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International
Journal
Of Modern Engineering Research (IJMER)

Study on Bogie and Suspension System of an Electric Locomotive (Wap-4)

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Abstract: *This project involves a detailed study on the **"BOGIE AND SUSPENSION SYSTEM OF AN ELECTRIC LOCOMOTIVE (WAP-4)"** in Indian Railways. It involves a list of information on the various parts of a conventional type bogie and also the various advantages of different types of suspension and damping systems installed. Detailed explanation of various electrical and controls of the locomotive were described in the report. Various physical testing methods of springs were focused under suspension chapter. This report isn't just focused on the conventional type loco, but also gives detailed differences observed between the 3-phase bogies from the conventional type loco. In electrified railways, the traction power systems carry power to trains and their reliability is vital to the quality of train services. There are many components in the traction power system, from interface with utility distribution network to contacts with trains, and they are physically located along the rail line. Subject to usage, environment, and ageing conditions of components deteriorate with time. Regular maintenance has to be carried out to restore their conditions and prevent them from failure. However, the decisions on the suitable length of maintenance intervals often lead railway operators to the dilemma of minimizing both risk of failure and operation cost. In the last 20 years, there has been a gigantic acceleration in railway traction development. This has run in parallel with the development of power electronics and microprocessors. What have been the accepted norms for the industry for, sometimes, 80 years, have suddenly been thrown out and replaced by fundamental changes in design, manufacture and operation. Many of these developments are technical and complex. Through this report, we bring to you all the salient features and all important aspects of bogies and suspension system of conventional type Electric Locomotive (WAP-4).*

I. Introduction

Indian Railways has a total state monopoly on India's rail transport. It is one of the largest and busiest rail network in the world, transporting 16 million passengers and more than 1 million tones of freight daily. IR is the world's largest commercial or utility employer, with more than 95 lakh employees. The Railways traverse the length and breadth of the country; the routes cover a total length of 63,140 KM (39,233 miles). As of 2002, IR owned a total of 216,717 wagons, 39, 263 coaches and 7,739 locomotives and ran total of 14,444 trains daily, including about 8,702 passenger trains.

1.1 Overview of Electric Locomotive

Due to scarcity of energies like coal, diesel and petrol and also due to increasing environmental pollution, electrification in the railways became a necessity. By electrification the following benefits can be obtained:

1. A pollution free environment
2. Easy and cheap maintenance
3. Saving of essential fuels like coal, diesel etc.
4. Faster, quicker and comfortable transports
5. Smooth starting and stopping

1.2 Trend

The first locomotive was invented by Cornish inventor Richard Trevithick in 1804 & the trend of locomotives started with steam engines, and then developed to diesel engines, which ruled the era for quite a lot of time. The diesel engines were very much flexible and would have a considerable hauling power compared to the steam ones. But a drastic change influenced the railways with the invention of electrically operated locomotives. These locomotives at the beginning required constraint to be fulfilled, which was to provide electric power always available for the locomotive. This took time and even a huge investment to install electric supply lines all over the areas and also provide adequate and correct amount of power for the loco anywhere it goes. The railway also had to install the sub-stations to boost up the power. Railways signed the contract with state electricity boards, with consent of NTPC which would provide railways a reliable and continual power. After the constraints were fulfilled, the emerging electric locomotives came into applications.

The new invention improved the efficiency of the railway system and moreover reduces the effort of the personal driving the locomotive. Slight modification made the system more and more efficient and flexible, which earned huge profits in the railway sectors. Now, the railways have to surpass the hardship of totally electrifying the network so that the locomotive can run all over.

1.3 Importance of Locomotives

The Locomotive is practically the sole responsible for the smooth running of the whole rail vehicle. It's because of the reason every locomotive is being checked by loco shed department for every 45 days and the maintenance is scheduled for some periods. The initially developed locomotives used power converters, which would convert the received AC power to DC power and feed to DC motors. The new microprocessor controlled locomotives take the AC power and feed the rugged AC induction motors by power conversions criteria these locomotives have surpassed all hardships and also running smoothly as of now. It has been proposed that the new locomotives would replace the old ones with its advantage and comfort for the driver. Making a thorough study of the convention type bogie and suspension of WAP-4 makes the report. The rest of the report portrays the locomotive parts, its working and technical data.

