Masters-2001

Build a Baldwin 8-16-D 2-6-0

A Locomotive Adventure
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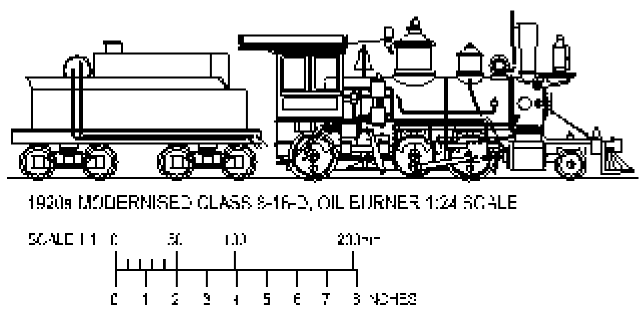
Color Photography by the Author

Chapter 3 - Chassis Detailing

Background - Construction - Detail



Ah and you thought it was going to be easy!! Perseverance, Courage and Dexterity...

Welcome back. The work we're about to do in this chapter is about the most difficult you'll encounter in this whole project. The work is fiddly, awkward and if not done carefully and properly will have consequences on the performance of the locomotive. Along the way you'll probably see easier ways to get to a certain goal. You may even want to back down and leave out a lot of the detail. That's OK if you want to do that, but your model will not be correctly detailed for a NG mogul. The background part of this chapter will reveal the development of the technology ultimately used on an 1870s Mogul and 4-4-0. Every detail we put on this chassis had a purpose on the prototype.

Once again this Chapter is divided in three parts:

Background:
This week we investigate the origins of the American 4-4-0, 3 point equalized suspension and Baldwin's adaptation of that concept into a 2-6-0 in 1860. We also look at the basics of the Stephenson Valve Motion as used on the 1870s 8-16-D and early brake systems. Now some of you will say, why waste my time writing all this; concentrate on the real issue of building the 2-6-0. Fair enough, but a model is more than plastic, wheels and lumps and bumps with funny names. There is a story behind every piece you model and these stories are not only totally cool, but give you a real understanding of what the detail means in the bigger picture of locomotive history. To me, building a model is an adventure into the history and workings of the prototype. I wish to demonstrate this as you as you build the model. Every bit of Bull I deliver in the 'background' section in some small way adds meaning to our little friend, the 8-16-D 2-6-0.

Construction:
This week we complete the modifications to the Aristo C-16 Chassis and turn it into a typical 1870s 2-6-0 complete with 3-point, equalized suspension detail. Our model will not have any actual working suspension, but we will detail the chassis to indicate the suspension system. We'll modify the side rods and install the pilot. We will complete the chassis work in this chapter.

Detail:
For the brave at heart, we'll add some minor details to the chassis. Up to you if you wish to carry out this additional work. The detail work carried out under 'Construction' (above) is not optional!!

Background

On the Trail of the American 4-4-0
The Quest for Locomotive Perfection

The American 4-4-0

Sometimes a story cannot be told in simple terms. The story of the American 4-4-0 is about the melding of many engineers' work. Each doing their part to make the next guy think about what 'could be'. Read the history books and you'll learn that American Engineer Henry R. Campbell invented the 4-4-0 in 1836. Nothing is that simple and there is a lot more behind the American 4-4-0 than just a wheel arrangement. I hope to put some clarity into this story, because, put simply, the 4-4-0 was locomotive perfection attained through evolution.

The strength of the 4-4-0 lies in its unique chassis design. Today we often hear the terms to describe the suspension system on the 4-4-0, terms like 'Fully Equalized' and '3 point suspension'. I fear these words have lost their meaning though the humdrum of model train product review and magazine enthusiasm. The Bachmann 1:20.3 4-4-0 is typical example. This model is without doubt the finest representation of the famous American yet. When it hit the hobby shop shelves, the reviewers pounced on its detail and accuracy and terms like Equalized suspension and 3 point suspension were used freely to accentuate the quality of the model. When the Bachmann 2-6-0 came out, same thing. Not one month ago I read a 2-6-0 review which stated "The 2-6-0...also retains the 4-4-0's prototypical suspension: the locomotive and tender are fully sprung and equalized". Lets get it right!! Neither the Bachmann 4-4-0 nor 2-6-0 have the prototypical 4-4-0 suspension system, and while some wheels are sprung, they certainly are not equalized. This sort of enthusiastic review only clouds the issue and encourages confusion. It does make me wonder, what would the model have been like if Bachmann had indeed built it to include the real prototypical 3 point equalized suspension system? What a model it would have been!!

The Fathers of the 4-4-0

As mentioned, Henry Campbell had a place in the design of the 4-4-0, but we have to go back to a time earlier than 1836, and back to Mother England to uncover it's beginnings.

The fathers of the American 4-4-0 were:

- Robert Stephenson (UK 1803 - 1859)
- Edward Bury (UK 1794 - 1858)
- Isaac Dripps (US 1810 - 1892)
- John B. Jervis (US 1795 - 1885)
- William Norris (US 1802 - 1867)
- Henry R. Campbell (US 1810 - 1870)
- Joseph Harrison (US, Not sure of dates)

These fellows all contributed to the 'whole', taking the loco from bare bones in 1829 to a reliable mass produced machine in 1845.

In the Beginning....

There was the 'Rocket', winner of the Rainhill trials, Liverpool and Manchester Railway, 1829. Designed by Robert Stephenson, son of George Stephenson. It seems remote but the 4-4-0 concept began here. There were lots of features on the 'Rocket' that would become standard to all locomotives that followed, but specifically the 4-4-0 heritage begins with Robert Stephenson's 'Bar frame' chassis design, used on the 'Rocket' for the first time and the pimple like steam dome found near the stack on the 'Rocket'.

The simple Bar Frame employed on the 'Rocket' in 1829.
London Science Museum, UK.

The Bar Frame is exactly as the name implies, a frame made from bars of iron, rather than iron plates. Prior to 1829 locomotives were often so heavy their weight would break the cast iron rails. Engineers had worked to resolve the problem...the aim was to find a balance between, locomotive weight and power. A locomotive chassis had to be strong. Engineers had traditionally used plates of iron riveted together like a plate iron bridge to form the chassis. Prior to that the chassis construction was a sandwich system of plate iron and oak beams. These early chassis' were strong, but very heavy. Robert Stephenson reduced the weight of his locomotive, by building the chassis out of straps of iron or bars, that were linked together in the from of a simple box truss. Iron was used only in the directions of the force lines. The rest was just air. The bar frame rigidity was enhanced by the pressurized locomotive boiler, the whole mass became a rigid unit. The bar frame concept would become standard to locomotive design in the US and mainland Europe, but never won acceptance in the UK.

The Rocket also featured an early 'steam dome'. It was a copper clad pimple on the top of the boiler near the front end. The concept was simple. Steam rises...the hottest (driest) steam would be found at the top of the boiler. Place a dome on top of the boiler, creating a defined 'high point' in the boiler and you have a collection place for the hottest steam. Place the regulator valve within the steam dome and the steam used to drive the cylinders will always be collected from the steam dome, where the best steam can be found. The idea was sound, but others would improve the efficiency of the design.

The Bury 0-4-0

The year of the opening of the Liverpool and Manchester Railway, one year after the Rocket's 1829 triumph at Rainhill. Edward Bury decided to devote his Liverpool engineering company to the building of steam locomotives. His first locomotive, an 0-4-0 based on Stephenson concepts, would also be built for the Liverpool and Manchester Railway.

Bury's locomotive had two innovations. It was this 1830 0-4-0 that had the first true Bar Frame. This was a full chassis made from iron bars in the from of a box truss. The Rocket's bar frame chassis owed its strength to the boiler forming part of the structure to save weight. The Bury Bar framed chassis was a self supporting structural element. The very same bar frame concept is used on our 2-6-0 model, along with most US prototypes. The other design innovation was the development of the steam dome into an integral part of the boiler in the form of a large dome directly over the firebox. A locomotive's speed and power is directly effected by the rate in which steam can be raised by the boiler. The Stephenson's steam dome had helped to focus that usable steam in one place for better collection. Bury realized the best place to collect the hottest steam at the fastest rate was to put the steam dome right over the hottest part of the boiler...above the firebox. Putting the dome up the front end, where Stephenson had located it, meant placing the thing over the coolest part of the boiler. Bury also made the dome a lot larger, so large in fact it became the whole top end of the firebox, thus providing an ample collection place for steam. The dome would create a current through the flow of steam rising to the rear of the boiler. The Bury boiler would become a symbol of his locomotive firm, and earned the name 'Bury's Coppernob Boiler' because of the big copper steam dome 'nob' over the firebox, some of us know this boiler as the 'Haycock' type. Look hard at this boiler readers. Here is the origin of the 'T' boiler found on early Shays, and its also the basis for the Classic American 'Wagon Top' boiler of the 4-4-0.

A typical 1830s Bury 0-4-0, with the 'Coppernob' boiler and bar frame chassis.
National Railway Museum, York, UK.

Another feature of the Bury Coppernob 0-4-0 was the placement of the firebox behind the rear drivers. This provided for an unobstructed chassis, enabling internal pistons and valve gear. The grate area of the firebox was also free of locomotive structure, allowing the firebox to breath better, enabling better steaming. The clear access to the firebox behind the last drivers lead to Bury's 3rd innovation. He introduced a hinged grate at the firebox base to enable easy cleaning of the firebox.

