Multiple Unit Capability For The Steam Locomotive

(The Overview)

James C. Mullaney, National Diploma in Computing

Email: jamescmullaney@eircom.net

Presentation to
The First World Steam & Tourist Trains Congress
Brienz
Switzerland
On Monday 6 October 2003

Multiple Unit Capability

Introduction

The concept of multiple unit capability for the steam locomotive is not a new one. Its requirement was recognised by the development of various types of articulated locomotives including Mallets, Garratts, and Fairlies. Essentially these were two locomotives sharing a common boiler, the fairlie being the exception in that it had two boilers. Since they allowed one crew to control two locomotives they are the simplest and earliest forms of multiple unit capability.

The concept progressed from there to a single driver controlling a number of locomotives with Wabco engineers during the 1940's having been said to have designed and patented pneumatic and electro-pneumatic control systems specifically for the multiple unit operation of steam locomotives.[1]

The concept was advanced further with the ACE 3000 project which envisaged ACE 3000 locomotives working in multiple with both ACE 3000 and diesel locomotives

The approach taken by the author in dealing with this concept is rather than developing multiple unit capability for the steam locomotive what is required is to develop the steam locomotive for multiple unit operations.

It is the author's opinion that the failure to develop the steam locomotive for multiple unit operations is a prime example of an absence of even the most basic systems analysis, an absence that resulted in the totally unnecessary demise of the steam locomotive.

What is it?

Multiple unit capability as applied to locomotives is the facility that allows a number of locomotives coupled together to be controlled by a single crew.

Why is it necessary?

Multiple unit capability is necessary because there are limits as to how big one can build a locomotive. These limits include:

> Loading gauge
> Track gauge
> Axle weight

There is therefore a limit to the adhesive weight of a locomotive and as a consequence there is a limit to tractive effort since:

> Maximum possible tractive effort at the wheel rim = adhesive weight x coefficient of friction between the wheel and the rail[2]

Since there is a limit to tractive for an individual locomotive there is also a limit to the power of any locomotive since

> Power = tractive effort x speed[3]

---

[1] David Wardale, The Red Devil and other tales from the age of steam, published by the author, Inverness, 1998, p371.
[2] David Wardale, The Red Devil and other tales from the age of steam, published by the author, Inverness, 1998, p367.
[3] David Wardale, The Red Devil and other tales from the age of steam, published by the author, Inverness, 1998, p367

These two fundamental equations apply to any locomotive and from them it can be clearly seen that the diesel or electric locomotive does not and cannot have limitless tractive effort. Diesel or electric traction offers the potential for limitless tractive effort because any number of them can be coupled to a train and controlled by a single crew.

What does its development involve?

The development of multiple unit capability for the modern steam locomotive in the first instance involves an analysis of the three following areas:

- Boiler Control
- Adhesion
- Locomotive Control

Based on this analysis it became apparent that developing multiple unit capability for the reciprocating piston engine steam locomotive would require the development of:

- Automatic Boiler Controls
- Adhesion would have to be divided into
  - Traction control
  - Anti-lock braking
- Locomotive control would require
  - The development of power actuated locomotive controls
  - The design of a drivers control panel
  - The development of a computer based interface for locomotive management

Boiler Control

The development of automatic boiler control for the modern multiple unit capable steam locomotive must start from the point of maximising the efficiency of the boiler. "To maximise the efficiency of any boiler two factors are of paramount importance: The fuel/air ratio and the temperature or pressure of the boiler.

The air to fuel ratio should be kept to a minimum that ensures complete combustion within the limitations of the combustion head design. Once these settings are arrived at they should be infinitely repeatable to a high degree of accuracy.

The temperature or pressure of the boiler should be monitored by the combustion system so that the exact amount of fuel and air are fired to achieve the target value. This target should be met at all times, regardless of any load change."[4]

Fuel Type

The author's view is that modern multiple unit capable steam locomotives will be oil fired for the following reasons.

Development time will be reduced as compared with developing a modern coal combustion system capable of supplying the exact amount of fuel necessary to achieve the target boiler pressure.