II. Literature Survey

The electric locomotives contain 6 traction motors each driving one shaft. Under each bogie there are three traction motors driving each shaft contain wheels. The conventional DC locos which evolved with the invention of the electric engines use DC series motors. The main transformer fetches AC power from the main power supply. The secondary of the transformer having an auto transformer winding which facilitates the variable voltage supply from the transformer. The secondary stage after the transformer is the reflector block where the sinusoidal supply gets converted to pulsed DC from the power by the bridges from circuited power converters. The power diodes convert the power from AC to DC. After the required Voltage is sent out from the transformer the converter phase is supported by filter network which smoothens the ripples of the DC rectified output. The rectified output is fed to the DC series motors. The DC motor rotates as per the given voltage.

2.1 Description of Locomotive General

1. Locomotives are designed to operate on 25KV AC. Single phase 50 Hz Over Head Lines. Locomotive is of Co-Co type. Consists of single body on two bogies, each having three driving axles.
2. Each bogie is equipped with three axles hung noise supported traction motors to drive the axle through pinion and gear and the body has driving caps at either ends. Inter connections between caps is provided by two corridor on either ends.
3. Current is collected from over head line by pantograph and is fed to an auto transformer through a high voltage circuit breaker is mounted on roof. The transformer steps down the 25KV to 1730V (2 x 865V). It is then converted to DC through two bridged connected Silicon rectifiers and is fed to traction motors.
4. Speed regulation is obtained by varying the voltage at the motor terminals by tap changer. Traction motors are permanently connected in parallel combination.
5. A locomotive is provided with rheostatic braking, besides vacuum and loco air brakes. Rheostatic braking can't be used in case of traction motor isolation and failure of any one of the rectifier.
6. The auxiliary machines are fed from ARNO converters, which convert the incoming AC single phase supply to three-phase at 380V. If one of the rectifier bridges becomes defective, the locomotive will work with other rectifier unit with half power.

2.2 Designation of Locos

Earlyrudimentary attempts of locomotives were the direct steam engines, direct internal combustion engine system, and the medieval version added to as steam electric system, internal combustion with electric drive, battery electric drive, have all been attempts in enhancing the technology and evolved at the stage of electrification of the track. Locomotives, except for older steam ones have classification codes that identify them. These codes are of the form (gauge, power, load and series). Indian railways engaged only two types of locomotives viz. WAG and WAP locomotives. Locomotives are classified as WAG and WAP depending upon gear ratios; it means more speed but low hauling capacity for passengers. Locomotives (WAP) and vice versa in case of goods locomotive (WAG), the max.speed of WAP type is about 110 kmph.

1. **WAG** stands for Wide gauge AC Goods.
   For example: WAG-1, WAG-2, WAG-4, WAG-5, WAG-7, WAG-9.
2. **WAP**stands for Wide gauge AC Passengers.
   For example: WAP-4, WAP-7.

III. Indian Class Wap-4 Electric Locomotive

WAP-4

WAP-4 belonging to Electric Loco Shed, Lallaguda hauling train number 22251

Power type	**Electric**
Gauge	5 ft 6 in (1,676 mm)
Top speed	Service: 140 km/h (87 mph) Test Runs: 180 km/h (112 mp
Power output	5,350 hp (3,989 kW)
Tractive effort	32000 kg/force
Career	Indian Railways
Number	Starting from 22069 to 22980

An example of WAP-4:

WAP-4 is a common electric locomotive used in India. It is capable of hauling 26 coaches at a speed of 140 km/h.

The locomotive was developed, after a previous class WAP-1 was found inadequate to haul the longer, heavier express trains(24-26 coaches) that were becoming the mainstay of the Indian Railways network. It was introduced in 1994, with a similar bodyshell to the WAP-1 class, but with Hitachi traction motors developing 5000 hp (5350 hp starting). Electricals are traditional DC loco type tap changers, driving 6 traction motors arranged in Co-Co fashion. This locomotive has proved to be highly successful, with over 800 units in service and more being produced. Newer examples have been fitted with Microprocessor Controlled diagnostics, Static Converter units (instead of arnos) and roof mounted Dynamic (Rheostatic) Brakes. The locomotive can be seen in service across the electrified network of Indian Railways and are homed at 13 sheds (depots).

Design:

The loco has a streamlined twin cab carbody design, with top-mounted headlamps. The first 150 or so units had the headlamp mounted at waist level, with the lights being mounted in a protruding nacelle. Later on the headlamps were placed in a recessed nacelle, and from road # 22579 onward, the headlamps were moved to the top. Newer locos also feature larger windshields, more spacious driver cabin with bucket type seats and ergonomic controls. The control panel also features a mix of digital and analog displays in newer units (all analog display in older versions).

