9 Locomotive Compensation

Introduction

Traditionally, model locomotives have been built with a rigid chassis. Some builders looking for more realism have added horn blocks and spring suspension, while others have tried to improve running using compensation beams. Springing and compensation add complications to the model which in some cases have improved running, but in others have produced less than satisfactory results. In this section we will examine compensation systems and some of the design features that influence their effectiveness. Initially we will summarize the three main options and their good and bad points.

The three options generally used are the rigid, sprung and compensated chassis. First though, let us look at what the chassis has to do. The main requirements of the chassis are to:

- Keep the wheels in contact with the track for good electrical contact
- Distribute the weight correctly so that there is sufficient weight on the drivers for good adhesion
- Provide stability on curves and uneven track
- Stop wheels from touching other parts of the body and chassis to prevent electrical shorts.

9.1 Rigid chassis

The rigid chassis often works better than it might appear. Even a rigid chassis will flex slightly, and the flanges are usually deep enough to prevent it derailing on track of reasonable quality. As there is a fixed wheel in each corner of most locomotives, it is fairly stable, and by adding a little weight, there is usually enough contact for electrical purposes. Another advantage is that because the wheels are fixed, they are less likely to touch other parts of the locomotive and cause electrical shorts. Where this chassis frequently fails is on weight distribution. This is not a problem with a 0-6-0, but it could be critical with a single driver locomotive. This type of chassis does not allow all the wheels to stay in contact with the track, especially on rough track.

9.2 Sprung chassis

The sprung chassis does have the advantage that it is better able to keep all the wheels on the track at all times. It should be almost as stable as the rigid chassis. The biggest problem with this chassis is that it is very difficult to select springs of the correct strength and to adjust the tension correctly. Full size locomotives spend many hours on the weighbridge before they are able to perform satisfactorily. As a consequence, weight distribution can be very uneven, leading to poor haulage. Because this system relies on horn blocks, there will be more moving parts to wear, and wheels tend to move fore and aft as well as up and down, requiring more care with clearances.

9.3 Compensated chassis

The compensated chassis is excellent at keeping all the wheels on the track all the time. Weight distribution can be designed on the drawing board by adjusting the beam lengths and pivot points. The number of moving parts can be kept to a minimum by mounting bearings directly into the beams, and as long as beams are made of relatively thin material, they will flex sufficiently to ensure that the bearings stay in alignment. The only movement for which clearance must be provided is the up and down. If the standards of track laying are up to scratch, this can be kept to a minimum, and no more than 0.5 mm each way is required in practice. The whole purpose of compensation is to mount the chassis on three points like a three legged stool. This is very stable when the locomotive is standing still, but things can change dramatically when the locomotive is travelling at speed. It is very important to take this into account when designing the chassis. This point is the one that is often overlooked completely and can cause the downfall of the compensated chassis.

To examine this in more detail, it is easiest to consider several examples. Once the principles are understood, they can be applied to most of the wheel arrangements that the modeller is likely to encounter.

9.3.1 The 4-4-0

With this wheel arrangement, how often have we seen the back axle fixed and a bar resting on the front driving axle? It is a true three point suspension, but the three points are very close to the back of the locomotive. To prevent the locomotive from falling over, the centre of gravity must sit within the triangle shown in Fig. 9-1, and ideally in the middle of the triangle as this will mean that all the four wheels are carrying the same weight. That is going to be very difficult with this locomotive. All the space behind the centre of the triangle is very likely to be taken up with the open footplate and the motor/gearbox unit in the back of the firebox. The smoke box is a long way forward of the triangle and is working against us. If the centre of gravity is too close to the front driving wheels, not only will there be little weight on the rear, powered, wheels, but it will be asking the front driving axle to prevent the locomotive rolling sideways on the curves. As the locomotive is resting on the middle of the front axle, that is not going to help in this. On a curve, the rear inside wheel will lift off the track and the front outside wheel will drop until it comes to the end of its travel.