The infrastructure for its use is already in place; the use of an alternative type of traction will not necessitate the development of an alternative fuel supply system. To undertake this development would impose an indirect cost which no organisation would willingly undertake given the continuing commitment to the use of oil and the internal combustion engine.

This commitment will mean that in the event of a scarcity of oil, companies in order to protect their investments will search for replacement fuel types, which can be used in place of fossil based fuels.

4 http://www.autoflame.com/overview/micro_modulation.html

These can include coal to oil facilities, the use of ethanol or the manufacture of bio-diesel from rapeseed oil amongst others. It would make sense for the modern steam locomotive to take advantage of the oil industry in this respect.

There are also the working conditions of the crew especially with the driver increasingly viewed as being there just to drive the train, not to get the best thermal performance from the locomotive. There is the requirement to provide the driver with simple, convenient, reliable, and foolproof rules for locomotive management[5]. The use of oil firing will facilitate this and will reduce the contribution of the crew towards getting a good performance.

The use of oil firing will eliminate the hardship associated with coal firing; it will also allow all daily servicing of a steam locomotive to take place in a *Lubritorium* type facility.

Drafting

Given that the Lempor Ejector is the best drafting device currently available for the steam locomotive it should be used in conjunction with an electrically powered variable drive fan for the following reasons:

A variable speed fan is recommended because knowing the fuel flow into a burner, the most accurate method of providing air flow to fuel flow is by controlling the speed of the fan on a basis of fuel flow.[6]

Lower Fan Horsepower: In addition to providing the most precise method for combustion air control, the use of a variable speed drive control of the combustion air fan provides a substantial reduction in fan horsepower at part load. Per the fan law, fan horsepower is reduced to the cube of the boiler load. **A boiler, which requires 218 horsepower to power a fan at 100% load, will consume a mere 0.22 horsepower at 10% load!** Operating a boiler on a hot standby mode is of little or no expense with the Compu-NOx system.[7]

Higher Combustion Efficiency: The Compu-NOx system is a true air fuel controller. Feedback from airflow is used as a safety check for fan speed control. The method provides the most accurate and repeatable air/fuel combustion control since airflow, through fan speed control, is always precisely matched to fuel flow throughout the firing range.[8]

Because the fan is electrically powered start-up from cold can be achieved by plugging the locomotive into an external power source until such time as there is sufficient steam in the boiler to power the locomotive's generator.

The use of a drafting fan will eliminate the blast pipe as a contributor to cylinder back pressure, it will also allow for greater freedom in the design of valve gear and the selection of various engine types the uniflow system being one.

Conclusions

The modern multiple unit capable steam locomotive will therefore be oil fired with the boiler draft provided by an electrically powered variable drive fan used in conjunction with the Lempor Ejector. The exhaust steam, which would otherwise be wasted, will be used for feedwater preheating and also for combustion air preheating. The result will be low emissions (already established), raised boiler efficiency and condensation of the exhaust steam without the complexity of the typical locomotive condenser.

[5] David Wardale, The Red Devil and other tales from the age of steam, published by the author, Inverness, 1998, p496.
[6] http://www.compunox.com/index.htm/Fanlaw/fanlaw.htm
[7] http://www.compunox.com/index.htm/Fanlaw/fanlaw.htm
[8] http://www.compunox.com/index.htm/Fanlaw/fanlaw.htm

Adhesion

Adhesion is a measure of the resistance of friction to slippage between two parallel planes or in layman's terms as applied to moving vehicles, it's the grip or lack of it between wheel and surface. To define adhesion as the percentage of a locomotive's weight on the driving wheels that can be converted into tractive effort does not fully define the term. To state that adhesion is a measure of how effectively a locomotive can translate its weight into pulling power before its wheel's spin out of control is also not a complete definition of the term. Both statements are incomplete because they apply to the pulling aspect of the locomotive and neglect that loss of grip or adhesion applies equally to the braking of the locomotive or indeed the entire train.