The loco features higher power rated silicon rectifiers and indigenously-designed 5400kVA transformer coupled with Hitachi HS15250 traction motors. Starting power is 5,350 hp (3,990 kW), with 5,000 hp (3,700 kW) being supplied continuously.
Original units were weighed 120 tonnes, which was brought down to 112 tonnes through the usage of lighter material.
WAP-1, WAP-3 and WAP-6 units were rebuilt to WAP-4 specifications after replacing the bogies & electrical.

Performance:
It is used to haul the premier Rajdhani & Shatabdi expresses at 140 km/h. In trials, the locomotive has achieved a top speed of 169 km/h, though Indian Railways limits its top speed to 140 km/hr.

With a 24 coach passenger train, the acceleration time / distances are:
110 km/h - 338 seconds (6.8 km)
120 km/h - 455 seconds (10.5 km)
130 km/h - 741 seconds (20.5 km)
Starting Tractive Effort (Te) - 32000 kg/force

Technical Specifications of WAP-4	
Manufacturers	Chittaranjan Locomotive Works
Traction Motors	Hitachi HS15250
Power output	5000hp
Gear Ratio	23:58 (One loco, #22559, is said to have a 23:59 ratio.)
Transformer	5400 KVA, 32 taps
Two silicon rectifiers, (ratings?).	
Axle load	18.8 t
loco weight	113 t
Bogies	Co-Co Flexicoil Mark 1 cast bogies; primary and secondary wheel springs with bolsters
Pantographs	Two high speed Stone India (Calcutta) AM-92 and CCPL IR 03 H.
Current Ratings	1000 A for 10 min, 900 A continuous

VI. Conventional Bogie and Its Components

4.1Bogie:

What is a bogie?

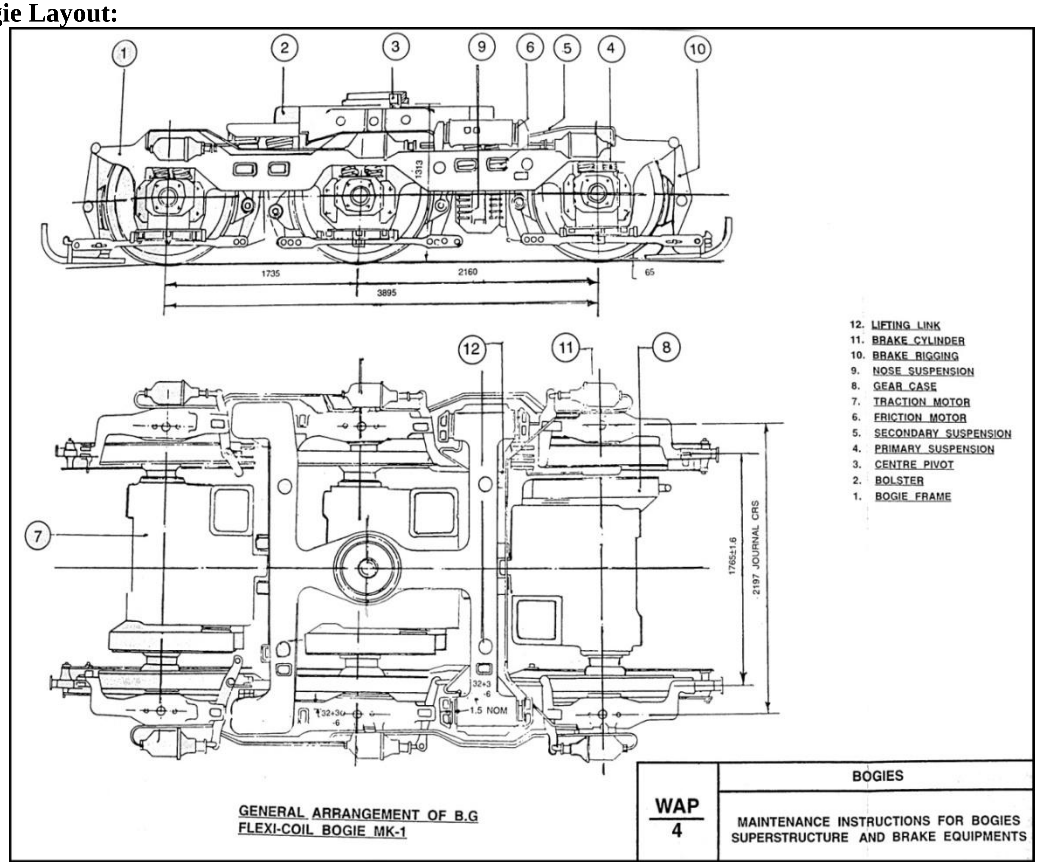
A **bogie** or **truck** is a wheeled wagon or trolley. In mechanics terms, a bogie is a chassis or framework carrying wheels, attached to a vehicle, thus serving as amodular subassembly of wheels and axles.