Bury's first 0-4-0 of 1830 would later be sold to the Petersburg RR in the US in 1833 and it is there that Bury's design features would become noticed. Bury continued to build locomotives in the UK until he under priced a batch of locomotives and suffered chronic losses. His company closed in 1850 as a result.

The Problem of the 4 legged chair

In 1830, Colonel Stevens began building an early US RR called the Camden & Amboy. His first locomotive would naturally be a product of our Robert Stephenson. During the Ocean voyage to the UK to order the locomotive, Stevens' mind drifted to thinking about the problem of locomotive weight breaking the cast iron bar rail, a nagging problem for most early railways. Stevens realized a new rail casting in the form of a 'T' would provide considerable added strength to the rail. So began the evolution of rail to the 'I' form of today.
Robert Stephenson would build Stevens a large 0-4-0, test the locomotive, and then dismantle it for the voyage to America. In 1831, upon arrival, the line's appointed Chief engineer, Isaac Dripps, would have the task of assembling the locomotive. Isaac had never even seen a steam locomotive before, let alone tried to assemble one from a 'kit'!! It says something about both Dripps to do something like that..and Stephenson for the quality of his instructions!! The locomotive would later be known as the 'John Bull' and is today preserved at the Smithsonian

Institution, American History Museum, as the oldest operable steam locomotive in the US. Strangely the locomotive was usual for the models Stephenson was building at that time. The 0-4-0 had design principles in common with the Bury 0-4-0 of the same year. The locomotive featured a Bury type boiler, and the 0-4-0 wheel arrangement was set out like the Bury 0-4-0, with the firebox slung behind the rear drivers for better clearance. Stephenson would not build later locomotives to this design, instead settling into the Stephenson' Long Boiler' series. (we'll look at the 'Long boiler' locos in the next chapter!!)

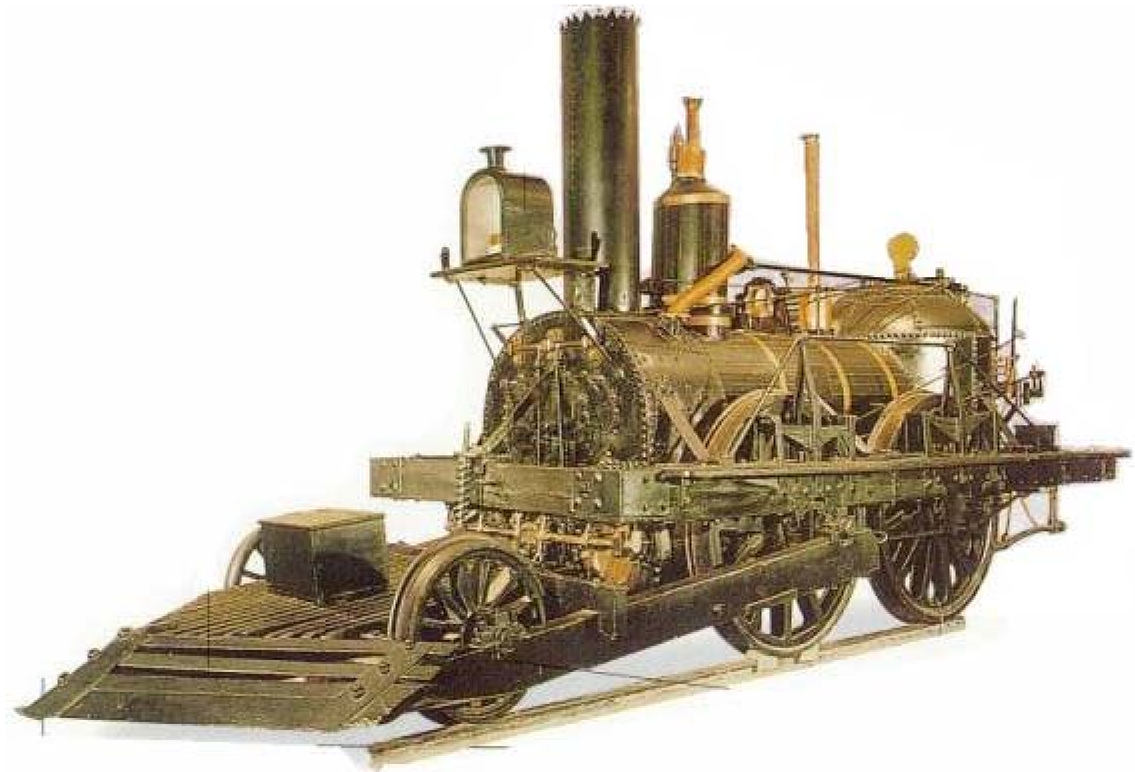
The John Bull at the Smithsonian

The John Bull did not run well. It steamed beautifully, but would not stay on the rails. This was also the case with the Bury 0-4-0 sold to the Petersburg RR in 1833. We all know this part. The early rails in the US were roughly driven and uneven at best. Greater distances were being built for less cost than in the UK. The early 0-4-0 locomotives were exactly like a perfectly formed 4 legged chair sitting on an uneven floor. The weight of the locomotive was only ever placed on 3 out of the 4 wheels at any one time, while the 4th driver could be found spinning in air! When the rail came back to level and the 4th driver again made contact, it'd often land outside the rail head and derail the locomotive. Something had to be done.

Issac Dripps modified the John Bull to incorporate two new features. In order to guide the locomotive's drive wheels to better align with the rail head, Dripps added a two wheel pilot truck to the front of the locomotive, the first ever pilot truck to be tested. The pilot truck had no lateral play, but could rise up and down to follow the uneven track. This pilot truck would guide the main 0-4-0 chassis so that when the 4th driver made contact with the rail again it would at least be on the rails. Dripps had created a 2-4-0 and had by default also created the world's first 'pilot' or 'cow catcher' through the structure that held the pilot wheels.

Dripps' pilot truck and cow catcher. Talk about an 1830s hot rod!!
John Bull, Smithsonian Institution, USA

The second innovation of Dripps was to realize that powered driving wheels were not just guided by rails, but could 'walk' over the top of a rail, again causing a derailment. He reasoned that the leading wheels of a locomotive should not be powered. Un-powered wheels are better 'pushed' into the rail walls, and more likely to stay on line. Going back to the John Bull, Dripps, disconnected the outside cranked side rods between the rear and lead drivers. The locomotive now was powered only by the rear set of wheels. His locomotive now was a unusual looking 4-2-0. The tractive effort of the John Bull was traded for reliability and the locomotive would indeed prove to be successful.



The Dripps modified Stephenson Locomotive. The unusual 4-2-0 John Bull
Nope, its not a 2-4-0 anymore, even if it looks like it!!

The Lesson of the 3 Legged Chair

During the early days of theatre, musicians confounded with their 4 legged stools rocking about on the uneven pit floor, switched to 3 legged stools. Now a 3 legged stool will always have all three legs on the floor, no matter how uneven the floor may be. The weight on the person is also distributed equally though the three legs if the person's mass sits right on the center point. The 3 legged chair is an example of the most basic form of '3 point suspension'!

In 1832, John B. Jervis, Chief Engineer of the Mohawk & Hudson RR (De Witt Clinton Fame!!). Was having trouble keeping a 'Rocket' inspired 2-2-0 called 'Rocket' on the rails...it was the old 4 legged chair problem again. Taking the lead devised by Dripps, he set about adding a pilot truck of some sort, Jervis came up with a neat 4 wheel bogie, which pivoted at a central node. The truck had the ability to flex in three dimensions and could also support the weight of the front end of the locomotive where the truck was fixed. The 2-2-0 became a 4-2-0. Completely by accident, Jervis had created the 3 legged chair version of the steam locomotive!! The 2-2-0 was like a 4 legged chair, but when Jervis added the 4 wheel pilot truck, the locomotive weight was supported not directly by each of the 4 wheels, but by the central bearing plate, which was a point common to the 4 wheels of the pilot truck. This was 3 point suspension in a locomotive for the first time:

Point 1 - Pivot point of the pilot truck
Point 2 - LH driver bearing
Point 3 - RH driver bearing