Adhesion, therefore has implications for both the pulling and the stopping of a train and to make the fullest use of the adhesion (grip) available the modern locomotive requires two separate but similar systems these being:

> Traction Control
> Anti-lock Braking

The similarity of both systems originates from the need to determine the speed of the wheels relative to the speed of the train and to take the corrective action appropriate to the given situation. Modern control systems rely on Doppler Radar to detect the train speed relative to the wheel speed, however with a steam locomotive this can be achieved in a simpler fashion by borrowing technology from formula one racing!

Traction Control

If we take the following equation as the starting point from which to develop a traction control system

> Maximum possible tractive effort at the wheel rim = adhesive weight x coefficient of friction between the wheel and the rail[9]

Then it is obvious that we are limiting the tractive effort to approx. 25% of the adhesive weight of the locomotive.

This however is not the complete picture because we need to take account of the coefficient of adhesion, which is defined as

> Coefficient of adhesion = maximum tractive effort / adhesive weight

With modern diesel and electric locomotive builders claiming adhesion factors of in excess of 40% (50% in the foreseeable future) and also stating that the limits of adhesion have not yet been reached for AC traction it is clear that a control system for wheel slip is essential.
Modern control systems do not seek to prevent wheel slip but actually allow the wheels to slip slightly on purpose, the theory being that slipping wheels will burn off any contamination between the wheels and the rail and thus give a better grip on the rails. This controlled wheel slippage is not good for the locomotive or the track but it can be an advantage for locomotives pulling steep grades and it is claimed allows an increase from 25% to 40% in the loads that can be pulled. The use of modern control systems views the use of sand as a last resort for the following reasons:

- Frequent sanding is costly
- Accelerated wheel and track wear (from 10 to 100times)
- Damage to the track structure due to fouling of ballast, drains and switch points
- Disruption of train detection systems
- Premature rotting of ties
- Damage to all bearing surfaces of the vehicles[10]

[9] David Wardale, The Red Devil and other tales from the age of steam, published by the author, Inverness, 1998, p367.

This is the approach taken by modern diesel and electric locomotive builders to wheel slip while the approach by modern steam locomotive engineers is that the mechanical coupling of modern steam locomotive wheelsets, with negligible play in the system due to rolling contact bearings and Franklin wedges. In addition the reasonably smooth output torque's obtained by the new method of crank positioning and the setting of high standards for sanding gear and tyre roundness allow high coefficients of adhesion to be used without the expense of additional control systems, maximising the adhesion factor.[11] Yet the same author also states that it is unlikely that reciprocating steam locomotives could ever have reached the adhesion coefficients made possible by the adhesion control systems now used with electric transmission.[12] This begs the question why not, if the factors (Porta's Kingdom of Railway Stupidity) that conspire to reduce adhesion are dealt with effectively, and the optimum engine and wheel arrangements are selected then the tendency to slip is reduced. Combine this with a traction control system and you have the best of both worlds and in any case in a multiple unit environment a traction control system is essential.

For a traction control system to operate it has to be capable of performing the following functions:

- Detection of wheel slippage
- Quantification of the amount of wheel slippage
- When appropriate take corrective action

Detection of wheel slippage on the steam locomotive can be achieved relatively simply by borrowing technology from formula one racing which compares the speed of the rear axle of the car (powered) to that of the front axle (non-powered) by means of speedometers on both axles. Any difference between the two indicates wheel slip of the powered axle. The same method can be applied to the steam locomotive given the presence of non-powered and powered axles and thus it can be said that **slippage of the driving wheels occurs when the speed of the powered axles exceeds that of the non-powered axles.** Therefore the speed of both types of axles has to be monitored; placing a speedometer on a non-powered axle and a speedometer on a powered axle does this. A monitoring system on a continuous basis then compares the readings from both speedometers and takes corrective action based on the scenario at a given time. The system would operate as follows:

While the locomotive is in operation

If the speed of the powered axle exceeds that of the non-powered axle
  Then
  The driving wheels are slipping due to excessive power
  Take corrective action based on slipping due to excessive power.