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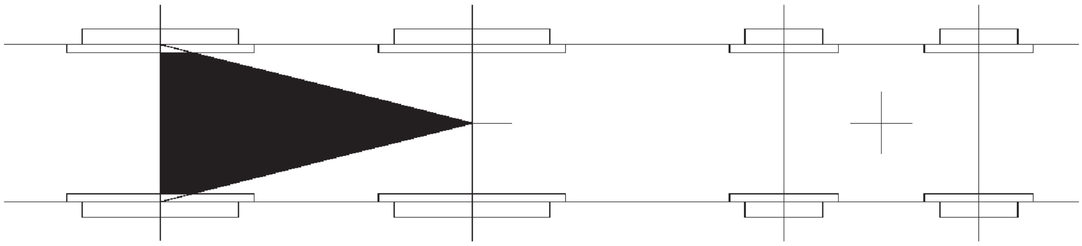

Figure 9-1 4-4-0 chassis with fixed gear driving axle and rocking front driving axle

A better solution is to rest the front of the locomotive on the bogie and to install a beam on each side, pivoted in the middle, between the driving wheels. In this solution, the triangle (see Fig. 9-2) is much larger and the locomotive is more stable. The weight acting on the compensation beams is evenly distributed between the four driving wheels, which is much better for pulling trains. As some weight is needed on the bogie, the ideal centre of gravity is very close to the front driving axle enabling more useful weight into the locomotive which will improve adhesion.

9.3.2 The 4-2-2: beams pivoted away from the middle

It is sometimes a good idea to pivot beams at a point other than in the middle of the beams. This time let us consider a 4-2-2 single. At first sight, this locomotive is very similar to the 4-4-0. The front of the locomotive could rest on the bogie, and the rest of the weight would be on two compensation beams, one each side between the driver and the trailing wheel. In the case of the 4-4-0 these are arranged so that there is same amount of weight on each of the two rear axles. As the rear axle in the 4-2-2 is only a trailing axle, it would be better to transfer some of the weight on that axle to the driving wheel. We can do this by moving the pivot point forward away from the centre of the beam. For example, if we move the pivot point forward so that the ratio of distances of the pivot to the driving axle, and the pivot to the trailing axle, is 1 to 2, the driving wheel will carry twice the amount of weight that the rear trailing wheel carries (Fig. 9-3). The triangle becomes a little smaller but it does move forward and does not affect stability on curves. Also, the ideal centre of gravity moves forward which makes it much easier to get even more weight in the locomotive, and hence on the driving axle.