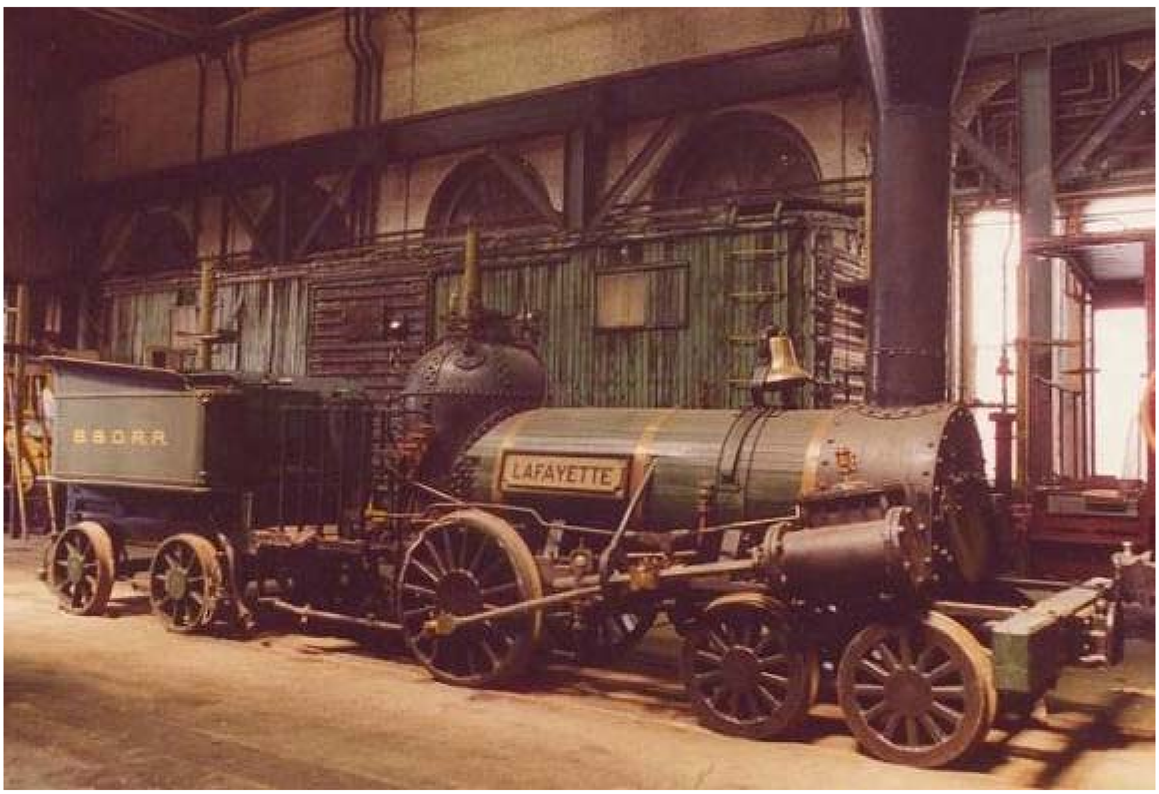
The 3 legged chair on rails.

The 4-2-0s went into production at the West Point foundry and these locomotives were forever known as the 'Jervis type' They could run on uneven track and no wheels would leave the rails. The weight of the locomotive was maintained evenly on the 3 suspension points. The 4-2-0 became the dominant motive power throughout the 1830s and well into the 1840s, where two thirds of all motive power were 4-2-0s.

The Pieces Come Together

In 1832 William Norris set up a locomotive engineering firm in Philadelphia. By 1836, Norris had only built 7 whole locomotives, but then he hit on something. Taking the efficient boiler designs of Mr. 'Coppernob' Bury, the 4-2-0 chassis of Mr. 3 'point suspension' Jervis and the external low incline cylinders of Mr. Robert Stephenson, Norris built the ultimate 4-2-0 locomotive. They would prove to be economical and reliable.

The first of this new breed of Norris 4-2-0 would be called 'Lafayette', built in 1837 and would become the B&O RR's first horizontal boilered locomotive.

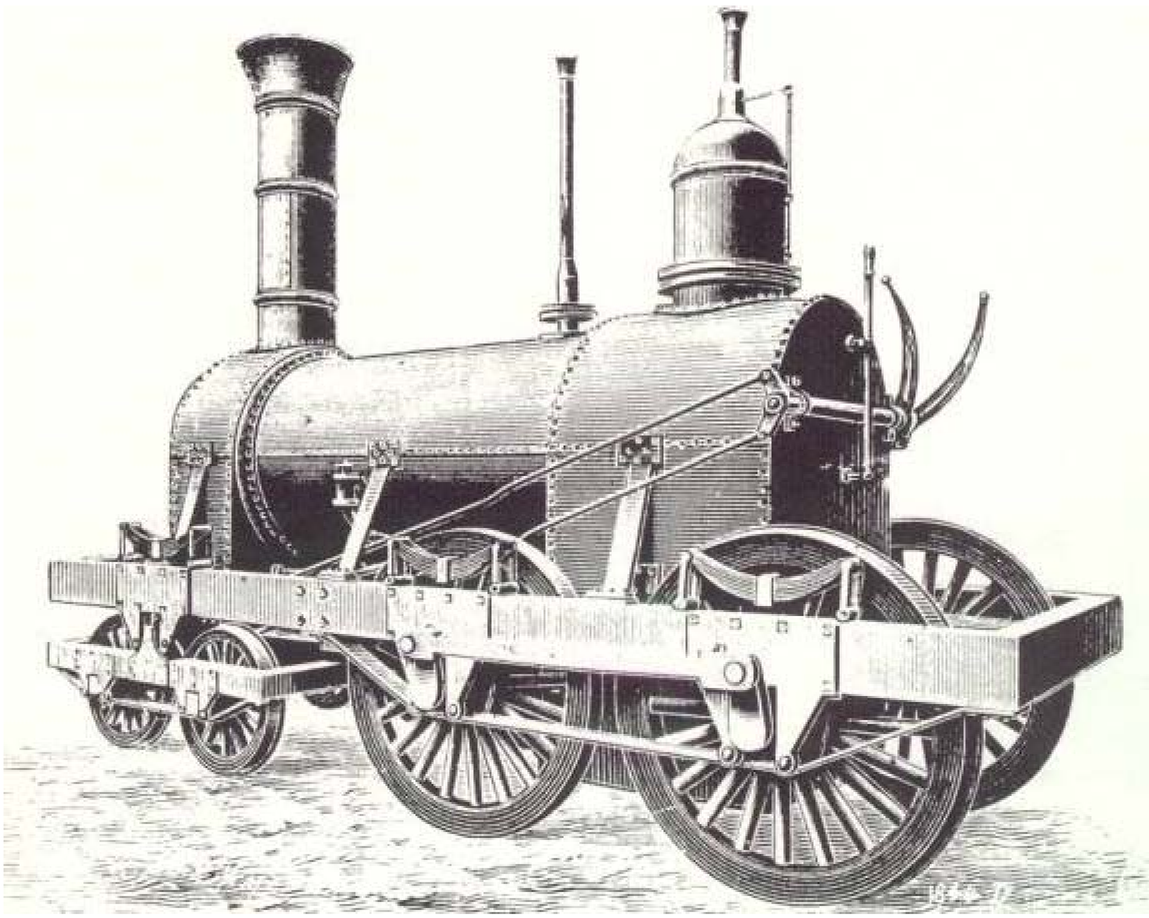


1927 replica of the B&O 1837 Norris 4-2-0, Lafayette. Note the Bury 'Coppernob' boiler, Bury firebox slung behind the driving wheels and the Jervis 4 wheel pilot truck. This is a picture of 3 point suspension. B&O Museum, Mt Clare, Baltimore, USA.

The Norris 4-2-0s would become the most reliable versions of the design, and would even be sold to Europe. By the early 1840s Norris would become the largest builder of locomotives in the US. By 1860 11% of all locomotives in the US were of Norris manufacture!! The 'lil Norris 4-2-0 would earn the nick-name "One Amed Billy' for its single external side rod and 'Billy' for our William Norris.

The 4-4-0 Emerges

In 1836, quite independent of the Norris experiments, Henry R. Campbell, Chief Engineer of the Philadelphia, Germantown & Norristown Railway designed the first 4-4-0. It was basically a Stephenson boiler, Jervis 4-2-0 with a 2nd set of drivers added behind the firebox. The 4 wheel pilot truck was a Jervis pivoting type, but the 4 drivers were rigidly framed. The locomotive was built by Brooks in Philadelphia in 1837 and at 12 tons, was a very large locomotive for that time. The Campbell 4-4-0 had ample power but did not track well. The rear set of 4 drivers suffered from the 4 legged chair problem again similar to the Bury and Stephenson locos. A different type of thinking was required to enable all driving wheels to carry the weight of the locomotive uniformly over uneven track. The solution was right in front of them, a Jervis style powered bogie had to be adapted somehow.



The Campbell 4-4-0, 1836

The First Fully Equalized 4-4-0

Later in the year of 1837, another Philadelphia Locomotive firm of Eastwick & Harrison devised the ultimate 4-4-0. It was built using every design principle to date. It used the Bury boiler, had a wheel set out based on the Norris 4-2-0, with the Norris external cylinders and 'One Armed Billy' Side rods, and it's set of driving wheels were equalized. Harrison devised the equalizing beam. Unlike the Campbell 4-4-0, where each driver independently carried the loco weight directly on the wheel bearings, the Harrison 4-4-0 had the drivers mounted to a rocking beam. Only the center of the beam or 'Fulcrum' point was actually mounted to the locomotive superstructure. The locomotive weight therefore was placed directly on the fulcrum point of the rocking beam. From there the weight was distributed equally to each of the 4 drivers mounted to the 2 beams (one each side). For the first time an 8 wheel locomotive behaved like a 3 legged chair!! The locomotive's weight was distributed evenly between the pilot truck central pivot, the LH beam fulcrum and RH beam fulcrum. 3 point suspension!!

The Harrison Equalized 4-4-0 of 1837. (Hercules) Note the Bury style 'Coppernob' boiler, Norris style 4-2-0 basis and equalizing beam between the drivers, above the sideboards.

