 3.1 Main components of a heavy haul locomotive (a hood unit). 1 – car body; 2 – driver's compartment (cab); 3 – equipment compartments; 4 – main frame; 5 – coupling device; 6 – pilot (cowcatcher); 7 – fuel tank; 8 – air reservoirs; 9 – battery compartment; 10 – bogies; 11 – wheelsets; 12 – journal housings (axle boxes); 13 – traction motors; 14 – gear boxes; 15 – brake cylinders; 16 – sand boxes.

vehicle, where the body and the main structural frame are supported via elastic elements based on small frames containing the necessary running gear with sprung wheelsets. These latter frames with wheelsets are now called bogies (trucks). A typical example of the setup of the main components of a conventional design solution for a heavy haul locomotive is shown in Figure 3.1.

Each bogie includes

- Wheelsets that comprise a pair of wheels semi-permanently mounted on an axle and designed for transmitting traction and braking torque to the wheels via traction gear and brake devices. Bogies may hold one, two or more wheelsets and support the superstructure of a locomotive through the journal bearing housings and provide the means of transfer of traction and braking effort to the vehicle that allows it to move along the track in a controlled way due to the rolling of its powered (driven) wheelsets on the rails.
- Journal bearings that provide the load bearing and wheelset rotation capabilities at the ends of each axle of a rail vehicle bogie (truck). Vertical loads are transferred through each of the journal housings (axle boxes) to the bogie frame through a device known as a roller bearing adapter that fits between the bearing outer ring and the frame pedestal. Journal housings serve to support the bogie frame via elastic-damping elements and are connected to the wheelsets by means of the bearings. Journal bearings enable

the rotation of the wheelsets, with their housings providing the necessary lateral clearances for the realisation of the vehicle's movement along the track, particularly crucial when traversing curves.

- Suspension components that provide elastic-damping connections between journal housings and the bogie frame (primary suspension) and between the bogie frame and the locomotive car body (secondary suspension) in order to transmit traction and braking forces. These bear the vertical forces from the weight of the suspended parts, and redistribute their weight among the elements of the running gear, absorb the dynamic forces arising during the movement of the locomotive on track that contains irregularities and the impact of external surrounding forces and other natural phenomena associated with train operations, enabling the locomotive to achieve the required power and safe dynamic interaction with the track. This also allows achievement of the necessary ride comfort standards in order to reduce dynamic loads transferred to the locomotive driver, as well as maintaining the operational conditions required for stable functioning of the locomotive equipment.
- Traction drives, where the main task is to transmit the traction torque of the traction motors to the wheelsets of the locomotive.
- Braking equipment that is used to exert braking force(s) on the wheels, which then transfer to the contact patches between the running rails and the wheels in order to maintain or reduce the operational speed, or bring the locomotive to a full stop whether operating as an independent unit or as a traction vehicle in a train configuration. Braking equipment also allows retaining the locomotive in a fixed (locked) state when parked on any track in order to avoid inadvertent movement. In this latter case, the mechanism of the brake system being utilised is called a parking brake.
- Sanding system elements designed to improve adhesion conditions between wheels and rails to enable an increased tractive or braking effort to be realised by a locomotive in cases when wheel skidding or sliding occurs due to the poor friction conditions at the wheel–rail interface. Sanding systems are normally designed to work automatically when in notch position 3 or less, or when the traction control system cannot overcome skidding and sliding with its traction algorithms.

3.1.1 LOCOMOTIVE BODIES

Locomotive bodies (car bodies) can be built in two primary design variations: a monocoque body design (Figure 3.2) [1] and various body-on-frame designs (Figures 3.3 and 3.4). In the first design approach, all elements of the monocoque body are rigidly connected such that the body shell and wall sheeting assist the main frame to carry all the loads and stresses associated with the process of movement of the locomotive, as well as loads acting from the equipment installed in it. It also handles all traction and braking forces, transferring them to the train, and receiving longitudinal dynamic loads from the train. Monocoque construction has advantages of high rigidity and low weight.

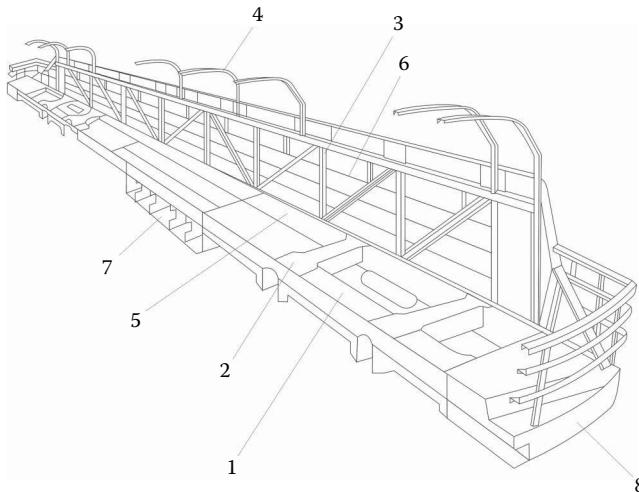


FIGURE 3.2 Monocoque locomotive car body design (Manufactured by Kolomensky Zavod, Kolomna, Russia). 1 – longitudinal sill; 2 – cross beam; 3 – vertical beam; 4 – arc for fixing the roof elements; 5 – metal packaging strip; 6 – strap for fixation of skin elements; 7 – frame for installation of fuel tanks; 8 – coupling box. (From Spiraygin, M. et al., *Design and Simulation of Rail Vehicles, Ground Vehicle Engineering Series*, CRC Press, Boca Raton, FL, 2014. With permission.)

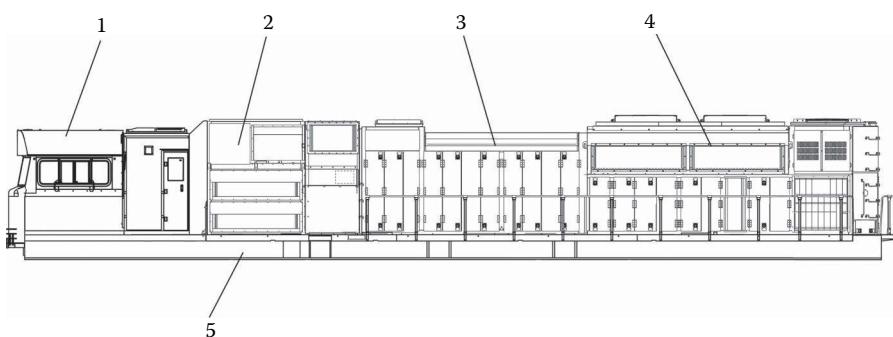


FIGURE 3.3 Example of a locomotive with a body-on-frame hood unit design (Manufactured by Electro-Motive Diesel, McCook, IL). 1 – driver's compartment (cab); 2 – auxiliary compartment; 3 – power plant (engine) compartment; 4 – radiator compartment; 5 – main frame.

Under the second design approach, a structural main frame (underframe) is the primary load-bearing component, and all the traction and braking forces and dynamic and impact loads are received, carried or borne by its strong longitudinal design. Other elements of the body, such as the side and end walls, the roof and the cab/s, are supported on the main frame and only carry loads from equipment fixed on these elements and provide protection from adverse factors arising from the operation of the locomotive equipment and comfortable working conditions for locomotive drivers in all weather and environmental conditions.

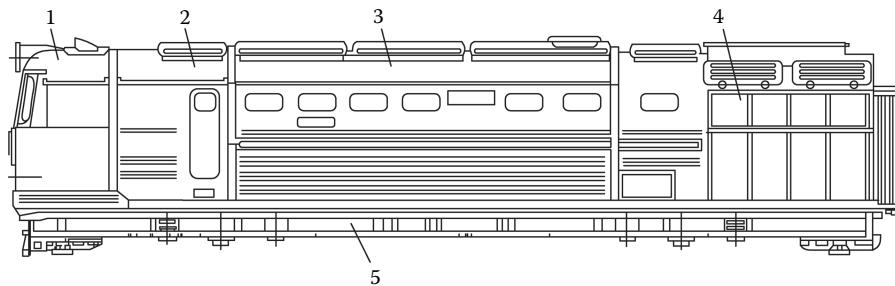


FIGURE 3.4 Example of a locomotive with a body-on-frame cowl unit design (Manufactured by Lugansk Diesel Locomotive Plant, Lugansk, Ukraine). 1 – driver’s compartment (cab); 2 – auxiliary compartment; 3 – power plant (engine) compartment; 4 – radiator compartment; 5 – main frame.

Based on the physical layout of the car body, heavy haul locomotives may be produced with either hood unit (Figure 3.3) or cowl unit (Figure 3.4) design styles. In the case of a hood unit design, equipment is located in compartments built on the main frame and covered with side walls and a roof that can easily be opened when required for maintenance. In addition, for easy access to the locomotive’s equipment, this design is usually equipped with a special external service platform (walkway) encircling these compartments. In car bodies with such designs, the driver can be located above or on the same level as the equipment compartments. The advantage of this design is better visibility in both directions of operation and easy access to the equipment for repair and service jobs. However, disadvantages are worse aerodynamics in comparison with cowl unit designs and some trackside safety concerns and environmental hazards for drivers and/or technical staff from natural phenomena such as rain or snow, wind, low and high temperatures, and dust pollution when equipment needs to be serviced or repaired in the open during the operation of the locomotive.

Cowl unit locomotives have a full-width car body for the complete length of the locomotive, the size and shape of which is only restricted by the existing loading gauge. Such a design has service walkways inside the car body to access the equipment when necessary. The installation or replacement of the equipment inside the body is usually done through removable roof hatches. This type of car body is preferred for high-speed operations because of good aerodynamics; although this is generally not an important issue for heavy haul operations, such locomotives provide better working conditions when operated in very cold or hot climates.

Car bodies are divided into two main zones: (1) a zone for technological equipment and (2) a zone for the location of the driver/s and the equipment that is needed to control the operation of the locomotive. This latter zone is called a driver’s compartment or cab.

The classification of car bodies can be further distinguished by the number and positioning of cabs, and by the design approach of the cabs.

Using the number of cabs, the car bodies are classified in a similar fashion to the many locomotive descriptions provided in Chapter 2, that is, one cab or two-cab designs. In the case of cowl unit designs, the main disadvantage of only having one cab is the low visibility for the driver past the other end of the locomotive.

According to the location of the cab/s, car bodies can be classified as

- End cab, located on the extreme end/s of the car body.
- Central cab, that is, centrally located in the length of the rail vehicle (this is very rare for heavy haul locomotives).
- Off centre cab, when the cab is shifted away from the central position in the longitudinal direction, but does not take the extreme end position, and the locomotive's technological compartments and equipment are placed behind the cab.

The cabs themselves can also be divided into two types based on their structural design parameters:

- Cockpit type design, where the cab is constructed as an integral part of the car body (e.g., a monocoque car body design).
- Capsular type design, as shown in Figure 3.5, where the cab frame is executed in the form of a protective capsule that is mounted in the car body or on the main frame, and may have additional elastic-damping and noise-insulating elements to provide a safe and ergonomically comfortable

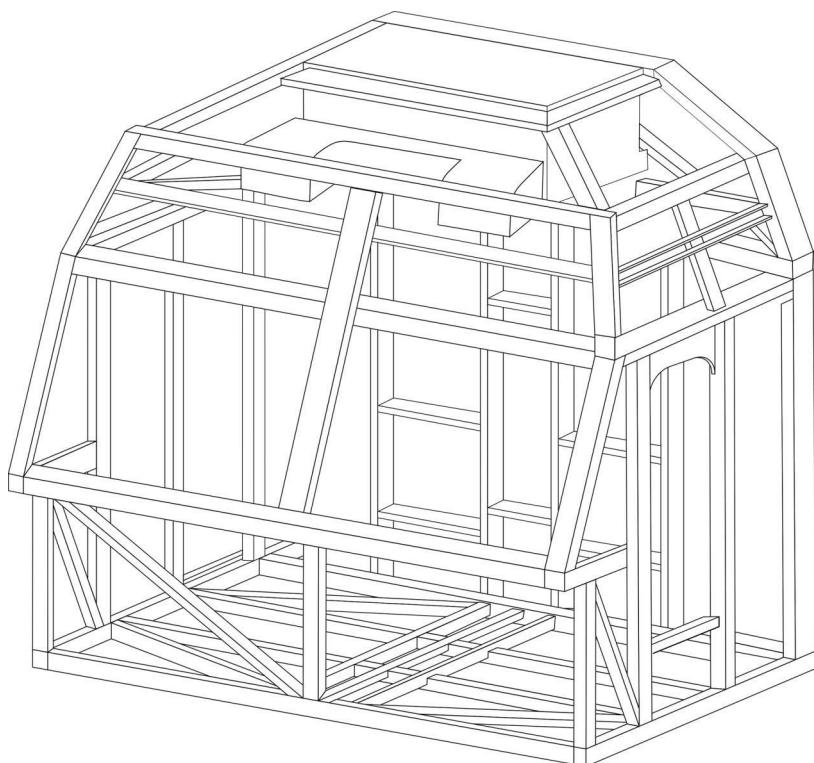


FIGURE 3.5 Modular cab of a heavy haul locomotive (Manufactured by Electro-Motive Diesel, McCook, IL).

working environment for drivers with reduced vibro-dynamics and noise impacts. Such a design is typically applied for locomotives based on a modular construction approach.

