Reducing Tram Costs.

The cost of new trams and tramways has risen considerably in recent years, and bus rapid transit has been cited as being a better economic solution to transport improvement. The reason for this cost difference needs to be addressed; why should a vehicle running on rails cost a lot more than one running on concrete or asphalt?

Costs are often not compared on a like for like basis, but even allowing for this there are still considerable differences, and these need to be reduced.

One source is the vehicle itself, trams have become heavier, and more like conventional heavy rail ones. Light Rail should be just that, a mode between buses and urban railways in capacity and cost. The move towards low floors has produced some complex vehicle designs, far removed from the relative simplicity of a low floor bus. A reason for this is that rail vehicles conventionally do not steer round curves, and only short wheel-bases will allow satisfactory curving performance. Until the advent of low floors, bogies were used to achieve this, but proved difficult to accommodate in low floor designs, so short fixed wheel-base sections with articulations between them have become commonplace. All this has increased cost; in contrast to bus design, which uses long wheelbases in either rigid or articulated bodies. Why cannot this be done with trams?

Over the years there have been attempts to use steerable wheels on trams, but these have failed with powered wheels, but are used with trailing wheels, using German EEF technology developed in the 1990s, after a programme to develop a lightweight, cheap tram, the VoV2000 project. This failed as regards powered wheels; in my opinion due the lack of suitable drive technology.

We must consider what is required to run wheels on rails. It is often thought that the flange on rail vehicles guides wheels along the track, but actually the flange is a limiting safety system, and ideally, the flange should not contact the rails. On a conventional rail vehicle, wheels are fixed to an axle, and the wheels are slightly coned. This forms a feed-back system, on straight track the wheels settle to run at equal diameters. On gentle curves, the outer wheel has to travel a longer distance, and the inner one shorter, so the running position changes so that outer wheel runs at a slightly larger diameter, the inner one at a smaller diameter. As this is a feedback system, it can become unstable, and “hunting” occurs. To enable a good ride, dampers have to be introduced to the bogies to reduce this. On sharp curves, conicity steering is unable to cope, and flange steering occurs, and as both wheels cannot both run at the correct speed, slippage, with wear and noise, occurs.

One way of achieving low floors has been to remove the conventional axle, and have independent wheels. This removes the feedback effect of the axle, but the coned wheels still largely settle into a suitable running position by gravity, keeping them largely at the same radius. This now allows wheels to run at different speeds when negotiating sharp curves, and has been reasonably successful, but there has recently been a tendency to return to axles with small diameter wheels, especially for powered wheels.

My proposal is to actually use the powered wheels as a source of steering. If each wheel could be driven at the precise speed required for the track curvature, and the wheels be pivoted on their vertical axis, they would run tangentially to the track; this after all is how electric wheel-chairs are steered! This requires a drive that can be run at a precise pre-determined speed, and a way of calculating that speed. Wheel-motors have been developed that incorporate a multi-pole permanent magnet synchronous motor as an integral part of the wheel; and these allow such a drive to be possible. The property of such a motor is that it can ONLY operate at a fixed speed, proportional to the frequency of the electrical supply. If two opposite wheel-motors are powered at equal frequency, it is almost the same as having a conventional axle between them, as it is a very stiff drive, allowing only a few degrees of torsion. On entering a curve, the frequencies are varied, so that the outer wheel is speeded up, and the inner one slowed down, at the precise rate so that the wheels run tangentially to the rails. This has been demonstrated on a scaled down rig, and can be seen on YouTube under “Steerable Wheel-motors”. This shows an equivalent to a 10m long wheel-base negotiating 25m radius curves. In this case the required frequencies were calculated from information from a detector array at the vehicle front, that by electromagnetic means measured the deviation of the track ahead.

By using such a system, a much simpler vehicle layout is possible, and running gear weight is considerably reduced, by both the halving the wheel number and the reduction of drive weight by use of Wheel-motors, which are very compact, simple and lightweight compared to conventional motors with gears and drive shafts. They are also very efficient, up to 97%, and operate naturally in regenerative mode when braking, and give the possibility of recovering over 60% of input traction energy when braking.

Wheel-motors are made by Stored Energy Technology Ltd in Derby (SET), and have been trialled under a Blackpool tram, successfully running over 2,000Km. However, these were fitted to a conventional bogie, so steering was not done, but they did run at differential speeds on curves. This trial can be seen on their web-site, set.gb.com

I want to see this taken forward to get a full size test / demonstration vehicle built with steering, and I include drawings. I am also building a miniature version to operate on a tramway layout in my garden; this includes all sorts of track topology, plain, grooved and points and crossings.