Anti-lock Braking

Loss of adhesion (grip) between the wheel and the rail also has implications when it comes to braking because insufficient adhesion can result in wheel slips and slides that can lead to wheel flats on wheel threads. Development of wheel flats leads to increased loss of adhesion, damage to the rail surface, increased damage to bearings and axles, and increased wheel noise. Extreme loss of adhesion may lead to collisions or derailments.[13]
The development of wheel flats is the result of the wheel locking under baking and then sliding along the rail; the aim of the braking control system is to prevent this happening in effect anti-lock brakes. Wheel lock under braking is preceded by a period of rapid deceleration and the braking must be able to detect this. This can be achieved on the steam locomotive by comparing the speeds of non-braked and braked axles. As in the case of the traction control system placing a speedometer on a non-braked axle and a speedometer on a braked axle does this. A monitoring system on a continuous basis compares

[10] Improved methods for increasing wheel/rail adhesion in the presence of natural contaminants, Transit Co-operative Research Program, Research Results Digest, May 1997, Number 17
[11] David Wardale, The Steam Locomotive – Motive Power For The Future, South African Railways Engineering Society, Pretoria, 1977, pA143.
[12] David Wardale, The Red Devil and other tales from the age of steam, published by the author, Inverness, 1998, p496
[13] Improved methods for increasing wheel/rail adhesion in the presence of natural contaminants, Transit Co-operative Research Program, Research Results Digest, May 1997, Number 17

the readings from both speedometers and takes corrective action. The system would operate as follows:
While brakes are being applied

If the rate of deceleration of the braked axle exceeds that of the non-braked axle
Then
The braked wheels are approaching locking due to excessive brake pressure
Take corrective action to prevent locking of wheelset

Conclusions

The modern multiple unit capable steam locomotive has to have an adhesion control system equal to that of modern diesel and electric traction. It should recognise that adhesion impacts on traction and braking and therefore two separate systems are required. Both of the systems described require one non-powered non-braked axle on the locomotive. This could be considered undesirable with regard to adhesive weight and braking force however the author's view is that the benefits would out weigh the disadvantages.

Locomotive Control

The essence of multiple unit capability is that the term locomotive can apply to one locomotive operated singly or a number of locomotives coupled together and operated as one very large locomotive. A locomotive control system that allows for the multiple unit operation of the steam locomotive requires the development of the following:

- Power actuated locomotive controls
- Driver controls for multiple unit operations
- A computer based interface between the Driver controls and the Power actuated locomotive controls for locomotive management

Power Actuated Locomotive Controls

Even if multiple unit capability were not a consideration the power actuation of locomotive controls should be developed for the benefit of the locomotive crew. The controls to be power actuated include, throttle, reverser, brakes, sanders, drain cocks, whistle and blow down valve.

Driver Controls for Multiple Unit Operations

The driver controls in the modern multiple capable steam locomotives will be radically different to those of the traditional steam locomotive because they will have to operate all the locomotives coupled to the train. The driver will therefore have a suitably designed control panel that will accept his commands and relay them to his and the other locomotives. Since these commands will be relayed via either the traction control or the anti lock braking to the power actuated locomotive controls the cab can be positioned so as to allow for the maximum visibility and indeed is not limited to one cab per locomotive. In addition to controlling other multiple unit capable steam locomotives thought needs to be given to workings with diesel or electric locomotives in a multiple unit scenario and how these are to be controlled.

Computer Based Interface for Locomotive Management

This is the heart of the modern multiple unit capable steam locomotive not just because it will be the controlling mechanism for the locomotive but also and as important because of the data it will produce. The data will be generated on real time basis, in addition it will be possible to store this data and analyse it at a later time and since information is the life blood of an organisation that which generates information can be described as the heart.

Multiple Unit Capability and the Objections

The list of objections to the continuation of steam traction on the then SAR compiled by David Wardale for L. D. Porta[14] is considered by the author to be representative of the views of railway management in general. Therefore it is necessary to assess impact of modern multiple unit capable steam traction on these objections and based on this to assess their validity.