Locomotive car bodies can be divided into two types based on the structural design of the frames used to create the body side profile:

- Truss framework design, as shown in Figure 3.6, which consists of a mix of straight and inclined beams in the car body's structure.
- Stressed skin (monocoque) design, as shown in Figure 3.7, which uses only horizontal and vertical beams in the car body's structure.

The stressed skin design type has a greater carrying capacity in comparison with the truss framework design, but the latter is more practically feasible to manufacture, particularly in regard to the skin elements of the body shell such as the wall covering sheets.

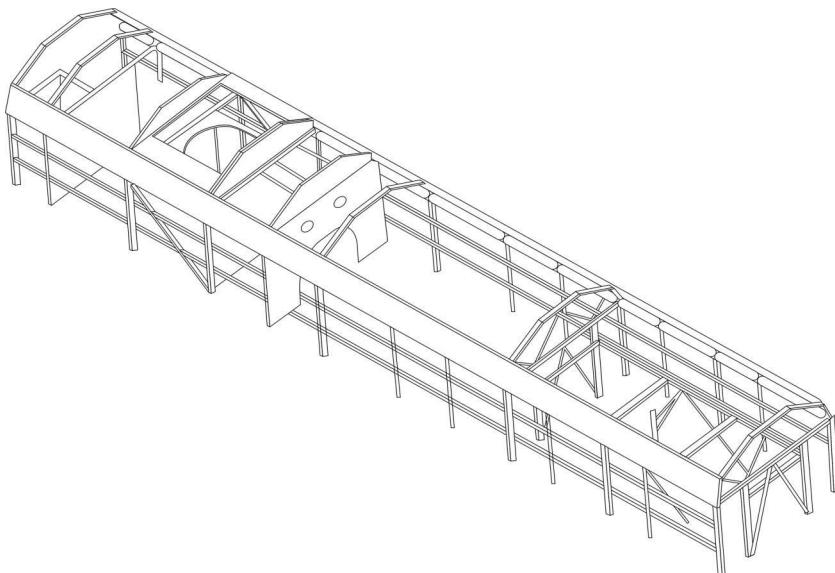


FIGURE 3.6 Body-on-frame car body structure with truss framework design (Manufactured by Electro-Motive Diesel, McCook, IL).

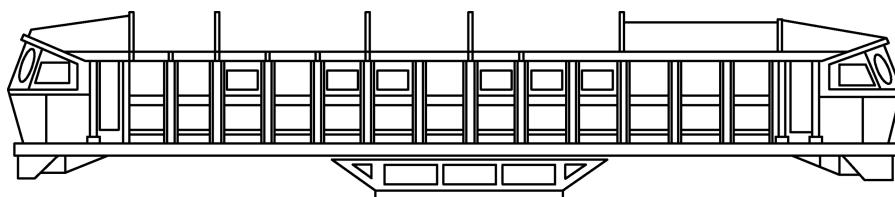


FIGURE 3.7 Monocoque car body structure with stressed skin design (Manufactured by Lugansk Diesel Locomotive Plant, Lugansk, Ukraine).

Descriptions of monocoque car bodies can also include the type of materials used for skin elements of the body shell such as the wall-covering sheets that can be manufactured from the following materials:

- Metal (ferrous metals, alloys, non-ferrous metals or a combination)
- Composite materials
- Combined, indicating combinations of different materials used as skin elements of a locomotive car body in order to optimise the weight and size ratio parameters while providing the required load-bearing capacity

Skin elements of the body shell, commonly produced from metallic wall covering sheets or composite materials, may consist of one or two sheet/s or sandwich panels with various fireproof insulation materials providing a reduction of vibration and noise transmission. Such skin elements may be designed to be either load carrying or non-load carrying.

Finally, the process of manufacturing can be part of the car body description, namely,

- Welded
- Riveted
- Glued
- Welded and riveted
- Combinations of these

Locomotive car bodies usually have multiple compartments and spaces to accommodate the locomotive equipment. The main technological compartments of the diesel-electric locomotive are as follows:

- Diesel engine compartment
- Electrical and power equipment compartment/s
- Radiator compartment
- Fuel tank/s
- Battery compartment/s

In the case of electric locomotives, the car body can be divided into compartments for the following:

- A main transformer or inductor
- Traction control equipment and other power and brake equipment
- Cooling and ventilation systems for processing main transformer oil and heat generated by other equipment
- Battery box or boxes

In addition, the boxes housing couplings with absorbing devices (draft gear) or buffers, mounted on the front and rear ends, are considered as parts of a car body when utilising a monocoque design approach (see Figure 3.2).

3.1.2 LOCOMOTIVE FRAMES

For locomotives designed with a main frame (underframe), all the loads from the weight of installed equipment as well as traction and braking forces and dynamic and impact loads are received, carried or borne by the strong structural design of the main frame. Such locomotives are relatively easy to manufacture and repair, but they have a much greater consumption of materials, the extra weight of which must be considered in the design so far as the axle load is concerned. In addition, the main frame must be constructed with a longitudinal camber, so that the frame does not sag when all of the equipment and body is placed onto the frame. An example of a typical main frame design for a heavy haul locomotive with two cabs is shown in Figure 3.8.

Locomotive frames can be divided into three groups according to the structural design of the main bearing elements (beams) of the frame:

- Centre beam design where loads and stresses are primarily carried by several centrally placed longitudinal beams running the full length of the locomotive
- Contour beam design where loads and stresses are primarily carried by external beams fully encompassing the frame's perimeter or outer contour
- Combined

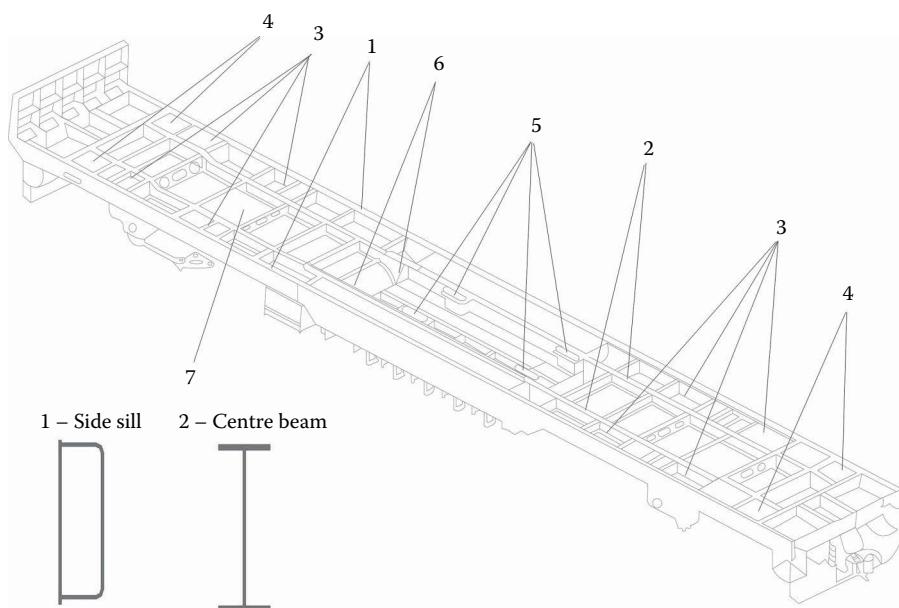


FIGURE 3.8 Example of a heavy haul locomotive main frame design (Manufactured by Electro-Motive Diesel, McCook, IL). 1 – side sills; 2 – centre beams; 3 – positions for secondary suspension springs; 4 – points for mounting cab isolators; 5 – engine mounting points; 6 – alternator mounting points; 7 – bottom plate of the main frame.

In the centre beam design, the main longitudinal beams, which react with all traction and braking loads, are located towards the centreline of the frame. In modern locomotives, it is common to use beams with T, I, rectangular or channel cross-sectional shapes, interconnected by transverse cross beams and bulkheads. At the ends of the main beams are the coupling boxes that contain the shock-absorbing devices of the automatic couplers. Centrally placed between the main beams, and longitudinally equidistant from the lateral centreline of the frame, are mounted pivot assemblies to support the frame on the bogies. Side sills are placed along opposite sides of the frame at both ends of the lateral beams. These are a lighter profile than the main beams, do not react longitudinal dynamic forces, and only provide support to the locomotive bodywork. In addition, the entire structure is fitted with top and/or bottom plates or sheets that have openings to allow technological equipment and ventilation ducts to pass through.

In the contour beam design approach, all traction and braking loads are reacted by external beams (primary beams) of the main frame. This design is very similar to a ladder-frame design, but with structural headstocks at each end of the locomotive providing the frame with a fully enclosed outer contour. Transverse beams (also called secondary beams) placed along the length of the frame are designed to be attachment points for the fixation of pivots, secondary suspension elements such as springs, or side bearings with return devices. Such frames are also covered with top and/or bottom plates as for the centre beam design.

In combined frames, loads and stresses are distributed to be taken by the outer and inner beams. In all three main frame types, cable conduits (channelling) can be installed internally along the main beams or other parts of the frame in order to accommodate the mounting of electric cables and wires, as well as piping lines for pneumatic air brake or hydraulic systems of the locomotive.

3.2 BOGIES

The bogie is one of main components of a heavy haul locomotive and usually consists of a frame that supports the locomotive car body through elastic dissipative ties or couplings (spring suspension elements; damping elements; stroke stops or bumpstops, which limit travel of the bogie frame with respect to the locomotive car body or frame; side bearings with roller return devices or other elastic-damping side bearing elements) as shown in Figure 3.9. The bogie frame is supported by journal housings (axle boxes) via elastic-damping elements, with the complete locomotive supported on the running rails through wheelsets connected to the journal housings by means of the bearings. The main purpose of the bogie is to improve the locomotive's dynamic interaction in the curved sections of track, to ensure the locomotive remains within its prescribed dynamic envelope, to maintain permissible dynamic forces between wheelsets and track, and to implement technical and economic specifications incorporated into the locomotive design during all real-world operational service scenarios.

The bogie frame also bears the loads from traction motors, traction gear mechanisms (suspended joints, drive shafts and gear boxes) and braking mechanisms. As a result, the choice of appropriate design characteristics for a bogie is a complex engineering task because it includes the selection of structural materials, work on

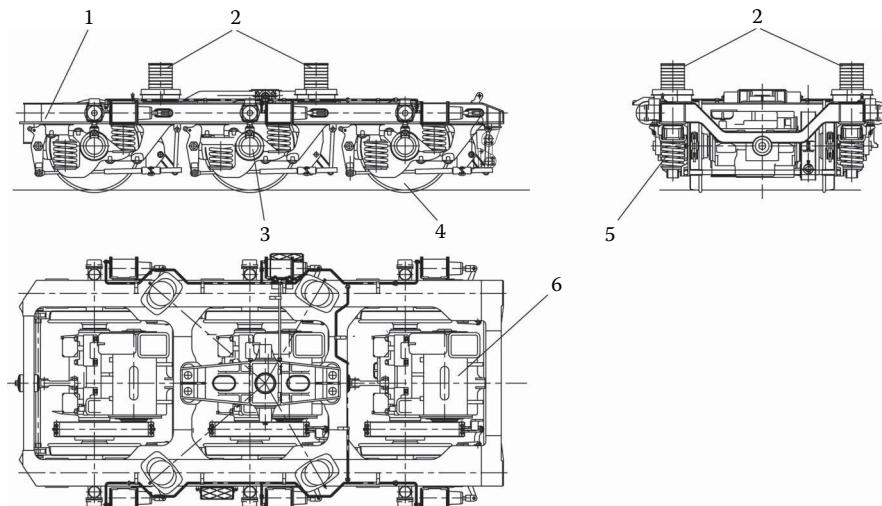


FIGURE 3.9 Three-axle bogie of a heavy haul diesel-electric locomotive (Manufactured by Lugansk Diesel Locomotive Plant, Lugansk, Ukraine). 1 – bogie frame; 2 – sideframe; 3 – journal housing; 4 – wheelset; 5 – coil spring; 6 – traction motor.

the layout of components, the calculation of the strength and load-bearing characteristics of the frame and the like.