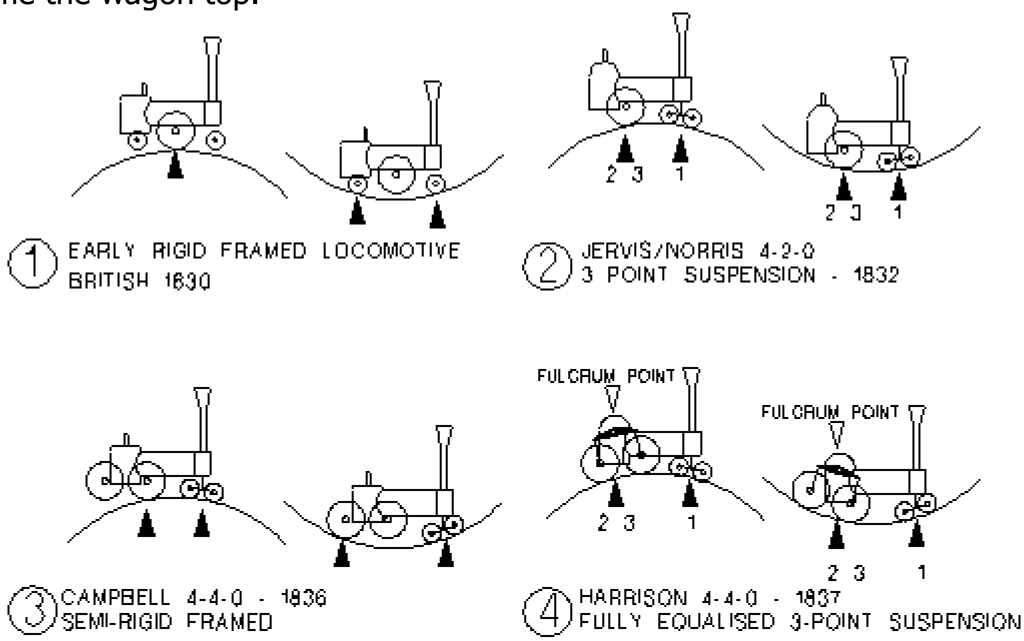
The Harrison 4-4-0 was said to be incredible. At 15 tons, it was large and could pull well, however during early trials it proved the worth of equalized suspension. It pulled 40 times its own weight, some 80 wagons fully loaded. What this proved more than anything was that a locomotive's weight distributed equally on all the drivers would mean 100% tractive efficiency. Funny, but the names Eastwick & Harrison are virtually unknown. Why didn't they end up locomotive Gurus like Baldwin etc?

The 4-4-0 Emerges

The success of the Harrison 4-4-0 would be heard even as far away as Russia. Eastwick and Harrison were invited by the Czar Nicholas I to found his St Petersburg - Moscow railway. Eastwick & Harrison closed their Philadelphia plant and set sail for Russia. They would go on to carve a niche in the railway business of Russia. Some of their first locomotives built for the Czar would be 2-6-0s, and here is one of the 'stories' I mentioned in Chapter 2. It is said that the 2-6-0 design was named 'Mogul' after their being the Czar of Russia's first locomotives, some would say the world's first 2-6-0s. I really don't know the true origins of the word!!. In any case Harrison disappeared from the History Books of the US after 1837.

In the US, William Norris went on to produce the Harrison 4-4-0 design. There is a superb surviving example of a Norris 4-4-0, built as Caldera & Copiapo Rwy No1, 1850, and preserved at Copianpo, Chile, In South America. It has all the Bury, Norris and Harrison features. I wish I had a good set of photos of her. Most shots in the books only show it from the front end and there ain't much to see.

The 4-4-0 design principle would remain unchanged from the Harrison design to the end of the 4-4-0 around 1900. The 'Coppernob' boiler would evolve into the 'Wagon top' boiler when Rogers of NJ would build their version of the 4-4-0, turning the cylindrical Bury firebox into a rectangle, to maximize grate area between the frames. With the shift of cylindrical to rectangle, the domed firebox became the wagon top.



The above diagram displays the evolution of the 3 point equalized suspension system. The black arrows indicate the loco weight distribution points over the wheels. You will see how the weight shifts over different wheels depending on the trackage. That equates to a loss of traction, and loss of efficiency. The trackwork in the diagram is kind of exaggerated, but serves to highlight the problem. In example(4) Harrison 4-4-0, The weight distribution remains on the fulcrum point of the rocking beam for the rear drivers regardless of trackage.

The modern prime movers of the 18 wheeler road rigs utilize exactly the same Harrison equalized principle today.

In 1845 Baldwin would begin building 4-4-0s after purchasing the original Campbell 4-4-0 patent. And from the factories of Rogers, Danforth/Cooke, Mason (bogie fame), Brooks, Baldwin and others, the 4-4-0s would flow, becoming the dominant power for over 50 years.


A rather famous 1856 Danforth Cooke & Co. 4-4-0, 'Texax' from Andrews Raid Fame.
Atlanta Cyclorama, Atlanta Georgia, USA.

Our Baldwin 2-6-0 is a direct descendant of the Baldwin 4-4-0 design.

Equalizing the 2-6-0 design

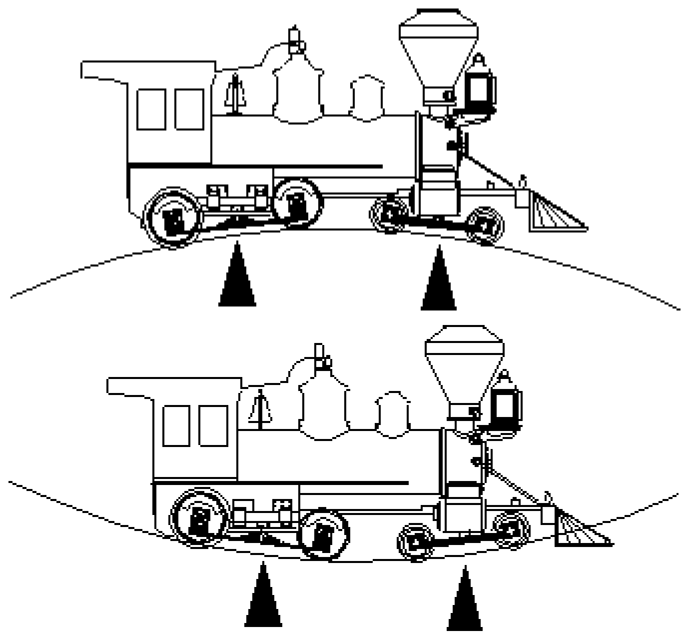
The 4-4-0s could negotiate the roughest of rails, but their ample power began to fade, as railroads placed greater demands on their locomotives. The solution was in the sums.

The 4-4-0 forms a triangle on the rails. The 3 points of the triangle being the 3-point suspension. Two of those points are the fulcrum points to the rocking beams of the 4 drivers. The 3rd point is the pivot of the pilot truck. If the pilot truck was removed for some reason, the whole boiler would pivot over the fulcrum point and smash into the ground at the front. Thus about 1/3 of the locomotive's weight is placed on the pilot truck (the bulk of the locos mass was also over the 4 drivers). A locomotive's weight placed over unpowered wheels is a loss of potential tractive power. Only 2/3s of the locomotive's weight of a 4-4-0 is placed on the drivers, and thus only that weight can be turned into tractive effort. Lets look at some case studies, these are very simplified sums to indicate the issue.

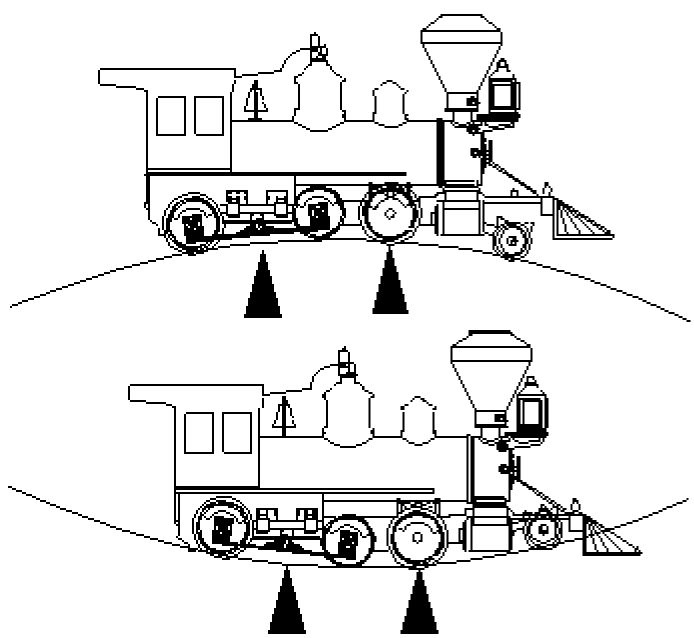
The NCNG #1, an 8-16-C 4-4-0 had a locomotive weight of 42,000 lbs. The weight on the drivers of this 4-4-0 was 27,000 lbs. Thus the weight on drivers was about 2/3s the loco weight.(64% actually). The locomotive had a tractive effort of 5420 lbs, or about 1/5th the weight on the drivers.

OK now our 'lil 8-16-D 2-6-0 also has a locomotive weight of 42,000 lbs. The weight on the drivers of our 2-6-0 is 35,000 lbs. Over 80% of the engine weight is now placed on the drivers, and the resulting tractive effort is 6400 lbs, just under 1/5th the weight on the drivers, all for the same overall locomotive weight.

This is what Baldwin did to adapt the 4-4-0 equalized suspension into a 2-6-0, placing a proportionally greater locomotive weight on the drivers. He placed a 3rd driver set directly in front of the 4 equalized drivers (hence the uneven wheel spacing), and had the new driver set individually sprung with vertical play. As the rocking beam of the equalized rear 4 drivers rose and fell over rough track, the new driver set would rise and fall along with it. The 3rd suspension point originally over the pivot of the pilot truck, moved to a new point above the new driver set. Not wholly a 3 point suspension system, the 2-6-0 was a flexible 4 point system, which tracked well with the improvements in rail grading by the 1860s.