(1) Pollution
This objection is not valid as the work of Roger Waller and described in his paper *Modern Steam – An Economic and Environmental Alternative to Diesel Traction* clearly illustrates[15]. One of the reasons for suggesting the use of a variable drive fan for boiler drafting was the higher combustion efficiency possible. The use of oil firing eliminates the ejection of char from the chimney.

(2) Steam locomotives cannot be worked in multiple with a single crew
This objection is not valid given that the very essence of multiple unit capability is that locomotives can be worked in multiple with a single crew

(3) Difficulty in recruiting staff for steam work due to the hard nature of the work and the filthy conditions, and more skilled staff required for steam than for diesel
This objection is not valid since modern steam with multiple unit capability will be oil fired thus will be cleaner and easier than firing with lump coal. The author expects that the skill level for staff working with modern multiple unit capable steam to be on the same level as those working with diesel or electric locomotives.

(4) Steam locomotive cannot be single manned
This objection is not valid because modern steam as described by Roger Waller is designed for one-man operation. Modern multiple unit capable steam with as described in this paper is intended for one-man operation. The author concedes that for line observation a second person may be necessary, however a cab-forward design would solve that.

(5) Steam locomotives have poor output characteristics at low speed
The author is not competent to comment on this objection until research and analysis into the subject is carried out and will be the subject of a subsequent paper.

(6) Operating difficulties are caused by the need for frequent coaling, watering and ash disposal
This objection is valid and illustrates the effect of low thermal efficiency since even with modern steam the objection can be reworded to "Operating difficulties are caused by the need for frequent fuelling and watering." It is proposed to address this in a future paper.

(7) Steam locomotives are expensive to maintain
This objection is not valid for modern steam having been identified by Roger Waller as one of the shortcomings of old steam power[16] and are due to old age or obsolete constructional practices.

(8) Locomotive tenders are too much dead weight to be carried around
This objection is valid but is an issue that the author does not consider to be within the scope of this paper. It will be covered in a subsequent paper.

(9) There are no manufacturers of steam locomotives left
This objection is not valid, DLM in Switzerland are manufacturers of steam locomotive and the preservation movement especially in the UK have shown that the skills exist to build steam locomotives. Given the demand a manufacturer would soon appear!

---

[14] David Wardale, The Red Devil and other tales from the age of steam, Inverness, 1998, p52.
[15] Roger Waller, The Sir Seymour Biscoe Tritton Lecture, Modern Steam – An Economic and Environmental Alternative to Diesel Traction, Institute of Mechanical Engineers, London, 2003, available at http://www.imeche.org.uk/railway/pdf/sir_seymour_flyer.pdf.
[16] Roger Waller, The Sir Seymour Biscoe Tritton Lecture, Modern Steam – An Economic and Environmental Alternative to Diesel Traction, Institute of Mechanical Engineers, London, 2003, available at http://www.imeche.org.uk/railway/pdf/sir_seymour_flyer.pdf.

(10) Steam locomotive thermal efficiency is too low
This objection is completely valid and it is an issue that must be addressed by steam locomotive engineers as a matter of some urgency. The author is not competent to deal with this area but intends to carryout an analysis of the subject for a subsequent paper.

(11) Any reversion to steam would require re-investing in steam servicing facilities and scrapping diesel facilities, which are not yet depreciated
This objection is not valid because the objection is specific to the conditions that prevailed on the then SAR but it serves to illustrate that modern steam has to approach diesel with regard to servicing. The author is of the view that modern steam should be capable of being serviced in diesel facilities, the major difference being the provision of boiler water.

(12) Steam locomotives have low availability
This objection is not valid for modern steam traction since it is capable of offering overall economies comparable with diesel or electric traction. To do so it must have availability comparable to both types, this being possible as a result of oil firing, modern construction and advanced boiler water treatment systems. The development of automatic boiler controls (a necessity for multiple unit capability) will further enhance availability.

(13) Steam locomotives are operationally inflexible – with diesels or electrics any number of units can be coupled together according to traffic demands
This objection is not valid since the purpose of multiple unit capability is to allow for operational flexibility.