The qualitatively and optimally designed bogie is based on correctly selected characteristics of spring suspension and traction drives, which are critically important parameters of the performance potential of a heavy haul locomotive.

The main indicators of the locomotive dynamic interaction with track, as well as implementation of traction and braking forces, are directly connected with proper and high-quality design of the mechanical parts of running gear. All the other locomotive systems only assist in achieving the specified design features when operating close to the extremes set by the design of the mechanical parts of the running gear. Therefore, engineers who design heavy haul locomotive running gear have to pay special attention to the quality of mechanical design solutions as these are the primary drivers of the ultimate performance of the bogie design.

3.2.1 CLASSIFICATION OF BOGIES

Bogies can be classified according to several criteria:

- By the number of wheel pairs enclosed in a frame. According to the UIC classification of locomotive axle arrangements, the axles within the same bogie (truck) are classified starting from the front end of the locomotive by alphabetical symbols for the number of consecutive driven axles (A for one, B for two, C for three etc.). Refer to Section 2.2 for more details. The three-axle and two-axle bogie designs shown in Figures 3.9 and 3.10 are the most common arrangements in use for heavy haul locomotives.

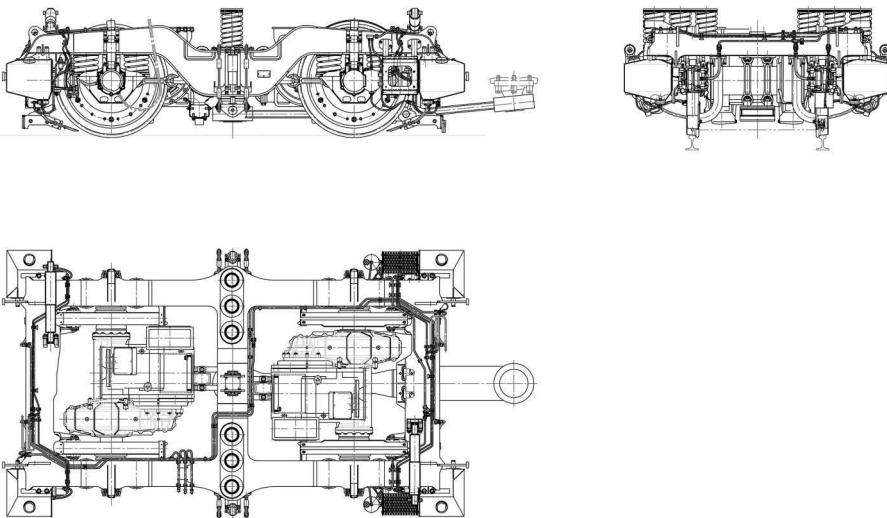


FIGURE 3.10 Two-axle bogie of a heavy haul electric locomotive (Manufactured by CRRC Zhuzhou Locomotive Company, Zhuzhou, China).

- According to the number of suspension stages used in the bogie:
 - Single-stage suspension, when the bogie frame and wheelset are connected with only one link (e.g., elastic-dissipative coupling) for each wheel
 - Double or two-stage suspension, when two levels of links are provided for each wheel
 - More stages are not usual with heavy haul locomotives
 - It is also necessary under this classification to consider the spatial orientation of these links; these usually are in the longitudinal (along the track in the direction of travel), lateral and vertical directions
- By the type of connection between an axle and a bogie frame:
 - Individual suspension, where each axle is connected to the bogie frame by its own set of elastic-damping elements. Figures 3.9 and 3.10 show bogies with individual suspension design
 - Balanced suspension, a design commonly used on older types of heavy haul locomotive, where the set of elastic-damping elements are grouped together using levers and balance beams
- By the type of suspension elements used in the bogie design:
 - Passive suspension, where uncontrolled elements such as leaf springs, coil springs, conical springs, elastic rubber elements, pneumatic or electromagnetic elements are used in the suspension design
 - Active suspension, where suspension elements have controlled characteristics, which may include several types of elastic elements and actuators that convert source (electrical, hydraulic etc.) energy into mechanical energy for providing the desired characteristics of the suspension element
- By the function of the axles in the bogie design:
 - Motorised axle, when driven by a traction motor

- Non-motorised axle, when the axle is used only to support the weight of a locomotive
- By the traction drive design:
 - Individual drive design, where the traction torque from the motor acts through a gear box on each axle. According to the UIC classification of locomotive axle arrangements, the use of a lower case ‘o’ as a suffix after the letter indicates that those motorised axles are individually driven by separate traction motors. However, this suffix is not used in the system for locomotive axle arrangements developed by the Association of American Railroads (AAR). Figures 3.9 and 3.10 show bogies with individual drive designs
 - Grouped drive design, where the traction torque from the motor or an output shaft of transmission is shared between multiple axles. This type of design is uncommon for heavy haul locomotives
- By the interconnection or separation of bogies used in a locomotive:
 - Articulated design, where a locomotive has articulated connections between two bogie frames in its bogie design; an example is shown in Figure 3.11. According to the system for locomotive axle arrangements developed by the AAR, a ‘plus’ sign indicates articulated connections being present in a locomotive design
 - Non-articulated design, where no articulated connection exists between bogies. This type of design is commonly in use for heavy haul locomotives. According to the system for locomotive axle arrangements developed by the AAR, a ‘minus’ sign is used to indicate the separation (non-articulation) of bogies

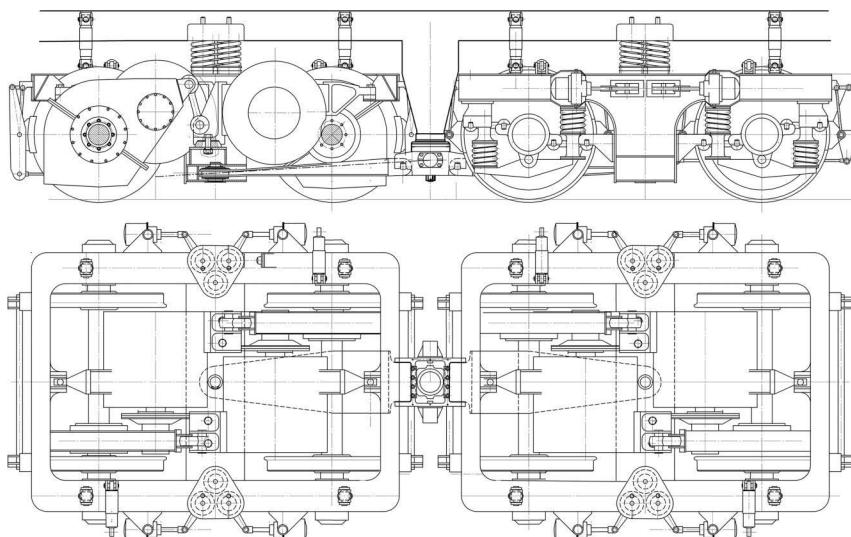


FIGURE 3.11 Four-axle bogie of a heavy haul diesel-electric locomotive (Manufactured by Lugansk Diesel Locomotive Plant, Lugansk, Ukraine).

- By the method of traction and braking force transmission from the bogie to the locomotive car body:
 - Through the pivot point
 - Through the traction rod(s)
- By the application of return mechanisms, which allows the return of the locomotive car body and the bogies to their central (original) position during operation on tangent track, and car body inclination and bogie rotation on curved sections of track
- By connection types between journal housings (axle boxes) and a bogie frame:
 - Connection with pedestal legs (also called a jaw connection)
 - Connection with cylindrical guides and a link arm (also called a traction rod)
 - Connection with radius links
- By traction motor mounting support designs:
 - Nose-suspended traction motor
 - Bogie-frame mounted traction motor
 - Axle hung suspended traction drive, which is uncommon for heavy haul locomotives, but was used on some freight electric locomotives
 - Body mounted traction motor which is uncommon for heavy haul locomotives
- By radial steering of wheelsets [2–4]:
 - Rigid bogie design
 - Semi-steering (yaw relaxation) bogie design
 - Self-steering bogie design
 - Forced steering bogie design

More detailed information and explanations on classification aspects is provided in Sections 3.2.2 through 3.2.4 which review and describe bogie design solutions and the major components used in such designs.

3.2.2 BOGIE FRAMES

The bogie frame is the primary structural component of a bogie and must be designed to receive and transmit the forces of the weight of the car body and its installed equipment, the dynamic and impact loads from wheelsets resulting from interaction between wheels and track, and the forces from implementation of traction or braking efforts through elastic-damping suspension elements. To perform their function, the bogie frame and associated load-bearing elements must possess the necessary strength and durability to ensure that the geometric, deformation and deflection characteristics are able to be maintained as designed under all operational loading scenarios. An example of a typical bogie frame is shown in Figure 3.12.

The bogie frame commonly consists of two longitudinal beams interconnected by transverse cross beam(s). Common design variants for the positioning of transverse cross beam(s) for heavy haul locomotives are as follows:

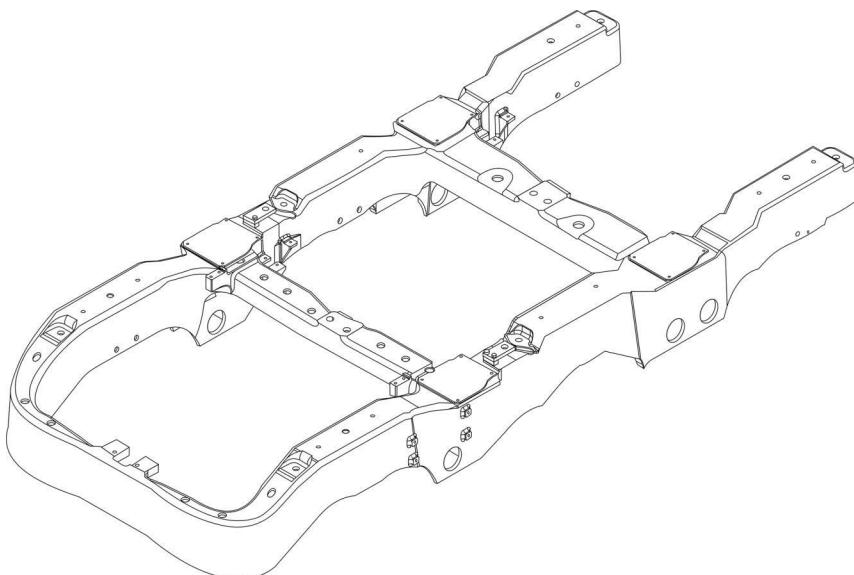


FIGURE 3.12 Bogie frame (Manufactured by Electro-Motive Diesel, McCook, IL).

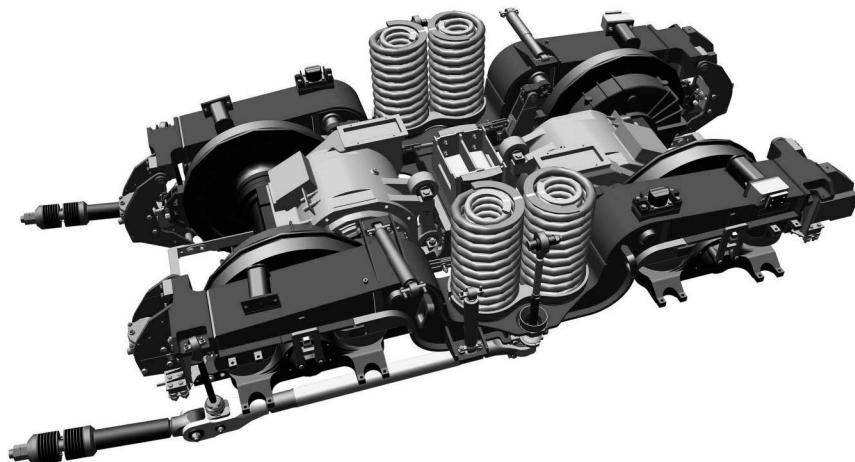


FIGURE 3.13 Two-axle bogie of an electric locomotive. (From © Siemens, AG, Graz, Austria. With permission.)

- One beam in the centre of a bogie frame. This type of design is also called an H-type bogie frame, and it is commonly used on two-axle bogies. An example of a bogie with such frame design is shown in Figure 3.13.
- One beam at the front and one or two in the middle of a bogie frame. Such a bogie frame, shown in Figure 3.12, is commonly used for two-axle or three-axle bogies. This type of design is also called a U-type bogie frame. Examples of bogies with such a bogie frame design are shown in Figures 3.14 and 3.15.