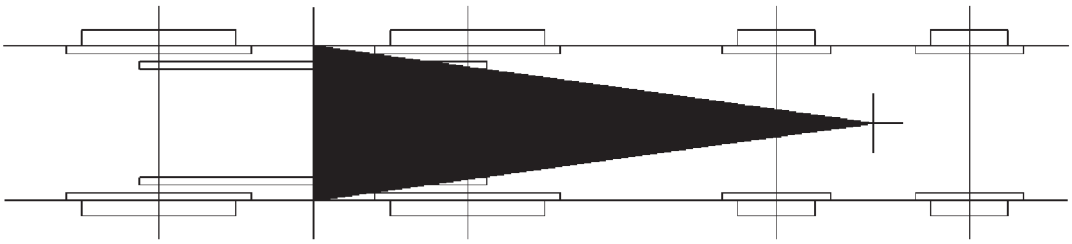

Figure 9-2: 4-4-0 chassis with beam compensation on the driving axles

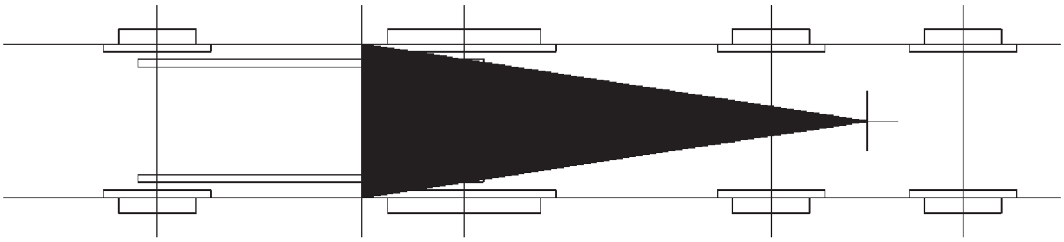

Figure 9-3: 4-2-2 chassis with unequal beam conspensation on the driving axles

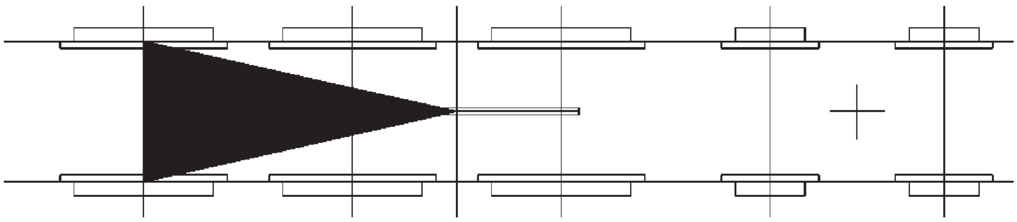

Figure 9-4: 4-6-0 chassis with rigid rear driving axle and single beam compensation to the first and centre axles

9.3.3 The 4-6-0

When compensating a 4-6-0, it is common to fix the back axle and rest the compensation beam on the middle of the centre and front drivers. This is not a very elegant solution. If we look at the triangle again (Fig. 9-4), we see that although the triangle is quite long compared to the 4-4-0, it is too near the back of the locomotive and affects stability on curves. This arrangement also makes inside working valve gear difficult if it is desired to include this.

Here we can look at three possible solutions and their advantages and disadvantages.

1. Move the triangle forward

One solution is to allow the front axle to rock, and place a beam either side between the rear and centre driving wheels (Fig. 9-5). The triangle is about the same size as before, but because it is moved forward, the locomotive will be more stable. The ideal centre of gravity is also moved forward, enabling us to add more useful weight to the locomotive, which improves the adhesion.

2. Four point suspension

This may be seen as a controversial solution, but has been included for you to make your own assessment and to make this section complete.

Four point suspension is achieved by fixing the front axle and placing a compensation beam either side between the centre and rear driving axles (Fig. 9-6). Clearly, this system sits the locomotive on four points instead of three, but it does have some merits. The advantages are that there is plenty of stability and the ideal centre of gravity is near the

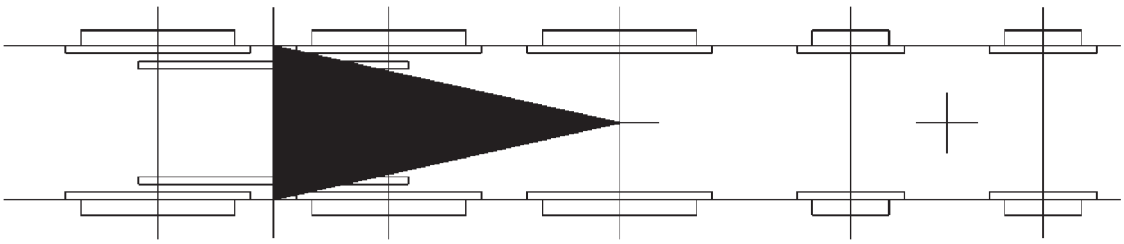

Figure 9-5: 4-6-0 chassis with beam compensation to the centre and rear axles, and rocking front axle

Figure 9-6: 4-6-0 chassis with 4-point suspension: beam compensation to the centre and rear axles, and rigid front axle