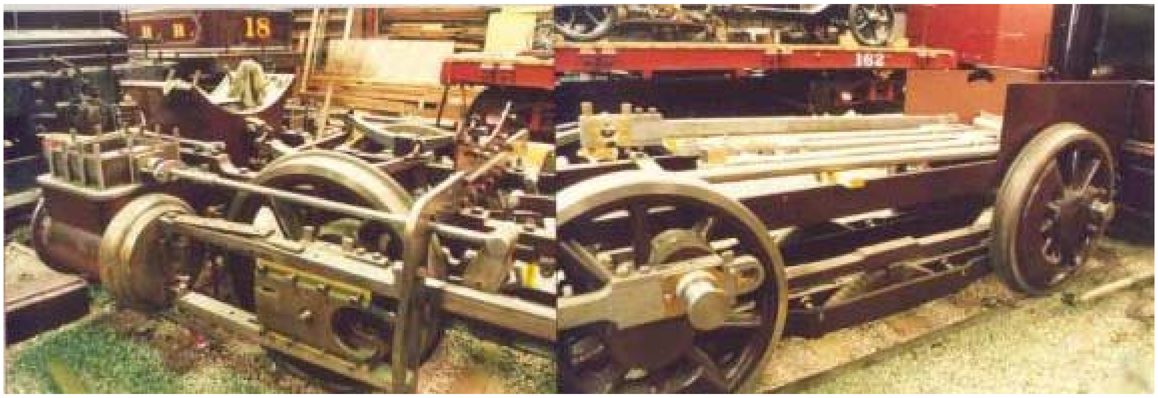
The Baldwin 8-16-C 4-4-0 equalized suspension



The Baldwin 8-16-D 2-6-0 Equalized Suspension

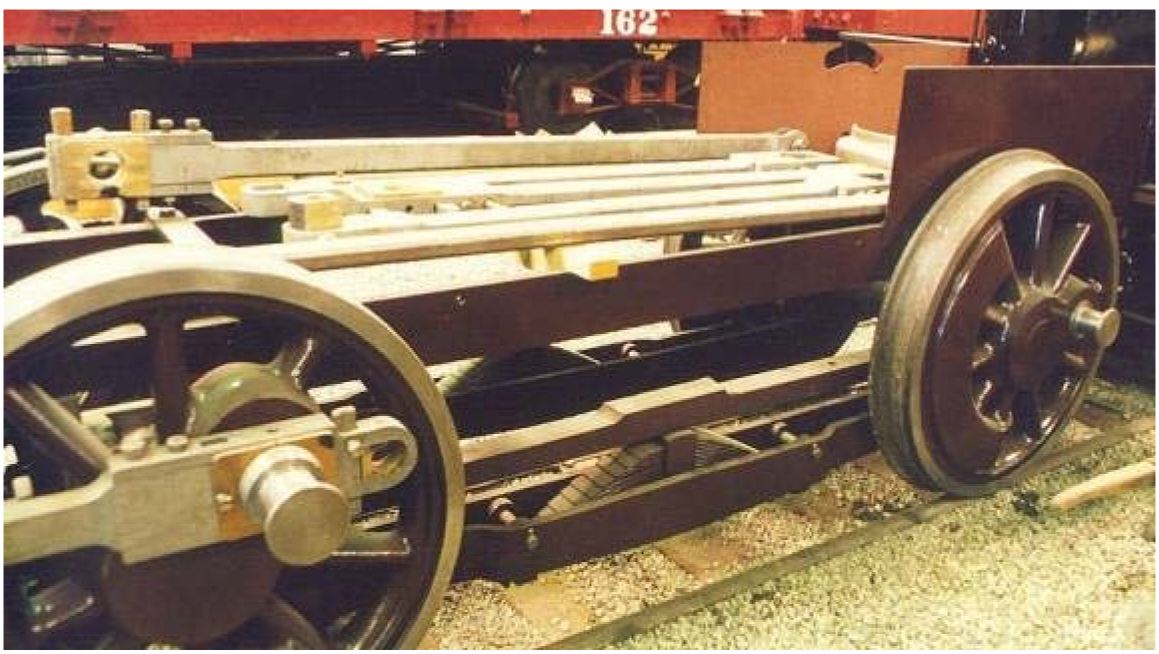
The above diagrams highlight the evolution of 4-4-0 to 2-6-0. Note the vertical play in the lead driver of the 2-6-0, which combines with the rocking of the equalized rear drivers. Note also how the locomotive weight is maintained over the drivers (4 points - two each side) on the 2-6-0 denoted by the back arrows. This illustrates how more of the locomotive's weight is placed on the drivers than the 4-4-0, equating to a greater tractive effort.

Note the fulcrum and rocking beam location of this 8-16-C 4-4-0 and 8-16-D 2-6-0 diagram. These are the actual details you'll be modeling on the 2-6-0 chassis this week.



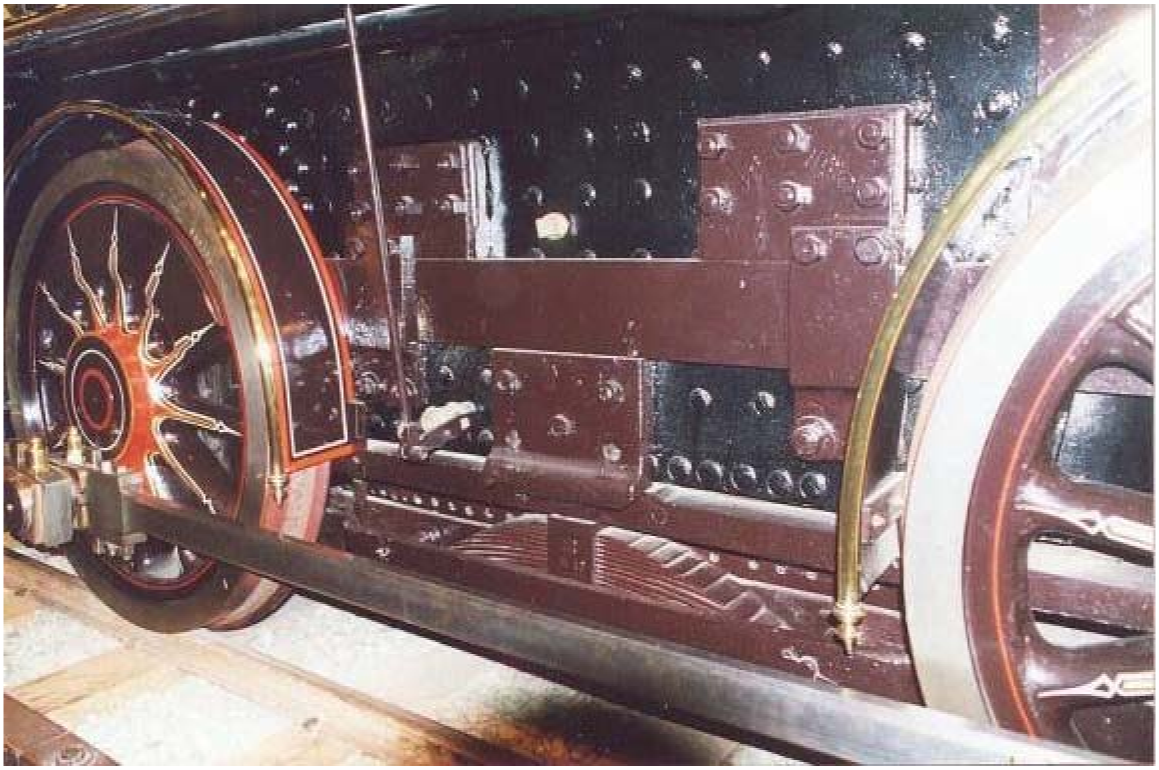
This is a composite picture of a typical Baldwin 8-20-D 2-6-0 chassis frames. You can see equalizing beam between the middle and last drivers, with the leaf spring sandwiched between. The lower chassis bar frame rests atop the spring..this is where the locomotive weight rests on the drivers. The spring is the fulcrum point for the equalized suspension.

Here's a closer look...



Checkout that equalizing beam and spring fulcrum. The bar right above the spring is the locomotive bar frame, as is the wider bar spanning near the top of the wheels.

Both Photos, the frames of Carson & Tahoe Lumber & Fluming Co #1 Glenbrook, 1875 8-20-D 2-6-0, Nevada State RR Museum



This is a close up of the equalizing beam and fulcrum of a complete 8-18-C 4-4-0 'Sonoma'. The equalizing beam is the lowest bar across the bottom of the chassis between the drivers, seen just above the chrome side rod. The fulcrum is the upside-down spring midway between the drivers. The locomotive weight rests on this spring providing a softer ride, through sprung suspension, and a pivot point for the equalizing beam. All the other bolted patches over the bar frames are the bolted connection of the boiler-firebox to the chassis. The big heavy patch above the spring is the support mounting, reinforcing the frame at the fulcrum point. It is here where the weight of the locomotive rests. This is what your model will look like between the middle and last drivers of the 2-6-0. Note also that the firebox area is nor directly bolted to the upper chassis bar frame, rather the 'patches' clamp over the bar frame. This enables a sliding - flexible connection between the firebox and chassis...an important feature to allow for the expansion and contraction of dissimilar heated metals. Sonoma, California State RR Museum, USA.

You will notice both the Bachmann 4-4-0 and 2-6-0 have these details cast into the firebox sides, but all is non-functional.... you tell me the Bachmann 4-4-0 and 2-6-0 have a suspension system as outrageous as this!! There is definitely a difference between sprung wheels and equalized wheels. And now you know what is really meant by '3-point' and 'equalized' suspension.