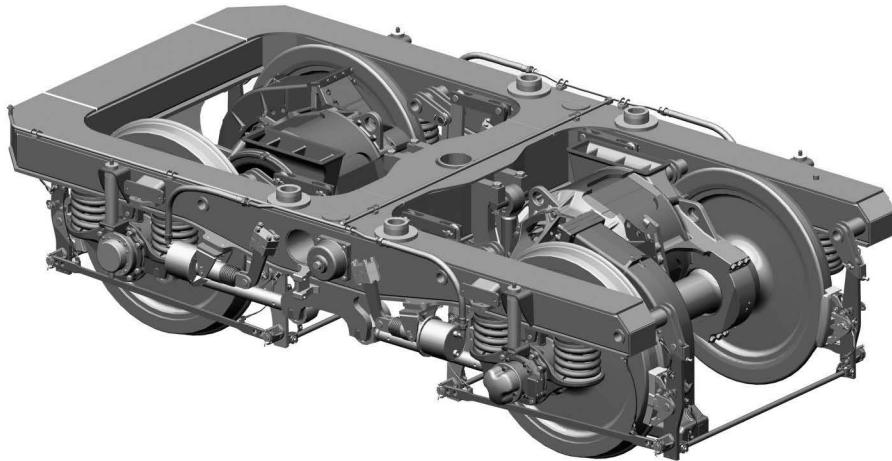


FIGURE 3.14 Two-axle bogie of an electric locomotive (Manufactured by Ural Locomotives, Yekaterinburg, Russia).

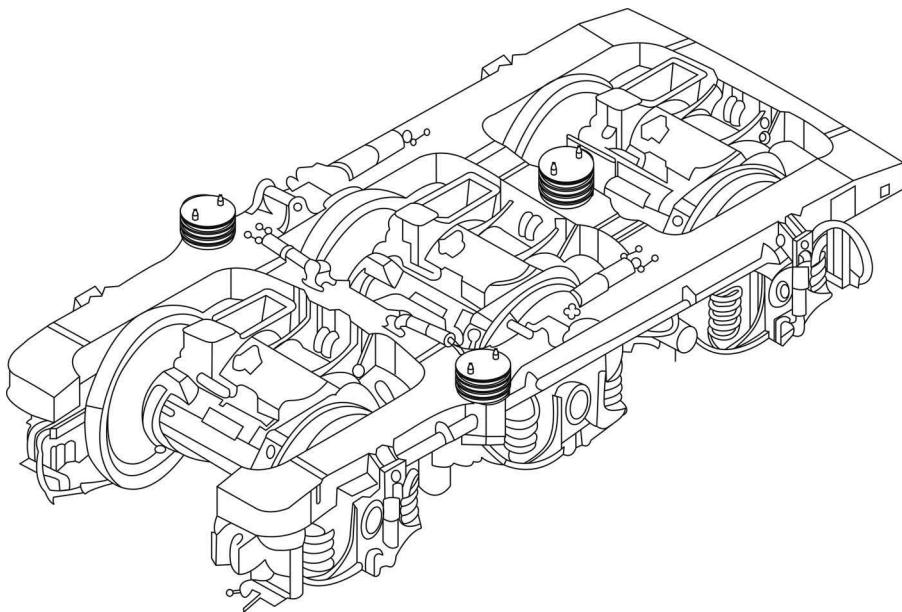


FIGURE 3.15 Three-axle bogie of a diesel-electric locomotive (Manufactured by United Group Limited, Newcastle, Australia).

- One beam at the front, one beam at the rear and one or two in the middle of a bogie frame. Such a bogie frame is commonly used for two-axle and three-axle bogies. Such a design is also called an O-type bogie frame design, and it can also be used for articulated bogies as shown in Figure 3.11. Examples of bogies with such a bogie frame design are shown in Figures 3.16 and 3.17.

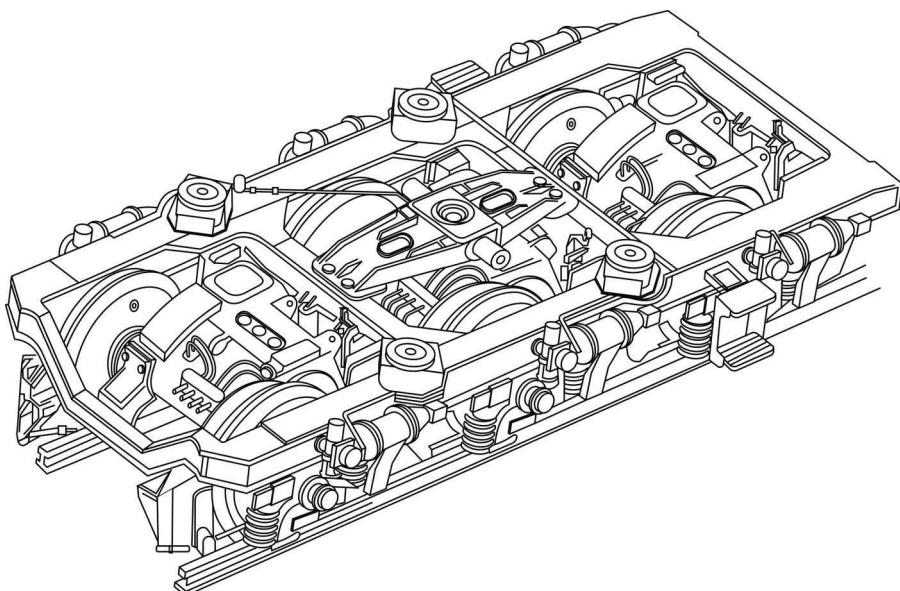


FIGURE 3.16 Three-axle bogie of a diesel-electric locomotive (Manufactured by Lugansk Diesel Locomotive Plant, Lugansk, Ukraine).

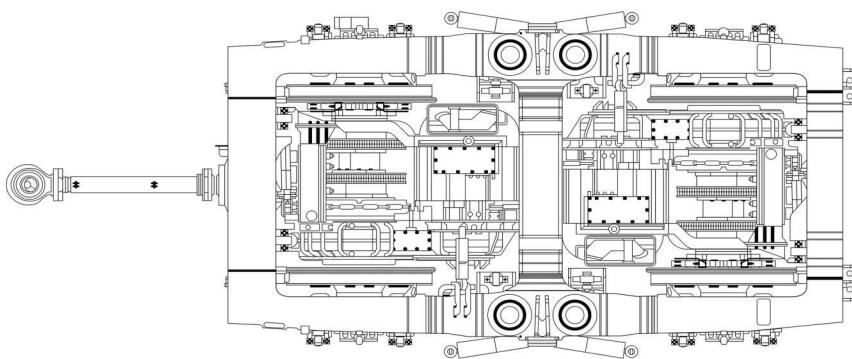
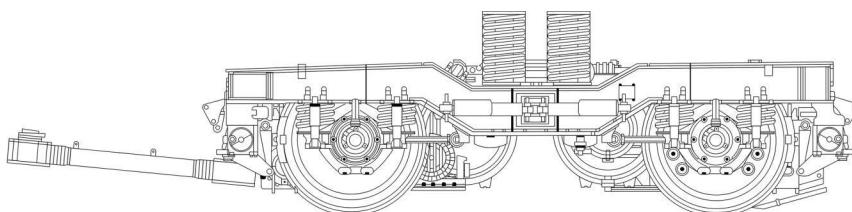


FIGURE 3.17 Two-axle bogie of an electric locomotive (Manufactured by Bombardier, Kassel, Germany).

Transverse cross beams are used to bear points of suspension for traction motors and gearboxes, as well as mounting pivot mechanisms and pivot beams.

Bogie frames can be manufactured using either a cast frame or a fabricated frame (welding of elements). Materials typically used for the construction of bogie frames are steels or alloys.

3.2.3 WHEELSETS

The wheelsets are key elements of a bogie. The main functions of locomotive wheelsets are:

- Guidance of the locomotive along the track within the permissible kinematic envelope
- Transmission of traction and braking forces to the rails that allows the controlled acceleration or deceleration of the locomotive

An example of a typical locomotive wheelset is shown in Figure 3.18. Despite the variety of wheelset designs used on rail vehicles, the wheelset of a heavy haul locomotive bogie commonly consists of the following main components:

- Axle
- Two wheels
- Gear wheel

Locomotive axles are made from special high-quality steels that must meet the specified internal grain structure and density requirements since the axles operate under high rotary and torsional bending loads. There are special requirements for the machining of axle surfaces. In particular, the transitions between differing diameters of the axle required at the positions of journal bearing, gear wheel and wheel seats should be designed so as to minimise levels of stress concentration under the various forces acting on the axle. Axles also have centre holes at the ends as shown in Figure 3.18 to

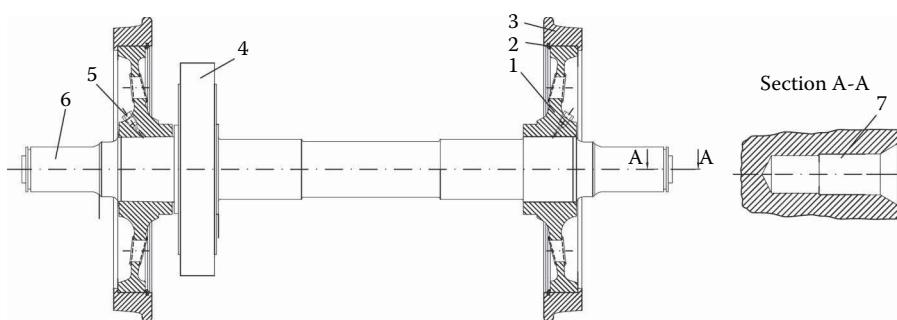


FIGURE 3.18 Example of a locomotive wheelset with tyre wheels. 1 – wheel disc; 2 – tyre ring; 3 – tyre; 4 – gear wheel; 5 – oil injection hole for assisting wheel press mounting and removal; 6 – axle; 7 – centre hole.

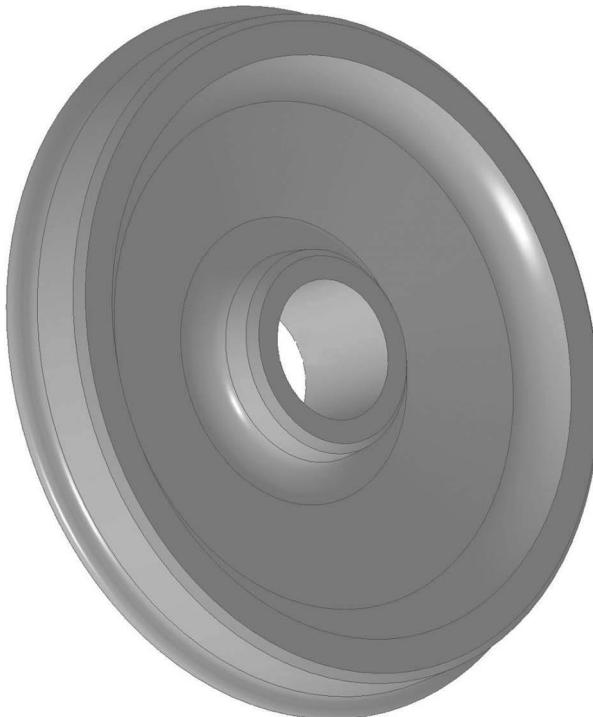


FIGURE 3.19 Example of a locomotive solid wheel.

facilitate manufacturing and maintenance operations (wheel press fitting, axle bearing installation and removal, re-establishment of wheel profiles in a lathe etc.).

Wheels are very critical components of the running gear and must provide exact geometrical and mechanical properties in order to minimise dynamic action and avoid derailments. During wheelset assembly, railway wheels are press-fitted onto the axle wheel seats. Two types of wheels are generally applied for heavy haul locomotives: tyre wheels (see Figure 3.18) and solid wheels (see Figure 3.19). In some cases, tyre wheels can incorporate a layer of low elasticity material in order to reduce wheel–rail interaction forces. However, this design is uncommon for heavy haul applications. All wheels can have different types of wheel tyres/discs in order to achieve desired construction and operational properties. Different profiles can be machined on wheel tread and flange surfaces in order to improve dynamic behaviour and interaction at the wheel–rail interface. Solid locomotive wheels can be classified according to the manufacturing methods as either wrought (forged) steel wheels or cast steel wheels.

Gear wheels are also press-fitted onto the axle wheel seats. Gear wheels are designed for the transmission of a traction torque received from the pinion of a traction motor to the axle. Various designs of spur gears can be used on heavy haul locomotives.

3.2.4 JOURNAL HOUSINGS

Journal housings (axle boxes) are connected to the wheelsets by means of the bearings which enable the rotation of the wheelsets, and make possible the transfer of traction and braking efforts as well as vertical and lateral forces to the bogie frame via elastic-damping connections. In addition, the journal housings should provide for the reciprocating movements of the wheelset in the lateral direction of the horizontal plane (so-called free run), which are needed for optimal dynamics of the locomotive in curved sections of the track and the reduction of the dynamic interaction forces between wheels and rails.