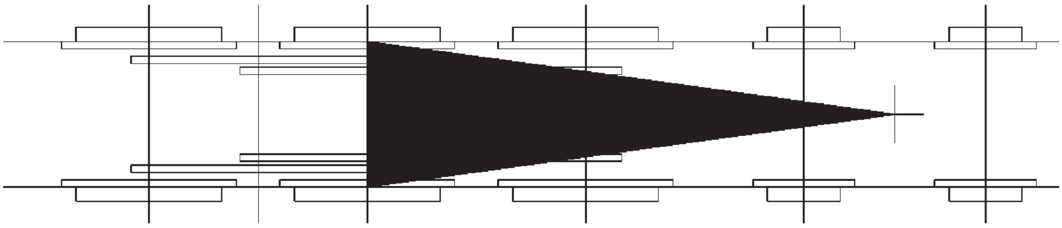

Figure 9-7: 4-6-0 chassis with equal weight distribution on all driving axles

centre driving axle, but it could be moved a little forward without affecting the stability on curves. This means there is plenty of room for adhesive weight. The disadvantage is that, because it is not a three point suspension system, it does not guarantee that all six drivers will be on the track all the time. It will, however, be able to compensate for rise and fall in the track.

3. The 'Rolls-Royce' solution
The 4-4-0 locomotive example demonstrated the advantage of sitting the front of the locomotive on the bogie. The 4-6-0 can also benefit from this idea but the beams become more complicated. A beam between the front two driving axles is still required, but this time the beam is pivoted on a second beam which is itself pivoted on the frame midway between the centre and rear axles, and bearing on them (Fig. 9-7). By moving the pivot point of the first beams forward at the ratio of 1 to 2, this will ensure that the same weight rests on all of the driving wheels. The triangle is now quite long and moved towards the front, giving excellent stability on curves. The ideal centre of gravity is also a long way forward giving added benefits for hauling heavy trains. The only slight complication with this system is that the beam bearing on the front driving axle needs to be pivoted above the centre axle, and so will have to be curved.

9.4 The motor/gearbox unit
Loco builders are often reluctant to mount a motor/gearbox unit on a moving axle, but in practice this only means that a little more clearance is required around the motor. It is, however, very important to allow the motor/gearbox unit to float, whether the axle is fixed in the chassis or not. It is very difficult to keep the two chassis bearings and the two gearbox bearings in perfect alignment when fixing the gearbox rigidly in the chassis, especially when the chassis flexes. Any alignment errors will effectively pinch the axle causing drag and premature failure of the gearbox. Most modern motor/gearbox units are small enough to permit a compensation beam to be fitted between them and the frame. A restraint is required that allows the gearbox to rock and move with the driving axle, but prevents it rotating about the axle, because in doing so, it will almost certainly strike some other part of the chassis or body and cause damage. The ideal restraining system will vary depending on the unit you are using but a type of fork in the middle of the chassis hooked onto the gearbox is one solution shown in Fig. 9-8.

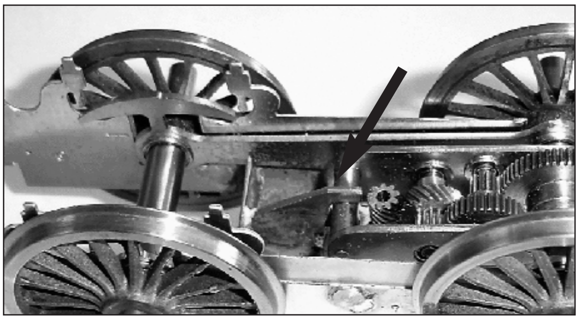

Figure 9-8. Compensated chassis fitted with motor/gearbox unit. The arrow highlights the fork preventing the motor/gearbox rotating about the driving axle

9.5 The maths of compensation
So far we have looked at enough examples and ideas for most people. If we want to take things a little further, we can calculate the weight we need, where it should be applied, and how it affects the length of beams. To show what can be done with some maths, as an example we will consider a 2-2-2 single with a wheel base of 70 + 70mm. The first thing to decide is what train the locomotive must pull. This can be worked out by measuring the force needed to pull the intended train along, or referring to Part 3, Section 1, or using one of the many formulae that have been published over the years. In order to come up with a number for this example, a simple and useful formula (which can be modified to suit your own requirements) is:

Tractive effort of the model in grams = Tractive effort of the full size loco in lbs divided by 100

Thus, if the prototype has a tractive effort of 11,000lb, the model should have a tractive effort of 110g.