Conventional FLEXICOIL bogie, CO-CO Type of WAP-4 Locomotive.

Table showing types of Locomotive bogies:

S No.	Type of Bogie	Loco Type	Characteristics
1.	B - B	WAG-1 WAG-4	One traction motor in each bogie drives, two wheel sets in each bogie.
2.	BO - BO	WAG-2	Two traction motors in each bogie. Each motor drives individual wheel sets.
3.	CO – CO	WAM-4 WAP-4 WAG-5 WAG-7	3 traction motors drives 3 wheel sets, each motor drives individual wheel sets.
4.	CO – CO Tri mount		3 traction motors drives 3 wheel sets, each motor drives individual wheel sets and loco body rests on CO - CO bogie at 3 places, each displaced triangularly. Centre leading point shares 60% body weight while rest 2 points at High Dynamic Load share 20% body weight each i.e. (20% + 20% = 40% of weight)
5.	CO - CO Flexicoil bogies	WAP-4 WAP-7 WAG-9	Each bogie is having double suspension system namely primary and secondary suspension.

4.2 Bogie Layout:



Components of Bogie

1. Bogie Frame	7. Traction Motor
2. Bolster	8. Gear Case
3. Centre Pivot	9. Nose Suspension
4. Primary Suspension	10. Brake Rigging
5. Secondary Suspension	11. Brake Cylinder
6. Friction Motor	12. Lifting Link

4.3 Design Considerations and description of Bogie:
4.3.1 General Description:

Bogie Frame and Bolster:

The bogie frame and bogie bolster of "FLEXICOIL" bogie Mark-I are of steel casting box type construction manufactures as per the standard laid down by RDSO.

The Locomotive body weight is transferred to the bolster through a centre pivot. The steel – cast "H" type bolster is supported on the steel - cast bogie frame at four corners, by pair of helical springs placed in spring pockets of main longitudinal member of the bogie frame. The bolster is located w.r.t bogie frame by upright pedestals which are integral part of the bogie frame. This arrangement serves to transmit force from bolster to bogie frame and vice-versa. Spring loaded sunbeam piston 2 nos. per bogie made of phenolic material to have high friction between bolster and bogie frame for damping in both vertical and lateral modes of oscillation are also provided in the above pedestal arrangement. Lateral stop are also provided on the bolster as well as on the bogie frame to limit the side movement by flexible action of the spring which is of the order of 32 mm. The bogie frame is in turn supported on the axles by another set of springs resting on the axle boxes .The load of the locomotive superstructure rest on the centre pivot bowl of the bogies. The bowl is fitted with vertical and horizontal liners made of fluon (Vx2) which provides rotational freedom between body and bogie in operation. Two lifting links located diagonally opposite provides the easier accessibility as well as reduce the number of mechanisms to engage or disengage the bogie when installing or removing.

Bogie Frame

Bolster of WAP 4 Locos

4.3.3 Suspension:

This flexicoil bogie Mark-I has two stages of vertical suspension in which helical spring have been used at primary and secondary stages. Primary, between axle box and bogie frame and secondary, between bogie frame and bolster. The transverse flexibility between the body and the bogie has been achieved by the flexicoil action of the helical spring at the secondary stage. The support of the bolster springs have been placed on the wider arm to give better stability in rolling.

A and B are Primary and Secondary suspension systems respectively.

4.3.4 Traction Motor:

The bogies are fitted with HITACHI HS-15250A type Axle-hung, nose-suspended traction motors with the help of suspension tubes with taper roller bearing inside. All the axles are power-driven. The traction motors working on pulsating current are air cooled by external blowers.

4.3.5 Gear Case:

It is a housing which covers the main bull gear and pinion of the traction motorand protects them from foreign material like dust, stones, water etc. It also holds lubricating oil for the relative motion between the bull gear and the pinion.

4.3.6 Nose Suspension Drive:

The nose-suspension drive is the drive mechanism for electric railcars, in which approximately half of the weight of the traction motor is supported by the wheel axle through the suspension limit, and the rest by the bogie frame through the "nose" on the motor frame. The suspension limit does not allow any relative movements between the wheel axle and the motor axle (except for a very limited allowance), which makes it possible to directly connect the two axles by a gearbox.