Three types of journal housings are currently in use for heavy haul locomotives. These are classified by the design of their connection to the bogie frame using:

- Pedestal legs as shown in Figure 3.20
- A cylindrical guide and a link arm as shown in Figure 3.21
- Radius links as shown in Figure 3.22

The second and third designs are commonly used for the development of radial steering bogies which reduce the lateral forces in the curved sections. For wheelset

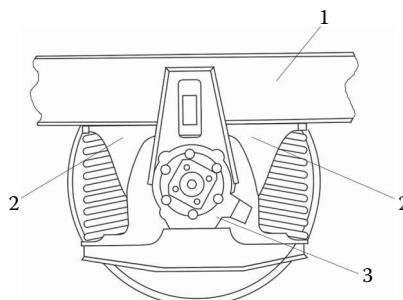


FIGURE 3.20 Journal housing with pedestal leg connection design (Manufactured by Goninan, Newcastle, Australia). 1 – bogie frame; 2 – pedestal legs; 3 – journal housing body.

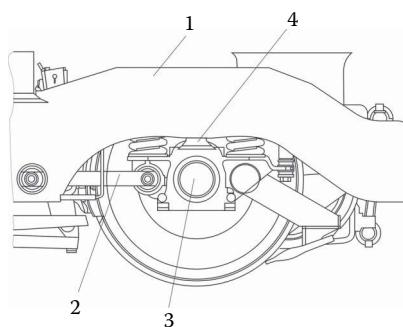


FIGURE 3.21 Journal housing connection with the usage of a cylindrical guide and a link arm (Manufactured by Electro-Motive Diesel, McCook, IL). 1 – bogie frame; 2 – link arm; 3 – journal housing body; 4 – cylindrical guide.

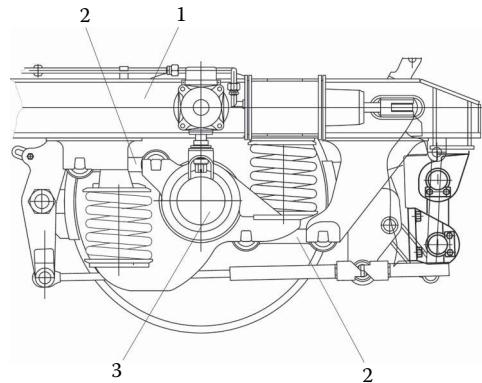


FIGURE 3.22 Journal housing connection with the usage of radius links (Manufactured by Lugansk Diesel Locomotive Plant, Lugansk, Ukraine). 1 – bogie frame; 2 – radius links; 3 – journal housing body.

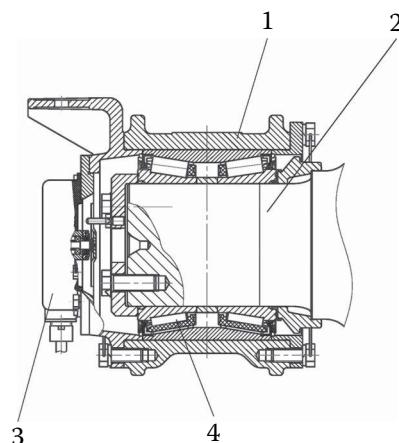


FIGURE 3.23 Journal bearing assembly (Manufactured by Ural Locomotives, Yekaterinburg, Russia). 1 – journal housing body; 2 – axle; 3 – tachometer; 4 – journal bearing assembly.

guidance in the longitudinal direction, the arms or links are fitted with rubber bushes that provide cushioning of the longitudinal thrust between journal housing and bogie frame.

Journal bearings on locomotives can be equipped with either cylindrical or conical roller type bearings. An example of a journal housing equipped with a bearing assembly is shown in Figure 3.23.

3.3 SUSPENSION

The need for the application of spring suspension on rail vehicles arises from the fact that the running rails and the track are not perfectly smooth and the rolling

wheels are also not perfect (tread surface irregularities, wheels not perfectly round, imbalance of mass and inertial forces etc.). Such irregularities lead to the resulting disturbing forces being transferred to locomotives.

In principle, if an ideal wheel rolling surface and an ideal track without any irregularities existed, the need for rail vehicles to be fitted with spring suspension would be eliminated due to the absence of perturbing forces acting on the running gear. However, there are no engineering and scientific solutions for the creation of the perfect track and the perfect wheel. Therefore, the design of locomotives went in the direction of the creation of spring suspension systems that can compensate or reduce the impact arising from the rolling of an imperfect wheel on an imperfect rail track. The aim of these systems is to provide optimal performance by achieving values of ride quality and other parameters as close as possible to the locomotive design solutions. These parameters concern equalising the distribution of weight loads between the wheels, minimising the dynamic forces caused by the interaction between wheels and rails, realising the maximum possible tractive and brake efforts for the locomotive/s to haul and control the largest possible train, and also minimise and damp the dynamic forces and natural oscillations received from the train under traction and braking. In addition, the suspension design should create safe and comfortable working conditions for the locomotive crew and minimise adverse impacts on the equipment placed on the locomotive.

3.3.1 CLASSIFICATION OF SUSPENSION DESIGNS AND ASSOCIATED ELEMENTS

Heavy haul locomotive suspension is commonly designed to perform in one or two stages (primary and secondary), and acting in the horizontal, vertical and transverse planes.

The primary suspension is usually located at the connection points of journal housings with their bogie frame, but it can also be located inside the wheelset or the wheels (so-called elastic or resilient wheels). The latter design is uncommon for existing heavy haul locomotives, but was studied for some experimental prototypes. The secondary suspension is commonly located at the connection points of bogie frames with the locomotive car body, but it may also be incorporated between various elements of the bogie itself.

Suspension systems of rail vehicles can include the following:

- Elastic elements that have stiffness, with their deformation being dependent on the external force applied, and their task being to allow controlled reciprocating movement of elements of running gear under the force loads and under oscillations arising therefrom.
- Damping elements and shock-absorbing devices have damping properties and are used to absorb vibration energy and reciprocating movement of elements of running gear.
- Elastic-damping elements have combined properties of elastic and damping elements.

The main characteristics of the suspension system are the deflection and damping values for each of the stages and planes as defined by:

- Displacements of elements:
 - Static displacement under the action of the static weight of the vehicle
 - Maximum displacement, which is limited by the maximum mutual displacement of suspension elements and by the need to remain clear of the railway structure gauge (which allows a safe amount of clearance outside the locomotive swept envelope as discussed in Section 2.2) under static or dynamic loading conditions
- Damping coefficients for each of the stages which show the rate of damping of oscillations of the elements of running gear.

If the set of elastic-damping elements are connected to each axle or journal housing of a bogie individually, such a suspension is called an individual suspension. An example of such a suspension system is shown in Figure 3.24. If the sets of elastic-damping elements for two or more axles are grouped together using levers and balance beams or joint leaf springs, the suspension is said to be a balanced suspension. An example of such a suspension system is shown in Figure 3.25. To ensure uniform redistribution of loads between locomotive axles and wheels, a combination of the elastic elements in groups is widely used. In this case, one group can be considered a point of suspension. Therefore, it is possible to add one more characteristic to suspension classification, this being the number of ‘points of suspension’. Although the balanced suspension is not in use for modern locomotives, it is present in some older heavy haul locomotives that are still in operational service.

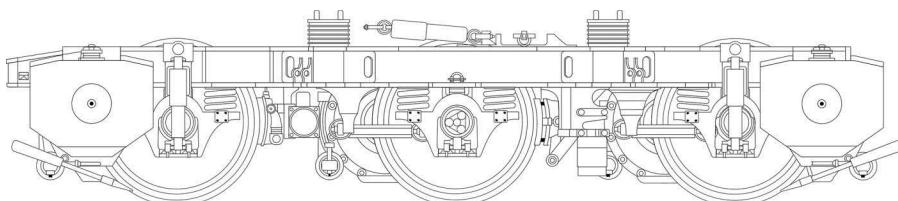


FIGURE 3.24 Three-axle bogie with individual suspension (Manufactured by United Group Limited, Newcastle, Australia).

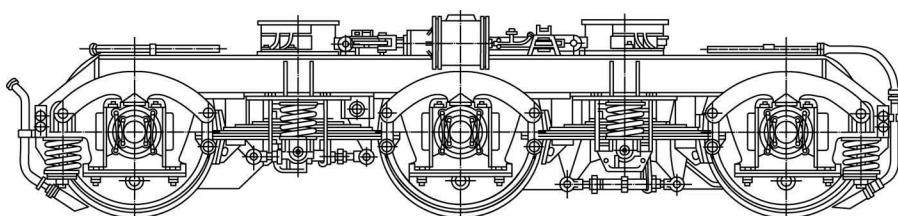


FIGURE 3.25 Three-axle bogie with balanced suspension (Manufactured by Lugansk Diesel Locomotive Plant, Lugansk, Ukraine).

The main elements supporting the locomotive car body and bogie frames are leaf springs, coil springs, rubber and rubber-metallic elements, elastomers, pneumatic elements and hydraulic cylinders. Each of these elements has different elastic-damping properties, but all have a load characteristic (dependence of the deformation of the element on the external force applied). In addition, the elastic suspension elements have damping properties defined by a characteristic shape of the applied force versus deformation curves for load and unload cycles. In some cases, when the load is removed from these elastic-damping suspension elements, the element may not return to its original size or state, resulting in permanent deformation, which is also characteristic of elastic-damping elements. One more important characteristic of elastic-damping elements is the potential need for changing the values of stiffness and damping properties under different ambient temperatures, operating time periods or number of loading cycles. All locomotives with passive suspension are equipped with these suspension elements, which are also called conventional suspension elements.

Any suspension system equipped with a control system is called an active suspension. For such a system, the suspension not only includes conventional elements, but also special devices (actuators) that generate control efforts. Actuators can be classified by their principles of work as follows:

- Hydraulic
- Mechanical
- Pneumatic
- Electric and electro-dynamic
- Magnetic and magneto-dynamic
- Complex or combined

In modern heavy haul locomotives, such actuators might be used for wheelset steering purposes or to facilitate re-distribution of wheel loads. The next Sections 3.3.1.1 through 3.3.1.5 discuss the conventional elements used in the design of heavy haul locomotive suspensions.

3.3.1.1 Leaf Springs

Leaf springs are one of the common elements of the suspension of rail vehicles and have both stiffness and damping properties. An example of a bogie with leaf springs in its primary suspension is shown in Figure 3.25. Stiffness characteristics of leaf springs provide resistance forces from metal leaves, and spring flexibility is dependent on the number and thickness of the leaves and their length. All leaves in the spring are covered with spring clamps that limit the relative movement between the leaves in the transverse direction. Disadvantages of leaf springs are their large specific gravity in comparison with other elastic elements, complicated manufacturing process and their poor repairability, as well as inconsistent damping characteristics due to variation in the friction force between the leaves. Leaf suspension designs were commonly in use on older types of locomotives, but are not used on modern heavy haul locomotives.

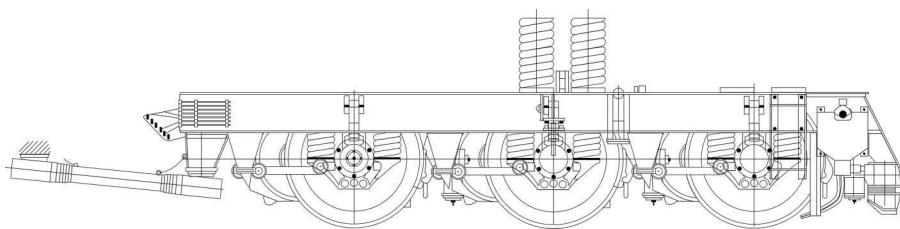


FIGURE 3.26 Helical spring suspension design of a heavy haul locomotive (Manufactured by Bombardier, Kassel, Germany).

3.3.1.2 Helical (Coil) Springs

Suspensions on helical springs, also known as coil springs, have currently found wide application because of their light weight and their ability to work as a vertical spring as well as in the transverse plane. It is common practice to use such springs in locomotive primary suspensions. However, the property of these springs to act in the transverse plane is often used in the secondary suspension. Such suspension is also called ‘flexi-coil suspension’. An example of the usage of helical springs in both stages of a locomotive suspension is shown in Figure 3.26.

In order to increase the stiffness of helical springs, they can be combined into sets. Obtaining non-linear stiffness characteristics is also possible through the use of steel wire with variable cross-sectional diameters along the length, as well as varying the diameter and shape of the spring.