The Stephenson Valve Gear

Locomotive Perfection - The 4-4-0. Virginia & Truckee #18,'Dayton' Built CP Shops Sacramento, 1873,
Photo taken the Nevada State RR Museum, Carson City.
Looked this ol' loco over with my friend and our very own, Nevada Tiny Pearce.

This is a short passage to try to simplify the workings of the Stephenson Valve gear, by highlighting its function and origin. Our 2-6-0 prototype had a Stephenson type Valve gear, but due to the system being built between the frames, our model will sadly have none of this detail.

The valve gear on a locomotive performs the task of directing the steam to the cylinders with the appropriate 'timing' to enable the locomotive to run forwards or reverse. The valve gear also limits the amount of steam admitted to the cylinders, to enable full power take-off through to the more economical 'coasting' of a loco at speed.

In the beginning the valves on a steam engine, such as the big James Watt Beam pumping engines, were operated by hand. An engine man had to pull a series of levers to direct the flow of steam to the appropriate side of the piston. Then young Potter came along and tied a bunch of string to the levers and invented the first automatic valve gear!!

An engine man operating the valves by hand on an early Watt steam engine. Note the vertical steam cylinder behind the valve levers, London Science Museum UK.

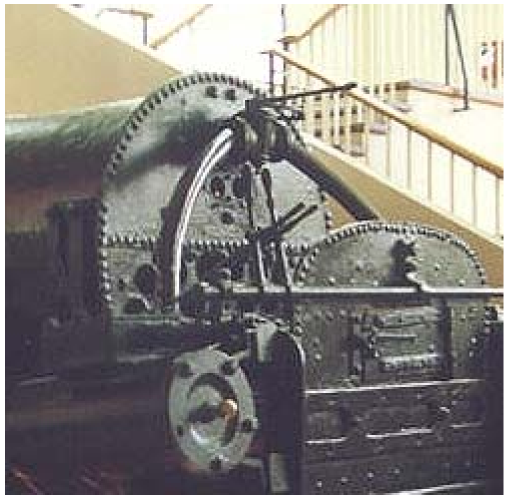
The Stephenson Automatic Valve gear type began with George Stephenson. George introduced the "Loose Eccentric" valve gear in 1816. This was a simple device which gave the locomotive crew direct forward and reverse control of the locomotive from the footplate. Basically this valve gear comprised of cam connected to the powered axle of the locomotive. The cam would rotate about the axle's center in an ''eccentric" motion as the axle rotated. The extent of lateral play in the eccentric motion equaled the distance the valve in the steam chest needed to move to direct the steam to both sides of the piston in the cylinder.

George had the cam fixed in such a way, that a lever on the footplate (later to be known as 'Johnson bar') could move the cam forward or behind the axle, hence the name "Loose Eccentric valve gear", in that the eccentric could 'slip' on the axle. When the cam was pushed forward of the axle, the slide valve in the steam chest would move all the way forward and admit steam to the front of the piston, thus pushing the piston back and rotating the wheel in a forward direction. From there on the cam would move the slide valve back and forth maintaining the steam direction about the piston for forward motion.

When the cam was slid rearward of the axle center, the valve would be moved to the rear end of the steam chest and admit steam behind the piston, pushing the piston forward, pulling on the wheel and placing the locomotive in reverse motion.

If the cam was moved to align with the center of the axle, the cam would rotate with the axle with no eccentric motion at all, and the valve would not slide at all, neutral.

The modern "Slip Eccentric" valve gear as found on many live steam models works in a similar manner.

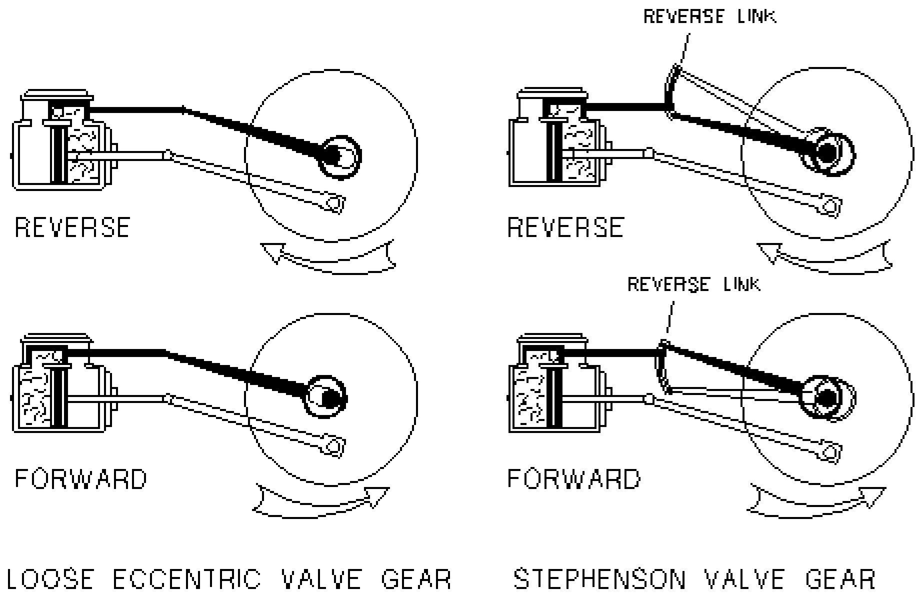


As simple as the system was, it was clunky and getting the loco set in forward or reverse in the first place could be tricky. The famous Robert Stephenson 'Rocket' had this type of valve gear.

The controls on the foot plate of Stephenson's 'Rocket'. The lever up at the top of the boiler is the throttle , with the steam pipes running down to the cylinders. The two X shaped levels in the center of picture are the 'Johnson bar' used to control the direction of the locomotive. The two levers would push or pull on the end of the slide valve which in turn would move the eccentrics down on the drive wheel axle to the desired forward or reverse position. Note the cylinder and steam chest right next to these levels. If the wheels came to rest in a awkward place, and the levers could not move the eccentrics, the crew would have to get out and push the loco a foot or two to a suitable position to enable the 'Johnson bar' to move the eccentrics.

In 1840, a chap by the name of William Howe (1814 - 1879) joined Robert Stephenson & Co as foreman of the works. It was here in 1842, that Howe got a sketch from a young apprentice at the works named Williams, who had an idea of a double eccentric motion. He devised a system of two permanently fixed eccentric cams on the axle. Both connecting to a curved 'link'. The two cams formed a permanent forward and reverse setting at the same time. The 'link' was the secret than enabled the valve rod to slide closer to the 'forward' cam or to the 'reverse' cam. All that was needed was to lift of lower the reverse link to alight the appropriate cam with the cylinder valve to choose the direction of motion for the locomotive. Howe developed the idea and tested it on a Stephenson locomotive for the first time in 1842.

The 'Howe' Valve motion was immediately adopted by Robert Stephenson who fitted them to a new batch of locomotives for the North Midland Railway in 1843. While Stephenson gave full credit to Howe for his invention (poor Williams!!), the system earned the name "Stephenson Valve Gear" in honor of the factory where the system was first implemented. It very quickly spread to universal use throughout the 1800s.



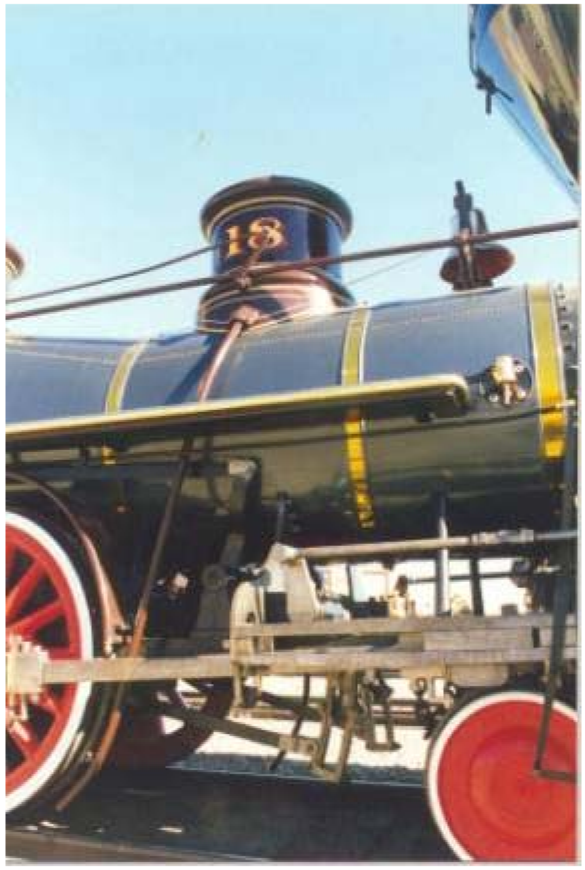
This diagram illustrates the Loose Eccentric Valve gear on the left, showing how a single cam on the axle is moved to place the locomotive in forward or reverse motion. The diagram to the right is the Stephenson or Howe valve gear. Two cams are used, permanently fixed in a forward and reverse setting per the "loose' type. The valve is connected to either the forward or reverse cam by sliding it to the appropriate cam via the reverse link.