4.3.7 Brake Rigging:

The means of distributing the braking forces from a brake cylinder to the various wheels on the vehicle. It consists of rods and levers suspended from the underframe and bogies and linked with pins and bushes. Rigging requires careful setting up and regular adjustment to ensure forces are evenly distributed to all wheels. Badly set up rigging will cause wheel flats or inadequate brake force.

4.3.8 Brake Cylinder:

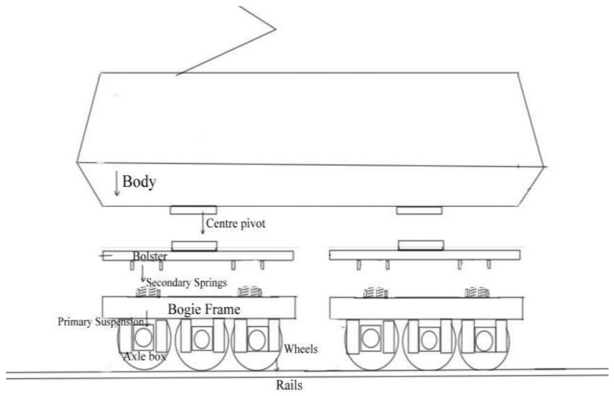
Six (203 dia. x 203 stroke) brake cylinder per bogie are used to operate clasp type brake rigging. Each cylinder piston is connected to the brake lever to actuate the brake on one
wheel only. The brake shoe adjustment in service is done by actuating adjusting rod at the bottom. Brake blocks and shoe are of conventional type.

'A' shows brake cylinder.

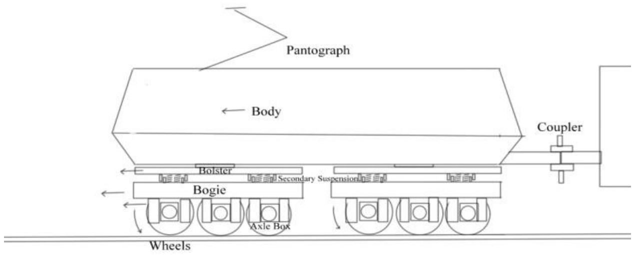
4.3.9 WheelSet:

A wheelset is the wheel-axle assembly along with bull gear.

4.4 Weight transfer to wheel axle to provide axle load to improve Adhesion:
WAP-4 Loco:
Locobody rests at centre pivot of bolster; bolster is resting on secondary springs at 4 places. Secondary springs are seated on bogie frame. Bogie frame is resting on primary suspension springs. These primary suspension springs are seated on axle box i.e., axle to wheel weight is transferred to provide axle load to have adhesion.

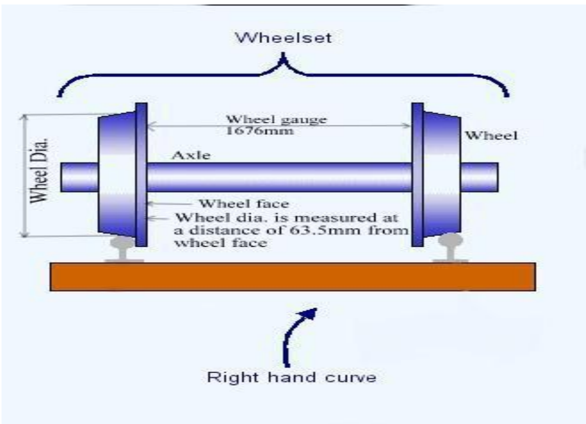


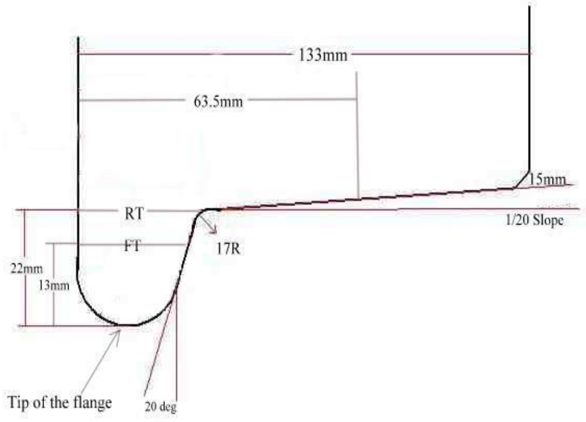
4.5 Mechanical Power Transfer:



1. When traction motor is rotating with input electrical DC power, mechanical power output comes to its pinion.
2. Pinion is engaged with bull gear of axle. When bull gear is rotating, its axle rotates.
3. When axle is rotating wheel rotates, with axle box on the axle. The rotational forces are converted to linear forces due to friction between rail and wheel.
4. These linear forces are shifted to bogie through bogie pedestal at both sides of axle box.
5. From bogie frame to bolster through pedestal at friction damper housing.
6. Now forces are shifted to bolster and from bolster to centre pivot; then centre pivot to loco body.
7. From loco body to centre buffer coupler, haul one train/formation.