3.3.1.3 Air Springs

Air (pneumatic) spring suspension is currently one of the sought-after elements of suspension systems because its elastic characteristics can be adjusted under certain loads and operating conditions, along with the ability for load transfer between the elements of the running gear. A typical air spring suspension system consists of the following elements: air springs, connecting pipes, the levelling valve, an additional reservoir, differential pressure and safety valve. An additional elastic element is installed inside the air spring in order to prevent suspension collapse and allow the vehicle to reach a place of repair in cases of failure of the rubber-shell or air feed line.

Changes of the stiffness characteristics are performed by the adjustment of air pressure and temperature parameters. Damping characteristics can be changed by adjusting the size of the additional reservoir and the flow capacity of the pressure valve. Typically, air suspension is used in the secondary suspension because it is more effective in absorbing low-frequency oscillations.

Air suspension can have several air springs connected in the loop and several additional air reservoirs. Air springs can also operate in pairs without the application of an additional reservoir.

The advantages of air suspension are the possibility of varying the stiffness and damping characteristics as well as low weight. The disadvantages are the additional energy costs for feeding air to them and filtering the air, and more expensive maintenance and increased cost in comparison with coil and leaf springs.

It is uncommon to use air springs in suspension designs of heavy haul locomotives, but it has a potential major benefit in terms of controlling axle load distributions that may improve the dynamic performance. An example of the investigation of air springs in the secondary suspension of a heavy haul locomotive is presented in Section 7.8.

3.3.1.4 Rubber and Elastomer Springs

The application of rubber and elastomer materials to create elastic-damping suspension elements in modern locomotives is a quite common design solution. Polymer and rubber materials have high absorption properties for damping of vibration energy, and they can also provide high cushioning characteristics by means of their enhanced properties of elasticity. However, because of low strength characteristics and poor thermal conductivity, these materials have to be reinforced with metal or carbon fibre components. Another disadvantage of these elements is their change in stiffness and plastic properties under varying temperature conditions found in operational service, and the loss of their ability to maintain their original form (permanent plastic deformation). However, these problems may be resolved as the modern chemical industry is constantly improving the manufacturing techniques and the chemical composition of rubber and polymeric materials. Additionally, there are some difficulties in terms of the large variations of stiffness parameters that require a detailed selection of such spring elements for a locomotive in order to provide the required level of deviation characteristics in the running gear design, which results in the need for additional testing of each element during the manufacturing process.

However, all of the above shortcomings are more than compensated for by the low manufacturing and operating costs for rubber and polymer elements, their low weight characteristics and the positive effects on damping and vibration. An example of the usage of rubber conical springs in a locomotive primary suspension is shown in Figure 3.27. An example of the application of rubber springs in a secondary suspension is shown in Figure 3.28.

3.3.1.5 Dampers

Damping and absorbing devices are classified by the type of working fluid used in them or by the physical process that creates an absorbing effort.

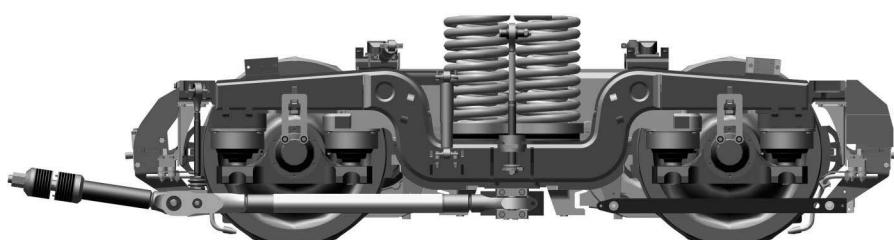


FIGURE 3.27 Two-axle bogie of an electric locomotive with rubber conical spring in primary suspension. (From © Siemens, AG, Graz, Austria. With permission.)

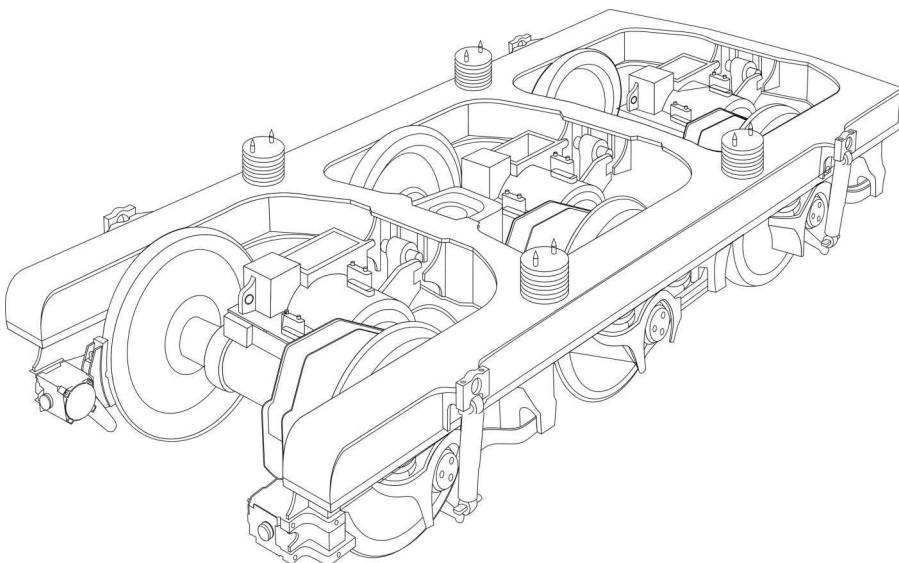


FIGURE 3.28 Three-axle bogie with rubber elements in secondary suspension (Manufactured by United Group Limited, Newcastle, Australia).

Dry friction dampers may be designed with a translational characteristic in which a damping force is generated due to a friction process between the piston and the cylinder (their mutual displacement), or be of a torsional type where the damping force is created by the friction between two or more disks, one of which has a rotational motion associated with a torsion arm actuated by motion of movable elements of the running gear. To ensure constancy of the friction process in such dampers, compensation has to be made for wear; special mechanisms are used which usually consist of spring elements and tensioners.

These types of dampers are sometimes used in the primary suspension, but can give problems due to the inconsistency of their characteristics and the initial force required for displacement, which can lead to locking of the spring suspension. During servicing of such rail vehicles, it is necessary to monitor the tightness of the friction elements. The advantages are the simplicity of design and the low cost of manufacturing.

Hydraulic dampers (shock absorbers) for damping and absorbing of vibration use the viscous properties of liquids. They usually consist of a cylinder in which a rod, with a piston that has holes drilled in it, is inserted. This makes it possible for the fluid to flow from one chamber of the cylinder to another. Flow can also be carried out through channels in the cylinder walls. These dampers have stable damping characteristics for low-frequency vibrations, but they are very sensitive to high frequencies because the latter is associated with liquid cavitation processes and hydraulic impact. The performance of these dampers is significantly affected by the ambient temperature and the temperature of their fluid. This type of damper is often installed in secondary suspensions.

Gas shock absorbers are filled with gas under high pressure and work on the same principle as hydraulic dampers. However, they do not have the disadvantages associated with the liquid flow process, and can therefore be used in primary suspensions.

Rubber dampers or rubber-absorbing elements act based on the damping properties of rubber. To increase the stiffness and strength characteristics of the rubber elements, they are covered and reinforced with metal or composite materials, fabrics and fibres. They can be used in primary and secondary suspensions.

Combined dampers integrate several types of dampers mentioned above. Among them, for example, are gas-hydraulic dampers that find wide application. Such dampers are also used in primary suspensions.

3.3.2 PRIMARY SUSPENSION

The main objective of the primary suspension is the damping of high-frequency oscillations arising due to force interaction between the rolling wheels and the rails, preventing their transfer to the locomotive car body and the bogie frame, as well as damping of vibration of the car body itself and reducing its impact on the force interaction between wheel and rail. In addition, the elements of the primary suspension may balance and redistribute the load between the wheels or wheelsets in the bogie. Typically, the static deflection of the primary suspension is 30%–40% of the total suspension deflection of a locomotive. Given these high frequency and low deflection characteristics, primary suspensions are able to utilise elastic elements such as coil springs, leaf springs or rubber elements. For this purpose, the dampers have inserts made from rubber or polymeric materials because these materials have high energy-absorption capacity. The low-frequency part of the oscillation spectrum is absorbed by hydraulic or friction dampers.

An example of the usage of coil springs and hydraulic dampers in the primary suspension of a two-axle bogie is shown in Figure 3.29. An example of the usage of coil springs and a friction damper is shown in Figure 3.22.

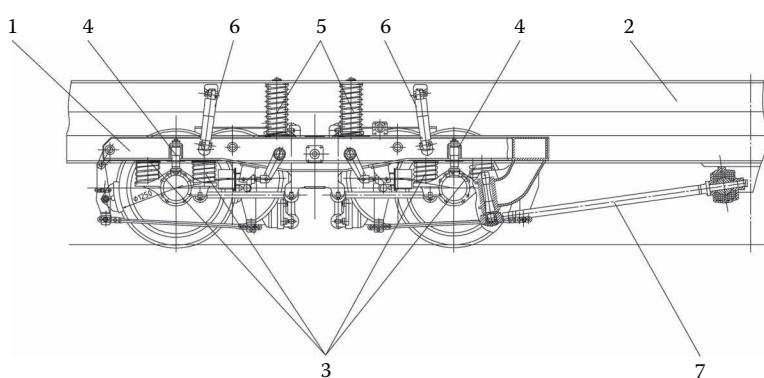


FIGURE 3.29 Suspension system of a two-axle bogie and its connection to locomotive frame (Manufactured by Ural Locomotives, Yekaterinburg, Russia). 1 – bogie frame; 2 – locomotive main frame; 3 – primary suspension coil springs; 4 – primary suspension dampers; 5 – secondary suspension ‘flexi-coil’ springs; 6 – secondary suspension dampers; 7 – traction rod.

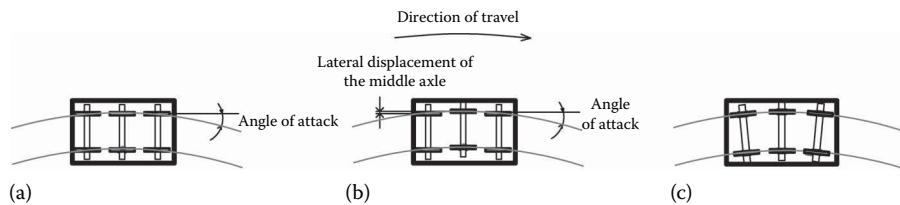


FIGURE 3.30 Conventional and steering bogies during curving: (a) conventional bogie, (b) conventional bogie with floating middle axle, and (c) steering bogie.

The conventional bogie, which is also called a rigid bogie, has some clearances provided in its primary suspension design in order to improve dynamic interaction between wheels and rails that allows small displacements of wheelsets, resulting in reduced cornering forces. However, for better dynamic performance and significant wear reduction, it is desirable to reduce wheelset angles of attack in curved sections of track as shown in Figure 3.30. For this purpose, steering of the wheelsets within a bogie is a good solution. Presently, four typical bogie designs can be used on heavy haul locomotives [2,3]:

- Rigid frame
- Semi-steering or yaw relaxation
- Self-steering
- Forced steering

The control methods, which allow for provision of steering, can be divided into three main groups [4]:

- Acting by means of wheel-rail contact forces
- Acting by means of centrifugal forces
- Acting by means of application of external forces

The semi-steering and self-steering designs are generally achieved by applying elastomeric bushes or by modifying kinematical mechanisms in the primary suspension design that allows elements to work in several planes and makes the primary suspension more flexible and adjustable under the action of wheel-rail contact or centrifugal forces. By contrast, the forced steering designs only work under the application of external forces. Some attempts have been made to implement the latter design in prototypes, but it is still uncommon in routine heavy haul operations. Examples of the orientation of wheelsets of various types of three-axle bogie designs during curving are shown in Figure 3.31.