Because the coefficient of friction for steel wheels on nickel silver track is about 5, we need 5 times this weight on the driving wheel, which is 550g. The leading and trailing wheels must also carry some weight to keep them on the track and to steady the locomotive. Experience has shown that this must be about 150g. From this we can see that the total weight of the locomotive is:

150g + 550g + 150g = 850g

If the compensation beam is to be between the middle and rear axle, and these wheels are 70mm apart, the beam obviously has to be 70mm long. Because we want 550g on the driving wheel and 150g on the trailing wheel, the pivot needs to be moved forward to the ratio of 150:550. That means the pivot must be 15mm behind the driving axle and 55mm in front of the rear axle.

To ensure that the front axle carries 150g, the centre of gravity of the finished locomotive must be in the correct place. This position can calculate in the same way. The distance between the pivot point of the compensation beam and front axle is 85mm (70mm + 15mm). If 150g sits on the front axle and 700g (550+150) on the compensation pivot, we can proportion the centre of gravity in the ratio of 150:850 from the pivot point. The centre of gravity should therefore be 15mm in front of the pivot and 70mm behind the front axle. As the locomotive in this example is symmetrical, it comes as no surprise that the calculated centre of gravity is over the middle axle.

9.6 Compensating the tender

Not everyone compensates the tender because it is not really a part of the locomotive, but rather a piece of rolling stock that always accompanies the locomotive. The only exceptions are when the tender is motorised or used to collect electrical current. There are a number of advantages to compensating the tender but we will look at some of the ways it can be done.

A common method of compensation is to fix the back axle and rest a beam on the middle of the middle and front axles. This system has a number of disadvantages. The first is that it requires some form of horn block, which means more moving parts, wear, and the problem of wheels moving into brake blocks. The second is that the bearings do not support any of the weight as it is all taken on the beam rubbing on the axle, with all the additional friction that this causes. The biggest disadvantage, however, is one of stability. There is a heavy locomotive in front of the tender, and loco and tender may well be coupled together by some form of bar. If the locomotive should become derailed, it is possible that the locomotive will sit on the coupling bar. If the pivot is too far forward, the weight of the locomotive will cause the tender to tip up, and the tender top may well do damage as it hits the top of the cab. Moving the pivot forward will make the tender more stable. This will reduce the amount of weight carried on the middle axle, but it will not adversely affect running.

It is also possible to mount the bearings in the beams fitted each side. This gives a four point suspension, or alternatively the rear axle can be allowed to rock, giving a three point suspension. With few exceptions, tenders were built with outside frames, in which case it is possible to fit the beams between the wheels and the outside frames, as shown in Fig. 9-9. This may mean that the pivot has to be some way above the axles but experience suggests that this is not a problem. The advantage of mounting the beams on the outside of the wheels is that it is much easier to take the wheels out for painting, and much smaller bearings can be used, which will reduce the drag.