4.6 Wheel Profile:





4.6.1 Wheel Profile Table

	New	Condemn	Wear
Root Thickness (RT)	37.5mm	31.5mm	6mm
Flange Thickness (FT)	32mm	29mm	3mm
Tread Wear (TW)	-	6.5mm max.	-
Wheel Dia.	1097mm	1016mm	81mm
Wheel Gauge	1676mm	-	-

NOTE:

1. Root thickness is measured at a height of 22mm from the tip of the flange.
2. Flange thickness is measured at a height of 13mm from the tip of the flange.

V. Suspension System

5.1Suspension:

Suspension is the term given to the system of springs, shock absorbers and linkagesthat connects a vehicle to its wheels and allows relative motion between the two. Suspension systems serve a dual purpose — contributing to the vehicle's roadholding/handling and braking for good active safety and driving pleasure, and keeping vehicle occupants comfortable and reasonably well isolated from road noise, bumps, and vibrations,etc.

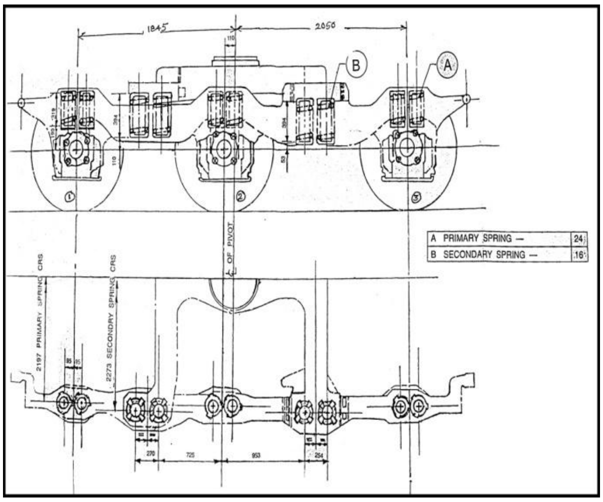
5.2 Suspension in Conventional bogie:

The suspension used in Conventional bogie is **Spring Suspension.**

There are two types of suspension systems used in this conventional type bogie, they are:

1. Primary Suspension
2. Secondary Suspension

The bogie is designed for two stages of suspension to give **flexicoil** action. Various combinations of helical springs are used in **secondary suspension** between bolster and bogie frame and **primary suspension** between axle box and bogie frame.



PRIMARY AND SECONDARY SUSPENSION LAYOUT

5.3 Characteristics of spring suspension:

5.3.1 Principle of a spring:

In distinction to a rigid beam, a spring, regardless of its form or shape, will exert a changing force as it deflects its hornblock. This relationship is linear, with maximum force being applied when the spring is fully compressed (to take the example of a compression spring), and zero force being applied when the spring is in its fully relaxed state – this principle is shown in figure 7. The actual deflection of the spring is directly proportional to a property, the 'springrate' (or 'spring constant') of the particular spring. If a spring relaxes to depress a wheel onto the rail, the reduction in the force applied to the hornblock will be counterbalanced by a distributed increase in the force the loco applies to its other suspension points. Springs absorb and discharge potential energy, and decouple the vertical forces between the wheels and the body.

Thus in a sprung loco traversing uneven track, there is a continuously changing set of forces applying between the wheel tyre and the rail, although the sum of those forces at the railhead is constant. The action of a spring in a prototype loco is related to the weight borne by the particular axle involved, and on the prototype each spring is designed to bear and operate on a specific load. If the spring is too strong, the weight of the loco will not cause it to operate properly over irregularities in the track, while if the spring is too weak the loco is likely to show dynamic instability.