(14) Coal transport costs are high and coal handling is difficult
This objection is not valid since the modern steam locomotive will be oil fired.

(15) Much more extensive depot facilities are required for steam
This objection is not valid for modern steam due to the use of oil firing and therefore there are no facilities required for coaling of locomotives or for ash handling.

(16) Steam locomotive water costs are high and a lot of boiler maintenance is necessary in bad water districts
This objection is no longer valid, Terlyn Industries Inc state the following on their website "Recent advances in chemical technology enabled Terlyn Industries, Inc. to develop a revolutionary performance steam locomotive boiler water treatment program."[17] In addition the reader is directed to "The practical application of 'Porta Treatment' – An advanced internal boiler water treatment system – On steam locomotives of the Ferrocarril Austral Fueguino, Rep. Argentina"[18]

(17) Overall economics of steam cannot be as good as with diesel or electric locomotives
This objection is no longer valid as Roger Waller's paper Modern Steam – An Economic and Environmental Alternative to Diesel Traction clearly illustrates.[19]

(18) Steam traction is simply outdated – which railways are adopting steam now
While this objection is not valid in that steam traction is not outdated (it is merely underdeveloped) it is valid to point out that very few railways are using steam traction. Its illustrates the difficulties that will be faced in persuading railways to adopt modern steam traction because what railway will want to be the only railway using steam traction.

---

[17] Http://www.terlyn.com/html/Isbtech.html
[18] http://www.martynbane.co.uk/Modern%20Steam/PT-290300003.htm.
[19] Roger Waller, The Sir Seymour Biscoe Tritton Lecture, Modern Steam – An Economic and Environmental Alternative to Diesel Traction, Institute of Mechanical Engineers, London, 2003, available at http://www.imeche.org.uk/railway/pdf/sir_seymour_flyer.pdf.

Conclusions

Of a total of 18 objections 14 objections namely 1,2,3,4,7,9,11,12,13,14,15,16,17 and 18 are in the opinion of the author invalid given the potential of modern multiple unit capable steam traction.

While objection 8 is conceded as being valid there are a number of possible locomotive types that do not require a trailed tender and this issue will be covered in a future paper.
Objections 6,10 are in the opinion of the author valid objections and are inter related because raising thermal efficiency (10) will reduce the need for frequent fuelling and watering (6) and also impact on (8) by allowing for smaller tenders or locomotive types not requiring trailed tenders.

Objection 5 will be the subject of a future paper.

Multiple Unit Capability and Reality

While multiple unit capability will allow the steam locomotive to compete with either diesel or electric traction it will not ensure a revival of steam traction because it highlights and emphasises two major deficiencies of the steam locomotive, these being:

- Thermal Efficiency
- The Power to Weight Ratio

In addition:

The author is aware that the development of his traction control system presents challenges due to the non-uniformity of torque of the steam locomotive. In this regard the comments of David Wardale (Item No. 38 of 1.4 Tractive Effort Diagrams) requires detailed consideration since they would appear to at variance with previous statements of his.

The presence of non-powered axles is undesirable with regard to adhesive weight, tractive effort and power and the presence of non-braked axles may not be possible.

In order to demonstrate steam locomotives working in multiple would require the designing and building of two locomotives and their demonstration to the public and railways. The resulting publicity that this would generate (even if it was purely curiosity) means that the concept would have to work perfectly from the beginning. This places an unimaginable burden on the entire project team and in the authors opinion is not the route to follow. The development route for modern multiple operational steam traction will take as its starting point a locomotive such as the 5AT or the 800AT. Based on the feedback from the congress the next contribution on this subject from the author will be entitled “The Development Route Leading to Multiple Unit Capability for the Steam Locomotive”

Finally in the authors opinion this paper illustrates that the steam locomotive has not reached or even approached the limit of its development and to quote L. D. Porta “advancing steam has a great future”[20]

[20] David Wardale, The Red Devil and other tales from the age of steam, published by the author, Inverness, 1998, p518