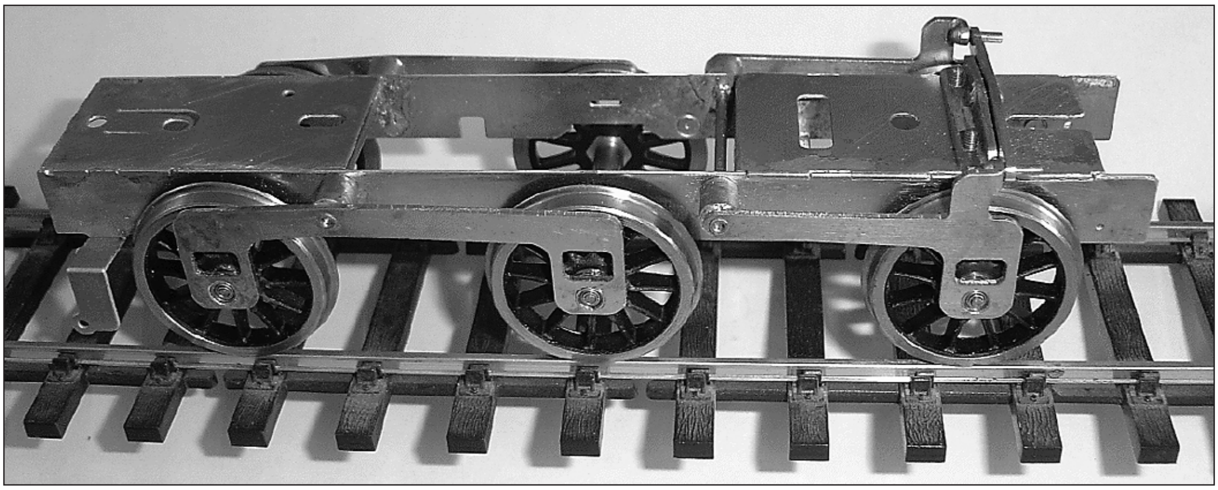

Figure 9-9. Tender chassis with compensation beams mounted outside the wheels

9.7 Some examples

Figure 9-10 shows a compensation beam fitted with ball races. The beam includes a dummy leaf spring and a cut-out to avoid the brake gear. The beam pivots on the hole in the middle indicated by the arrow.

Figure 9-11 shows two examples of bogie beams pivoted on a stub axle in the middle of the bolster. This assembly is then screwed to the cosmetic frames. Note the two rivet heads indicated by arrows that the loco chassis rests on. The weight of the locomotive prevents the bogie frame from rocking fore and aft, but allows the bogie to rock from side to side.

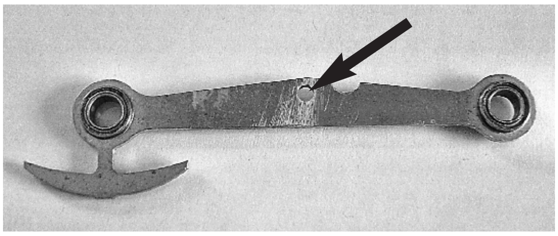

Figure 9-10. Compensation beam fitted with ball races

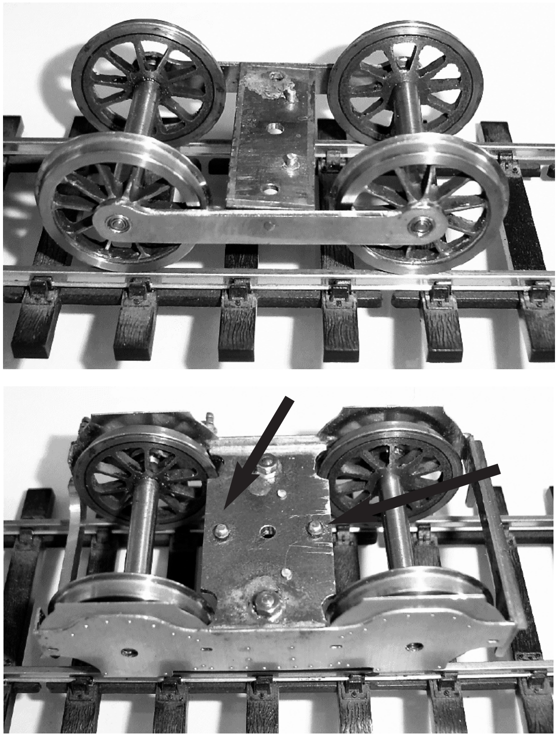

Figure 9-11. Bogie beams pivoted on a stub axle.