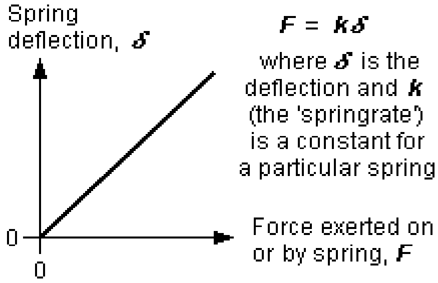


Fig 7 Force v deflection for a spring

5.3.2 Viability of springs in small-scale models:

A prototype loco is suspended, being held up by the strength of the springs. It is generally accepted as being difficult to reproduce the characteristics of prototype springs in small-scale models because:

1. the mass to momentum relationships in the prototype do not scale linearly to models;
2. with the exception of the use of commercial music wire strings as beam springs, it can be difficult to provide the range of model springs appropriate for all the different weights of model locomotives;
3. it can be difficult to adjust the springs so that the loco is both level and at the correct buffer height;
4. it is difficult to assess what the design value of the deflection of a spring should be;
5. Model rail does not deflect under the weight of a model loco like prototype rail does.

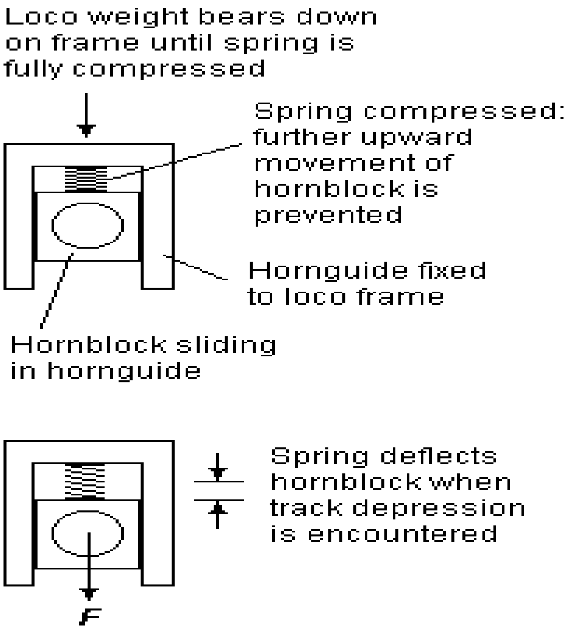


Fig 8 Spring-assisted hornblock (coil)

5.3.3 Spring-assisted hornblocks:

A spring-assisted hornblock is one traditionally containing a coil spring between a hornblock and its hornguide. Under the weight of the loco, the spring compresses either fully (to bind the coils together) or until the hornblock is restrained from further upward movement by some limiter device fitted to the hornguide or the frames of the loco – see **figure 8**. The spring in such a hornblock therefore depresses its axle into depressions of the track, and the deflection is in proportion to the springrate of the particular spring. The downward force of the spring will diminish the greater the depression of the track (see **figure 9**).

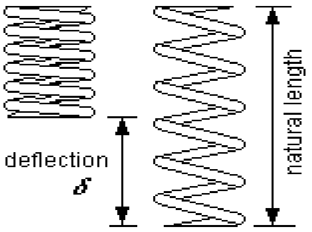


Fig 9 Coil spring deflection

Spring-assisted hornblocks do not provide the equalizing advantages of beams, nor (when in their fully compressed state) the shock-absorbing advantage of properly suspended springs – any upward projection of the track will transmit itself directly and abruptly to a loco chassis fitted with spring-assisted hornblocks. Moreover, if the spring rating is not chosen to match the weight being supported, a loco fitted with spring-assisted hornblocks may show non-optimal haulage, depending on the state of the track.

Note: The above does not imply that all coilspring hornblocks operate in a 'spring-assisted' fashion as described above.

A cantilever leaf spring can also be used to act in a spring-assisted fashion – see **fig 10**.

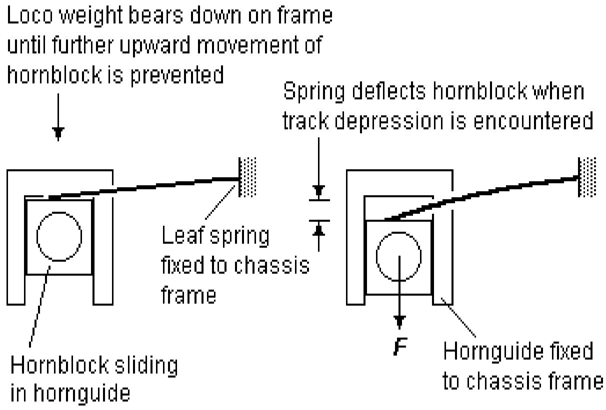
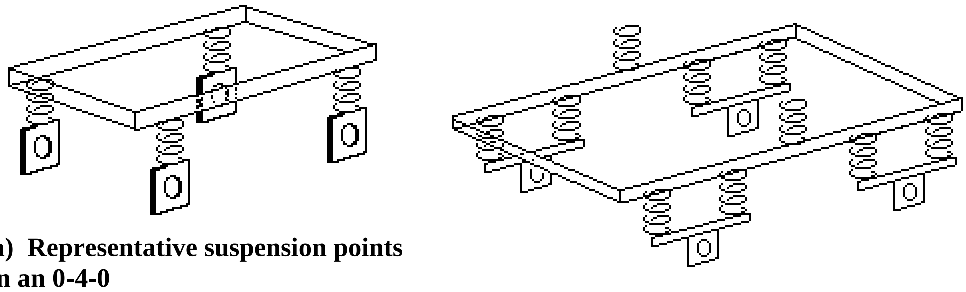