3.3.3 SECONDARY SUSPENSION

The secondary suspension is located between a locomotive's main frame and its bogies and is designed for supporting the locomotive car body on the bogie frames and absorbing the vertical deflection. Typically, the static deflection of the secondary suspension is 60%–70% of the total suspension deflection of a locomotive. In addition,

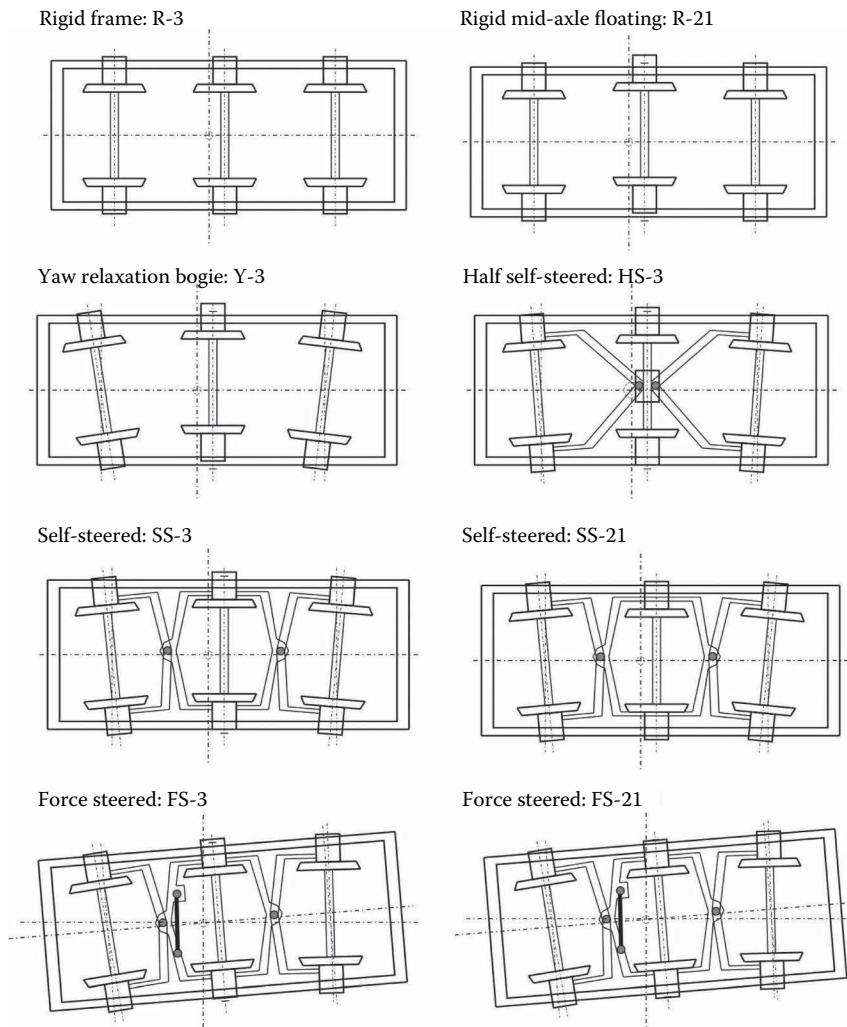


FIGURE 3.31 Examples of wheelset orientation of various three-axle bogie designs during curving. (From Simson, S., Three axle locomotive bogie steering, simulation of powered curving performance: Passive and active steering bogies, PhD Thesis, Central Queensland University, Rockhampton, Queensland, Australia, 2009. With permission.)

the elements of secondary suspension make possible rotations and displacements of bogies relative to the car body within the prescribed limits and their return to the initial position. The secondary suspension elements include

- Springs
- Side bearers
- Dampers
- Actuators

Any of the spring elements described earlier in Sections 3.3.1.2 and 3.3.1.3 can be used in the secondary suspension. However, by analysing existing designs with an application of such elements, it is possible to state that ‘flexi-coil’ suspensions have found the most widespread application in designs of modern heavy haul locomotives. An example of such a suspension design is shown in Figure 3.29.

Side bearers are designated to transfer vertical loads from the car body onto the bogie frames. In addition, they should provide the ability for bogies to rotate relative to the car body and allow movements in all planes within the prescribed limits. In addition, the side bearers can generate return moments and reduce hunting oscillations of bogies, as well as provide a tilting motion of the car body when the locomotive operates in the curved sections of the track.

At the present time, commonly used types of side bearers are [1]

- *Side bearer pads (rubber springs)* – an example of their application is shown in Figure 3.32, where metal plates are present inside the rubber springs to separate the rubber layers, and the edges of the metal plates are covered in rubber to avoid corrosion.
- *Side bearers with return devices* – an example is depicted in Figure 3.33, the concept being that the side bearer can have rubber or coil spring(s) and even an air spring at the top, while it has rollers which operate in their nest with a lubricant at the bottom, the advantages being low coefficients of friction and the ability to get different values of return moments.

The dampers used in the secondary suspension designs are commonly hydraulic dampers, as described in Section 3.3.1.5, which are generally needed to damp

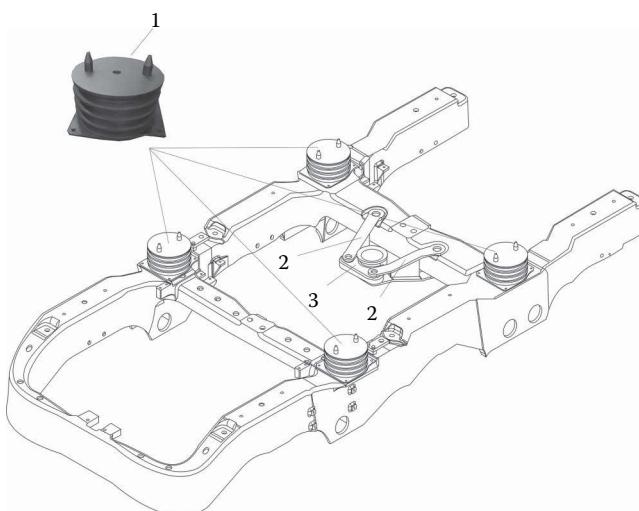


FIGURE 3.32 Secondary suspension and traction transfer elements mounted on the bogie frame (Manufactured by Electro-Motive Diesel, McCook, IL). 1 – side bearing; 2 – yoke; 3 – traction rod.

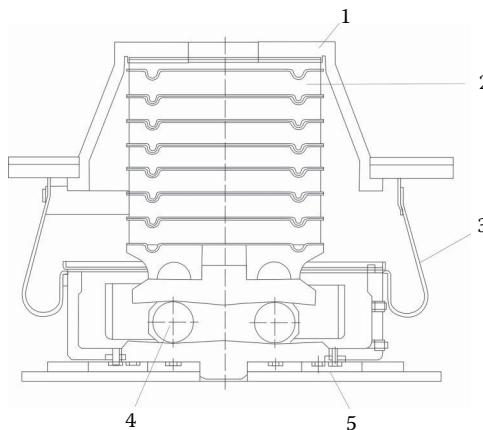


FIGURE 3.33 Side bearer with roller return device (Manufactured by Lugansk Diesel Locomotive Plant, Lugansk, Ukraine). 1 – top plate connected to an underframe; 2 – rubber elements; 3 – dust cover; 4 – roller; 5 – base plate connected to a bogie frame. (From Spiriyagin, M. et al., *Design and Simulation of Rail Vehicles, Ground Vehicle Engineering Series*, CRC Press, Boca Raton, FL, 2014.)

vertical and lateral movements. The dampers working in the vertical direction are applied to achieve the required ride comfort. Meanwhile, the dampers for the lateral direction are needed to improve stability and guidance at higher operational speeds.

Actuators can be used in secondary suspension designs for the improvement of weight distribution/utilisation by a heavy haul locomotive in order to realise maximum possible tractive efforts. Mechanical optimisation of the secondary suspension is not a very attractive option in such cases because it can only be optimised for some specific tasks when travelling over tracks with specific characteristics. In order to get more universal results, it seems very reasonable to work on the characteristics of the secondary suspension and to use an active spring suspension instead of a conventional design. This means that hydraulic or air actuators can be mounted between the main frame and bogies, either to act in conjunction with other suspension elements (e.g., springs or side bearings) or singly (adjustable air springs). However, at the present time, this direction requires further research for progressing future design solutions.

3.4 DESIGN COMPONENTS FOR TRANSMISSION OF TRACTION AND BRAKING FORCES BETWEEN A LOCOMOTIVE FRAME AND BOGIES

On heavy haul locomotives, these components include pivot assemblies and traction rods.

3.4.1 PIVOT ASSEMBLIES

Such assemblies are used to transmit traction and braking forces from the bogie to the car body or the main frame of the locomotive. The pivot assembly is also the

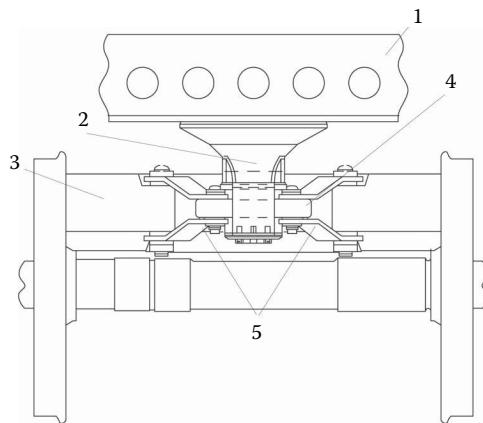


FIGURE 3.34 Example of pivot assembly (Manufactured by Electro-Motive Diesel, McCook, IL). 1 – main frame; 2 – pivot pin; 3 – bogie frame; 4 – yoke; 5 – traction rod.

point about which a bogie undergoes rotational movement in the horizontal plane relative to the car body. An example of a pivot assembly is shown in Figure 3.34.

Pivot assemblies can be divided into two types characterised by their position relative to the centre of the wheelset axles in the horizontal plane:

- *High location of the pivot point* – in this case, the force transmitted from the bogie to the car body is at a point that is located higher than the centre of the wheelset axles in the horizontal plane. Examples of such a design solution for bogies are shown in Figures 3.9 and 3.14.
- *Low location of the pivot point* – in this case, the force transmitted from the bogie to the car body is at a point which is located below the centre of the wheelset axles in the horizontal plane. An example of such a design solution for an articulated bogie is shown in Figure 3.11.

A higher value of tractive and brake efforts can be achieved by a locomotive that has pivot assemblies with low pivot point locations in comparison with a locomotive which has the same design and configuration, but with high pivot points.

Pivot assemblies of locomotives can have a rigid design when the bogie can perform a translational motion in the vertical plane and a rotation in the horizontal plane. In addition, pivot assemblies can be designed with additional gaps that allow some small motion in the horizontal plane transverse to the longitudinal axis of the locomotive.

Pivot assemblies with spherical joints allow the bogie to carry out rotational movement within specified limits with respect to all planes. In addition, these can have movement in the vertical plane and partial displacement in the horizontal plane.

From the design point of view, the pivot assembly can consist of a pin rigidly fixed to the main frame or car body of the locomotive on one end, while, on the other end, a pin is inserted in the pivot yoke which is fixed to the frame of the bogie (Figure 3.14) or the bolster (Figure 3.16).

The advantages of rigid pivot assemblies are the simplicity of their design and low cost of manufacturing. Pivot assemblies, which allow lateral motions, have better dynamics in comparison with rigid joints. Furthermore, pivot assemblies with spherical joints can provide improved dynamic behaviour for a locomotive in comparison to other existing designs.

3.4.2 TRACTION RODS

Traction rods are used to transfer traction and braking efforts. Examples of the usage of traction rods for the connection of the pivot assembly are shown in Figures 3.32 and 3.34. When a powered rail vehicle is not equipped with pivot assemblies, as shown in Figure 3.29, then traction rods can directly connect a locomotive car body and a bogie.

For damping of oscillations caused by traction and braking forces, traction rods can be equipped with absorbing devices; most often in such cases, rubber and rubber-metal elements or bushings have found wide application.

3.5 ELECTRIC TRACTION DRIVES

Electric traction drives are designated for transferring kinematic power from the traction motors to the wheelsets of a heavy haul locomotive. Such drives are usually represented as a part of the wheelset assemblies, which include the following components:

- Traction motor
- Gear box
- Wheelset

The design and parameters of traction drives are often dependent on the installation designs of traction motors and associated gearing. As mentioned earlier in the discussion of bogie classification (see Section 3.2.1), two design variants are common for heavy haul locomotives:

- With a nose-suspended traction motor
- With a bogie frame-mounted traction motor

The nose-suspended traction motor design is most commonly used for heavy haul locomotives. Torque from the motor is transmitted to the gear box, from the pinion mounted at the end of the rotor to the driven gear wheel which is seated firmly on the axle. This enables the effective transfer of high tractive effort. However, about 60% of the weight of the traction motor and the traction drive account for unsprung mass with the nose suspended design; this causes increased dynamic effects of the locomotive on the track. This drive is the most simple in terms of design concept and service, but has poor dynamic performance in view of the large weight distributed as unsprung mass.

The design with a bogie frame-mounted traction motor can also be used for heavy haul locomotives. The traction motor is directly connected to the bogie frame. The traction drive has one side mounted on the axle and the other side commonly uses a nose-suspended suspension approach. The axle receives a torque through mobile and flexible connection elements that provide the necessary freedom of movement of the wheelset or the wheels relative to the traction motor. In this case, unsprung weight is sharply reduced and this improves the dynamic performance of locomotives. However, such a design may have an adverse effect on the rotor life of the traction motor.