Howe developed the system just to make the act of setting the locomotive's direction of travel easier. There was a desirable, undreamed of outcome from the Howe reverse link. Crews using the system on their locomotives discovered it was possible to move the reverse link only part way, thus cutting off the steam to the cylinder before the end of the piston stoke. This had enormous advantages in steam economy. Once a train had gained speed and momentum, it wasn't necessary for every piston stoke to get 100% steam admittance. By moving the slide valve connection closer to the 'neutral' midway point of the Howe reverse link, the slide valve would slide a lesser amount, admitting less steam to the cylinder...just providing enough steam to maintain the momentum. This is like 4th gear on your stick shift car. 1st gear is the full forward position. The 'cut-off' principle was applied to all valve gear to follow and became the tool of a skilled engineman. You've seen how the 'Johnson bar' has teeth in the radius mounting at the floor. The teeth are there to allow the crew to set the 'cut-off' on the valve gear.

The typical Stephenson (Howe) reverse links seen between the frames of 'Sonoma',
There are two links, one for each cylinder. The links are in the 'neutral' position in this example.
8-18-C 4-4-0 - 'Somona', Cal State RR Museum.

You can imagine using a lever to lift and lower all that metal to align the slide valve with the correct cam took a bit of muscle. So it was that our friends at Rogers Locomotive Works of NJ, devised a counter weight to the reverse link, making it easy to lift and lower the thing.

I've mentioned how sometimes lands apart, two people might invent the same thing, well it seems that history has revealed another source of the same idea. William James of New York devised an identical system to the Howe Valve gear in 1832 and fitted it to a locomotive for the B&O. The locomotive was later destroyed in a boiler explosion and the idea disintegrated with it.



The V&T 'Dayton' 4-4-0 valve gear. Note gear in 'forward' motion.
A very typical Stephenson Valve gear installation,
Nevada State RR Museum, Carson City.

All valve gear designs to follow such as Walschaerts, Baker, Southern, Young, etc were founded on the same 'limited cut-off' principle. The various types responding to the required sliding distance of the slide valve or piston valve types. The question's been asked which is best and why. I don't know. Given how similar some of these systems are, I suspect the reason for 'reinventing the wheel' were for reason of maintenance costs and restrictive patents. Some valve gear have more 'pivoting' less wear parts, while others have more sliding parts which also wear more. Sometimes to avoid payment of royalties for patents, it was necessary to redesign a system to work the same way but be sufficiently, noticeably different.

Early Locomotive Brakes

Prior to the 1870s it was common practice for the locomotive to have little in the way of braking system at all!! In the early days there were all kinds of methods devised to try and stop a locomotive. Given that most of the effort put into locomotive design centered on getting the thing to GO and to go faster, stopping was a secondary consideration.

You've seen how the speed way drag hot-rods use parachutes to stop!! Well some early trains were stopped by a guy throwing an anchor such as a rock or barb on the end of a length of chain out the back!! You can imagine the trackside damage!

The early proper brakes were adaptations of wagon brakes on a horse/cart. Not so good for stopping, they could hold a loco at rest.

Lets now turn to American locomotives of the 1870s. When our 8-16-D 2-6-0s were delivered in 1875, they had no fitted brakes of any kind to the loco, however the tenders wheels were fitted with a hand operated brake. These tender brakes were used to hold a loco at rest and also provide some drag when going down hills. If a loco had to stop quickly, the engineer would throw the valve gear into reverse and crack open the throttle.

Railroading of the 1870s was a very different practice. Trains didn't roam from end to end of a line in nice continuous run. A locomotive's job was to 'shunt' a collection of wagons from place to place. A bunch of courageous lads would run along the tops of the wagons and manually crank the brakes of each wagon using the overhead brake wheel. Every few miles the train would stop as the crew would set up the braking pattern of the train for the next section of track...the loco would then drag the consist onward, with brakes applied in some cases. The loco would haul the consist up grade and the consist would retain itself and the loco on the down grade. You can imagine the job of a brakeman was dangerous. Many ended their days crushed under the train or thrown from the wagon roof into line-side cacti!!

George Westinghouse

Obviously the most important invention of all railroading was getting things going with the steam locomotive, but I can't think of a more important second invention than George Westinghouse's Air brake system. Getting things stopped safely. Put simply, the Westinghouse brake system saved lives. It also revolutionized the efficiency of railroading. A train could travel in a continuous run, with the braking done from the cab while in motion.

Now George had been involved in a lot of 'safety systems' . He'd been behind the development of early signaling systems. In 1869 Westinghouse came up with the idea of the Air Brake. Using a system of steam generated compressed air, Westinghouse could crank the brakes 'on' on a train. Air pressure was used to push a piston inside a small cylinder which would drive a crank that would tighten the lines connecting to the brake shoes on the wheels, and bring the brakes 'on'. The amount the brakes were 'on' was based on the amount of air pressure in the brake cylinder. If the air pressure escaped from the system, the brakes would come off, allowing the train to free-wheel. When the train was at rest, the hand brakes would have to be cranked on.

In 1873 Westinghouse reversed his system such that air pressure was used to keep the brakes 'off'. This was the world's first 'Automatic Brake' or one where if the air line in the train was broken, the brakes would come 'on' automatically with the resulting loss of air pressure. A heavy gauge spring was used inside the brake cylinder to keep the brakes 'on' and the air pressure was used to push the piston against the spring, releasing the brakes. If the end of a train broke away, causing a run-away, the air pressure in the line would escape and both the main train and run-away would automatically stop.

So important a development was the automatic brake system, that it was decided it should be implemented on all US railroads. Westinghouse was quick to ensure standardization of the system so that all parts used on all railroads were the same.

Back to our ' lil 8-16-D 2-6-0. It was normal in the late 1870s that locomotives were delivered from the manufacturers without the air brakes. These would then be retro-fitted by the railroad, using Westinghouse as specialized brake contractor. During this period, the original tender only brakes were adapted to run on the Westinghouse system. The main locomotive still had no brakes of any kind. The tender brakes were enough to control the loco during yard work, and the automatic brakes of the whole consist would brake the loco during runs.

In 1884, the first air brakes were factory fitted to a Narrow Gauge locomotive. The locomotives were the South Park's famous Cooke Moguls. Cooke fitted the Westinghouse system to both loco and tender.

During the 1880s most NG lines had brake systems fitted to the drive wheels as well as the tenders of their locos. It is for this reason a lot of the early NG locos have exposed brake cylinders fitted in all kinds of positions...anywhere where there was room to fit the equipment as an add-on.

It was during this time that the two typical braking systems were adopted as standard on US locos, that being 'Engine brakes' and 'Automatic brakes'. Engine brakes were based on Westinghouse's original air system where air was used to push brakes 'on'. Engine brakes were applied to the whole locomotive only, including the tender. Automatic brakes were applied only to the train and controlled from the loco. In the cab would be found two brake levers, one for engine brakes and one for automatic brakes. During a run, the engineer would use the automatic brakes to control the train, and the engine would follow along. If the train needed to stop in a hurry, the engineer would have to co-ordinate both brake levers to stop the train without freezing up the wheels on the loco first, he might still throw the loco into reverse and crack regulator.

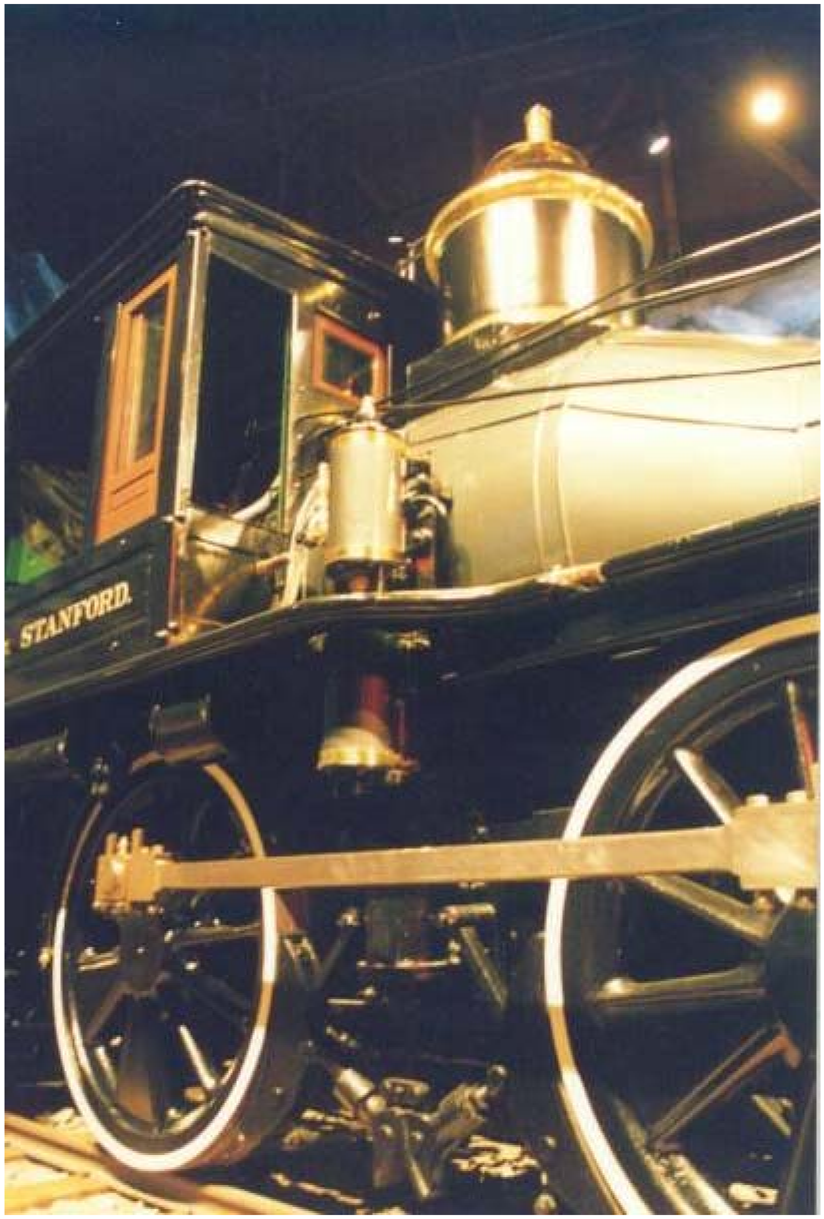
I'm not sure why the Automatic brake system wasn't adopted for the loco as well, even as a separate system. I suspect the reason could be because direct air pressure used to drive the brakes 'on' would provide more control in the confines of yard work. The automatic brakes relies on the energy stored in the heavy spring to press the brakes 'on' and as a result the brakes cannot come on any harder than the spring will allow.