Fig 10 Spring-assisted hornblock (leaf)



(a) Representative suspension points on an 0-4-0

(b) Representative suspension points of a modern prototype bogie

Fig 11 Springing allows multiple suspension points

5.3.4 Suspension points:

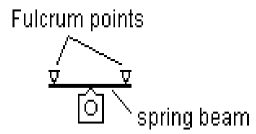
In contrast with rigid beam suspension, there is no limit to the number of primary suspension points allowed for springs. A 0-4-0 has four suspension points (seefigure 11(a)), an 0-6-0 or Co bogie has six, an 0-6-2 has eight, and so on. This principle applies to more complicated cases where more than one 'layer' of springing might be involved, andfigure 11(b) gives a representation of a prototype example of an EMU/DMU having two main suspension points between each bogie and the body, and two suspension points for each wheel to the bogie frames: in such more complicated cases, the notion of what constitutes the difference between 'primary' and 'secondary' suspension points becomes somewhat academic.

5.3.5 Spring beam configurations:

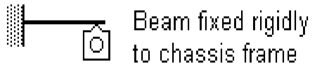
The deflection of a spring beam varies considerably depending on how it is supported. A common form of support and one that lends itself to being able to control the datum height of the hornblock when under deflection, is where the hornblock spring is restrained loosely against two fulcrum points – see **figure 12(a)**. The beam can slide along and rotate freely around these 'simple' supports, according to the force being applied to the beam. The cantilever spring (see **figure 12(b)**) is one where the spring is fixed rigidly at one end only. This spring configuration is probably the most difficult to control in terms of being able to set the datum deflection height of the hornblock accurately, but has the virtue of being easily adjustable.

Multiple hornblocks can be supported by using multiple instances of **figure12(a)**, or by using a continuous single spring beam held against multiple fulcrum points – in **figure 12(c)** for example, depending on the strength of the spring beam, a significant degree of equalization will be imposed between adjacent hornblocks. Full equalization is given where a single spring beam bearing onto two hornblocks is allowed to pivot about a point (typically the midpoint) along its length. See **figure 12(d)**. The degree of equalization given by the beam will depend on its strength; if it is too weak, it will not act sufficiently to rotate itself about the pivot, and if it is too strong, it will become in effect a rigid beam.

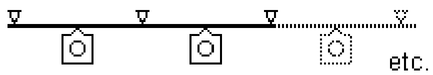
The behavior of all of the above examples of spring configuration will be significantly different from each other, and slight variations in the cross-sectional area of the spring material and distances between fulcrum points will produce very different deflection values.



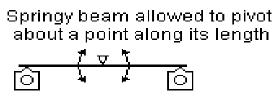
(a) Spring beam between two simple supports



(b) Cantilever beam



(c) Multiple span ('continuous') spring beam



(d) Equalizing spring beam

Fig 12. Spring beam configurations

VI. Conclusion

We have understood the various functions of a bogie of conventional locomotive (WAP-4) and made a detailed study of the suspension system, which involves both primary and secondary suspension systems.

We also studied how spring testing is made and segregation of the springs based upon their load bearing capacities (within tolerance limits). Also, we’ve understood the failures that have been occurring under various circumstances during operation and their solutions have been explained in a detailed manner. We have understood the operating principle of the present day locomotive using traction motors majorly 3-phase induction motors and have drawn a study of bogies and suspension system.

Railway organization is one of the most developed means of transportation in India. It helps the national production, social and industrial development including economics stations of the country. In view of the several advantages over the road transport, the railways got priority of development over highways. Since the introduction of railways in 19th century, India has made considerable progress in developing railway industry as a large scale undertaking.
Indian railways are now heading towards modernization of traction, automoval in operations and in tradition of recently introduced technique to meet the requirements of high speed and heavy passengers and goods traffic.
Indian Railways is the best system in the world next to USSR.

VII. Bibliography

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