An example of a nose-suspended traction motor design is shown in Figure 3.35, and an example of the application of a flexible coupling in a traction drive with a bogie frame-mounted traction motor is shown in Figure 3.36.

The design of traction drives can also be classified by the number of gear boxes installed in the system. This can be one (as shown in Figure 3.35) or two gear coupling used per one traction motor and per axle. The example of a two gear box design is shown in Figure 3.37.

One of the main characteristics of gear boxes is the gear ratio, which is also a main characteristic in locomotives as described in Chapter 2.

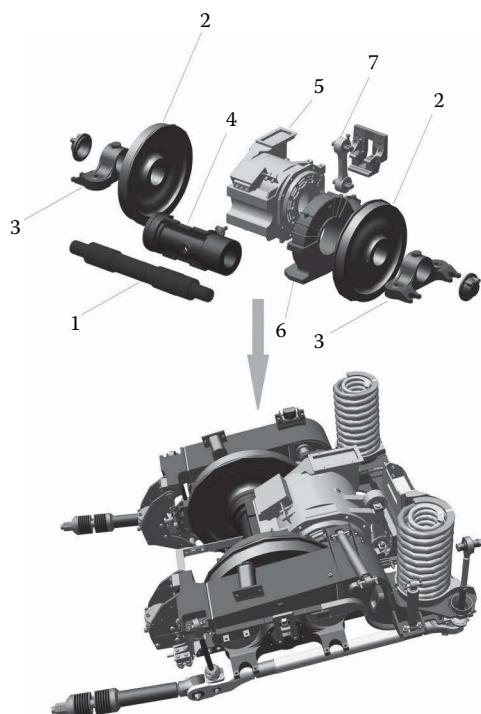


FIGURE 3.35 Example of a nose suspended traction motor design. 1 – axle; 2 – wheels; 3 – journal housing; 4 – tube assembly; 5 – traction motor; 6 – gearbox assembly; 7 – dog bone. (From © Siemens AG, Graz, Austria. With permission.)

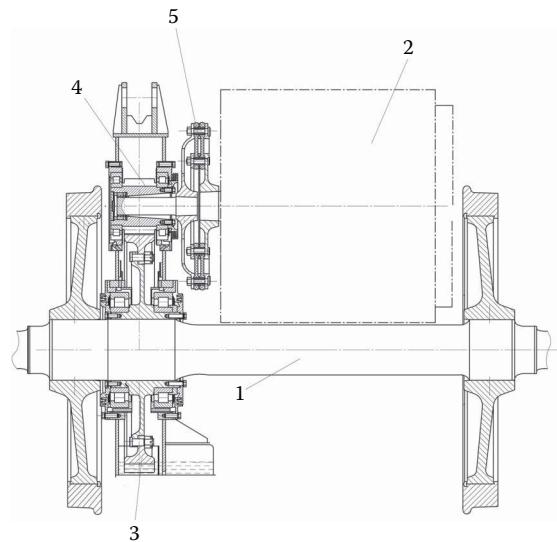


FIGURE 3.36 Example of a bogie frame-mounted traction motor design (Manufactured by Lugansk Diesel Locomotive Plant, Lugansk, Ukraine). 1 – axle; 2 – traction motor; 3 – gear wheel; 4 – pinion; 5 – flexible coupling.

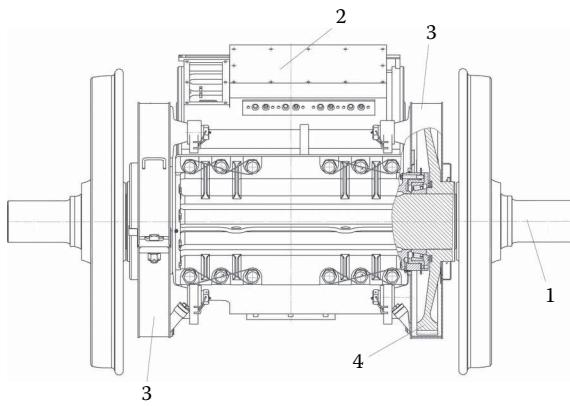


FIGURE 3.37 Example of a traction drive with two gear boxes (Manufactured by Ural Locomotives, Yekaterinburg, Russia). 1 – wheelset; 2 – traction motor; 3 – gear housing; 4 – gear wheel.

3.6 BOGIE SUBSYSTEMS

The bogie is equipped with other subsystems that are also important components of running gear. In this section, we will examine brake, sanding and wheel flange lubricating subsystems installed on the bogie. The latter subsystem is optional and can be replaced by a wayside lubrication process on heavy haul routes.

3.6.1 BRAKE SUBSYSTEM AND ASSOCIATED DEVICES

As described in Section 2.7.2, the standard brake subsystems used on bogies of heavy haul locomotives are the air brake and parking brake.

3.6.1.1 Components of Air Brake Systems

The following elements of the pneumatic system are usually located on the bogie frame: air pipes used to supply brake cylinders, brake rigging with connected brake shoes and the brake cylinders. The number of brake cylinders shows what type of mechanism is in use: if one cylinder is acting on several brake shoes located on different wheelsets, then such a mechanism is called a grouped scheme; if each wheelset uses its own cylinder, then it is called an individual scheme.

If only one brake shoe is used to produce the braking force on each wheel, as shown in Figure 3.38, such a design is called a single-shoe brake system. When the braking force is applied from both sides of the wheel by means of two brake shoes, as shown in Figures 3.39 and 3.40, such a design is called a double-shoe braking system.

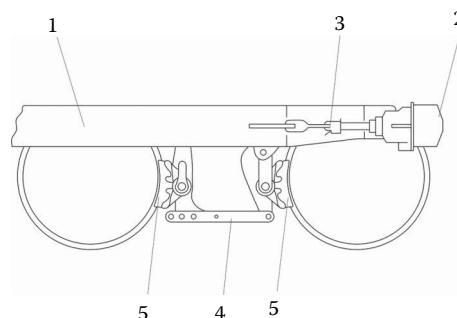


FIGURE 3.38 Example of a single-shoe braking system.

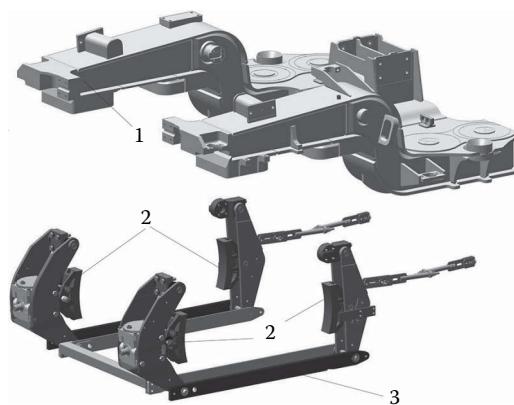


FIGURE 3.39 Example of a double-shoe braking system. 1 – bogie frame; 2 – brake shoes; 3 – brake rigging. (From © Siemens AG, Graz, Austria. With permission.)

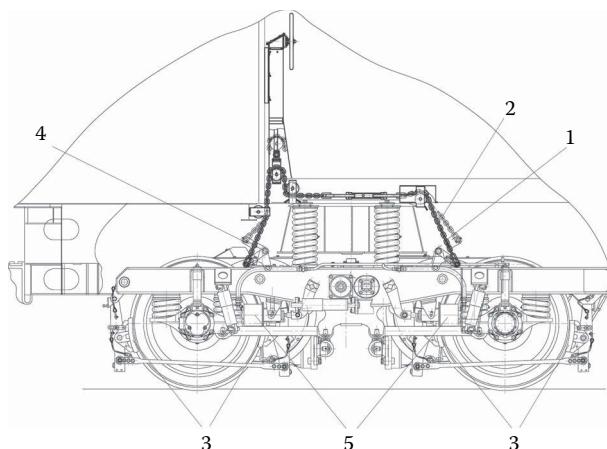


FIGURE 3.40 Example of parking brake system (Manufactured by Ural Locomotives, Yekaterinburg, Russia). 1 – chain, when brake released; 2 – chain, when brake applied; 3 – brake shoes; 4 – brake rigging; 5 – brake cylinders.

The braking system needs regular adjustment of brake shoe position, which is commonly performed with a special mechanical or automatic slack adjuster connected directly to the rod of the brake cylinder, or by means of brake rigging systems that have resetting latches, plates or rods.

The brake blocks used on heavy haul locomotives these days are commonly equipped with cast iron or composite shoes.

3.6.1.2 Parking Brakes

The parking brake is used to prevent inadvertent movement of the locomotive and the train during periods when the train is stopped on the main line or stabled in a siding.

The control with which to activate the parking brake can sometimes be located in the driver cab, but more often is inside the locomotive body or mounted on the main frame. A wheel or lever is generally used to actuate a gear or brake rigging. An example of the actuation with a chain mechanism is shown in Figure 3.40. The system creates a tension of the chain and the brake rigging sets the brake shoes in the applied state to press the brake blocks against the wheels, thereby preventing the wheels from rotating. When the parking brake is not applied, the chain is not under tension and the wheels are released.

3.6.2 SANDING SUBSYSTEM

Locomotive sanding systems serve to enhance the adhesion coefficient between wheels and running rails when locomotives operate in modes of traction and braking under conditions of insufficient friction which limits the implementation of the necessary tractive and braking efforts. This can be attributed to the presence of some surface contaminants at the wheel-rail interface, caused by either natural or man-made factors or events. The main components of such a system are shown in Figure 3.41.

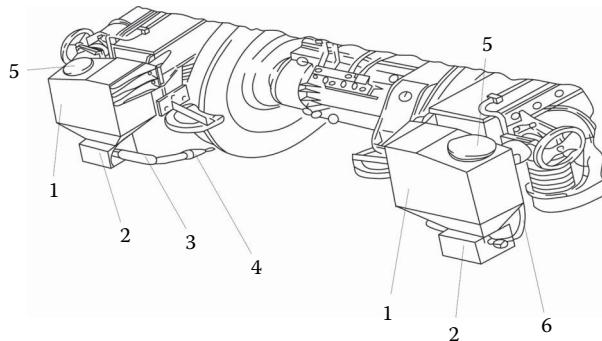


FIGURE 3.41 Example of a bogie-mounted sanding subsystem installation (Manufactured by Goninan, Newcastle, Australia). 1 – sand box; 2 – sand trap; 3 – sanding pipe; 4 – sanding nozzle; 5 – sand box filler; 6 – air pipe.

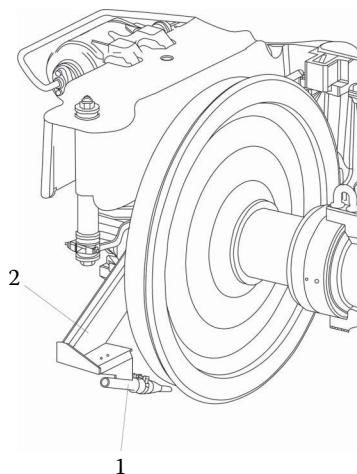


FIGURE 3.42 Example of car body-mounted sanding subsystem installation (Manufactured by Electro-Motive Diesel, McCook, IL). 1 – sanding nozzle (pipework not shown); 2 – mounting bracket.

Sand boxes and the sand traps can be installed on the bogie, as shown in Figure 3.41, or on the locomotive car body. In the latter case, the bogie is equipped with sanding nozzles only, as shown in Figure 3.42, and flexible pipework is used in order to supply sand to them.

3.6.3 WHEEL FLANGE LUBRICATION SUBSYSTEM

Flange lubrication systems are often used for the improvement of dynamic interaction and the reduction of wear processes at the wheel–rail interface when locomotives operate on curved sections of the track. An example of a locomotive wheel flange lubrication system is shown in Figure 3.43. Similar to sand systems, the lube

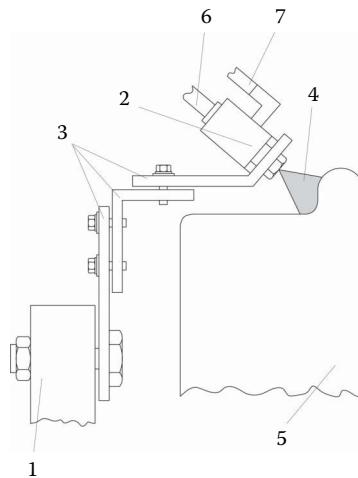


FIGURE 3.43 Example of wheel flange lubrication installation (Manufactured by Electro-Motive Diesel, McCook, IL). 1 – journal housing or bogie frame; 2 – nozzle assembly; 3 – adjustable brackets; 4 – lubricant; 5 – wheel; 6 – pipe to lube system; 7 – pipe to air control system.

tanks and other pieces of equipment can be installed on the bogie or on the locomotive car body. Solid lubricant can also be applied to the wheel flange by direct contact instead of spraying liquid lubricant.

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