If you're building the 1875 version of the 2-6-0 model, you need not put any brakes on the loco at all, including no air-compressor if you wish. If modeling the late 1870s, fit the air compressor including all the air and steam lines associated, but no brakes on the drive wheels. If modeling post 1880s, we'll install the brake cylinders on the locomotive, and under 'detail' work you can choose whether you want to install the fragile brake shoes to the actual drive wheels as well.

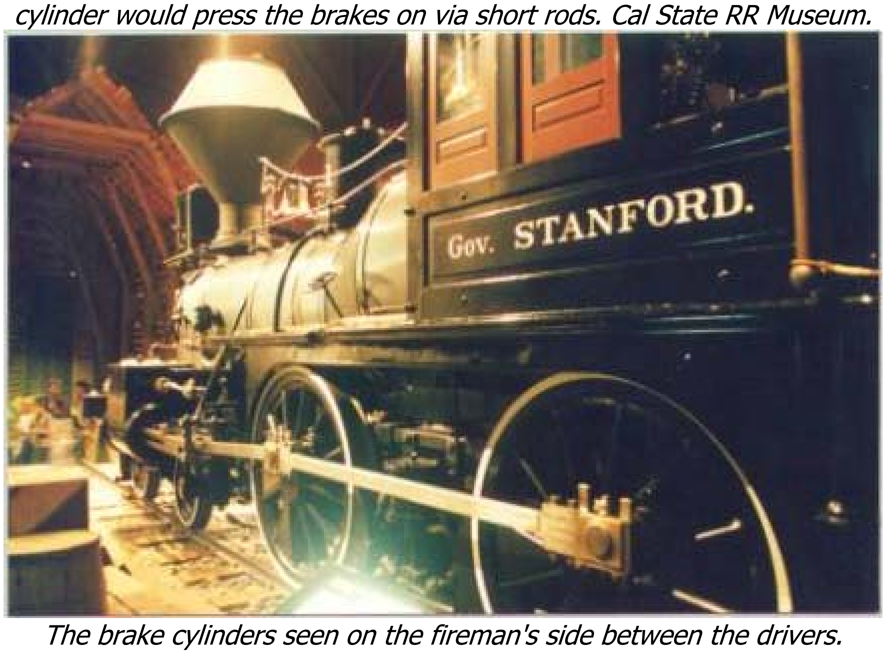
Post 1880s Engine Brake Systems

I'll quickly go through what these early fitted engine brake systems looked like on a locomotive. You can choose the ultimate method of fitting the brake cylinders yourself.

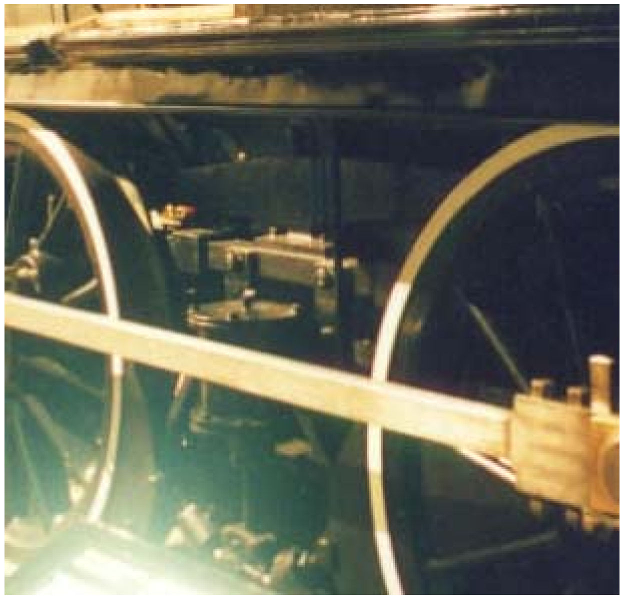
The first engine brake systems had the brake cylinder fitted vertically between a pair of drivers. On a Baldwin 4-4-0 or 2-6-0 the cylinder was fitted between the rear pair of drivers. The vertical drive of the brake cylinder would push the brake shoes laterally through short connecting rods. On the Cooke Mogul the vertical brake cylinder was fitted between the lead and middle drivers only. The Bachmann 2-6-0 has a brake system of this type, fitted between the middle and rear drivers only.



Gov Stanford CP 4-4-0. Note early use of engine brake cylinder in vertical position (seen behind the side rod) The cylinder would press the brakes on via short rods. Cal State RR Museum.



The brake cylinders seen on the fireman's side between the drivers.

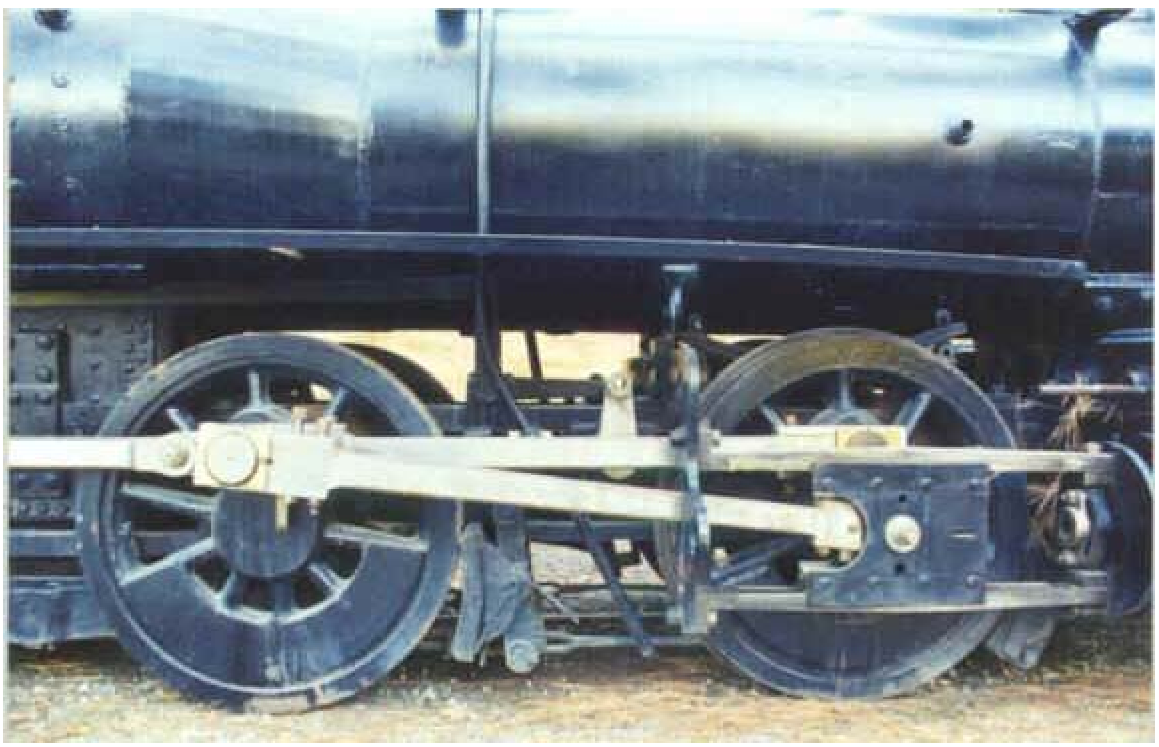


Cal State RR Museum, Sacramento

With refinement, the brake cylinders were fitted horizontally toward the rear end of the chassis. The horizontal thrust of the brake cylinders would move a long lever that would tighten or release a series off rods under the loco chassis. Brake shoes were fitted to all drivers, connected to these brake rods.

Early Horizontal brake cylinders, retro fitted mid way between the drivers of V&T #12 'Genoa',1873 4-4-0, Cal State RR Museum, Sacramanto.

Nevada County Narrow Gauge #5, 8-22-D Baldwin 2-6-0. Horizontal brake cylinders placed behind the air tanks at rear of loco under cab floor (out of sight). Horizontal bars driver brake shoes under chassis, brake lever seen between middle and last drivers. Nevada City California.



NCNG #5- note bars connecting brake shoes. Bars run below chassis, Nevada City California.

Look hard between the middle and last drivers of this D&RG T-12 4-6-0. You'll find a horizontal brake cylinder and break lever of a most typical post 1900 form. This is the design I'll be using for our 1920s version model 2-6-0.

As for Westinghouse he founded a number of companies handling brake systems, signaling (Union Switch & Signaling Co.) and later the Westinghouse Electric Co. which produced some of the earliest electrified railroads in the US. Today you might even have a steak frozen in a Westinghouse freezer.