I now believe that steering information can be attained from the electrical conditions of the motors themselves, removing the need for the track detector array. A problem is safety under failure mode. The suspension showed on the You Tube trial was unstable in the event of drive failure, but I have since developed one that will revert to flange guidance in failure mode. This works on trials on my garden layout, and is essentially similar to the German EEF unpowered running gear.

The recovery of regenerated energy would be greatly enhanced by incorporating Ultra-capacitors into the vehicle. These would recycle regenerated energy for use in acceleration; and also greatly reduce peak currents in the electrical distribution system.

Using this technology, it should be possible to achieve vehicle a weight of 10 Tonnes per 100 passenger capacity, with traction energy consumption of 0.5KWh / Km. The aim should be also to get cost down to that of buses on a similar capacity basis. Indeed, bus body technology would be used, the vehicle form being essentially similar to an articulated bus.

The vehicle roof will be free of electrical equipment except for the pantograph; other components will be either under seats and cab, and indeed under-floor, even for a low floor design. This will make possible a much lighter and lower height vehicle body.

Having achieved a low cost, lightweight vehicle, attention should now be put to the track. A lightweight vehicle with low track-forces will allow a lighter track construction to be possible, and the low height vehicle will reduce the cost of incorporating subways and underpasses. The excessive removal of utilities should not be pursued, the thinner trackbed will help, and temporary track can be used during any utility work, as is done in mainland Europe. The Ultra-capacitors will help here, as short sections of off-wire running will be possible.

Thought should be put into what voltage tram systems should use. Traditional systems used 550-600Vdc; but second generation systems have gone for 750Vdc as standard. This increase in voltage reduces current, and transmission losses are reduced by about 36%, but it has a disadvantage regarding the power electronic components in the vehicle. If 600V operation were to be implemented, standard industrial grade components could be used, which are relatively cheap, and also have lower electrical losses, and can be operated at higher frequencies, which reduce audible noise; and reduces the size and weight of filter components. The increased transmission loss would be overcome by the use of Ultra-capacitors; which will reduce transmission losses about ten-fold.

All of this would enable tramway costs to come down to levels comparable to that of busways, but giving all the advantages of trams and light rail, and energy costs would be considerably reduced. (A rail vehicle has vastly lower rolling resistance than a road based one.)

I would like to see funding made available for a trial of such a system, it could be the start of a new British industry, important in that we may well see the end of conventional rail vehicle building in this country, with the possible closure of Bombardier in my home city of Derby.

A Way Forward.

A company should be created to take this development forward. It would work with SET, but be separate. Atlas Works in Derby, where SET is situated, has spare premises which could be used, and space for a test track, which has been planned for some years, but not taken forward for funding reasons, apart from a short indoor track, where the Blackpool tram used for trials now resides, and can be demonstrated. A traction power supply exists. I have the tacit agreement from the site owner for this to be possible.

The vehicle body would be preferably be constructed by a bus manufacturer, and would use as much as possible existing bus designs. The Wheel-motors and electrical equipment would be built by SET, and mechanical work on suspensions and assembly would be carried out by both SET and their sister on-site company, GGS Engineering.

I estimate that the cost of getting to the production of a working prototype, and provision of the test track would be about £2M. Beyond this, more finance would be necessary to get through full approvals, and to get high speed tests carried out (the initial test track would be an oval , about 300m in length, and allow continuous running, with good tests of curving performance, but would not allow speeds much higher than 15mph.) There happens to be (for now) a test track literally over the road at the Bombardier site, but of course its future is now uncertain. This is largely straight, so between the two, full trials could be undertaken.

Another possibility is setting up a test / demonstration track on the site of an old railway in Derby. This has been earmarked by the City Council for future transport use, either light rail or busway. A test light rail line set up here could therefore eventually be a part of a light rail system in Derby. It would be built with cost reduction in mind, and different forms of track construction, along with lightweight overhead equipment could be trialled, to find the most economic ways to attain light rail and tram systems.

About the Author.

I am an electrical engineer, and was the originator of the Wheel-motor, and a founder of Stored Energy Technology Ltd, in which I still have an interest, though I am no longer a part of it. SET do not themselves want to be involved in vehicle development, but to supply Wheel-motors to others.

I would want to be involved in the new company, largely in an advisory capacity, and my technology is available free of charge. My aim is to see the increased implementation of tram and light rail schemes by considerable cost reduction.

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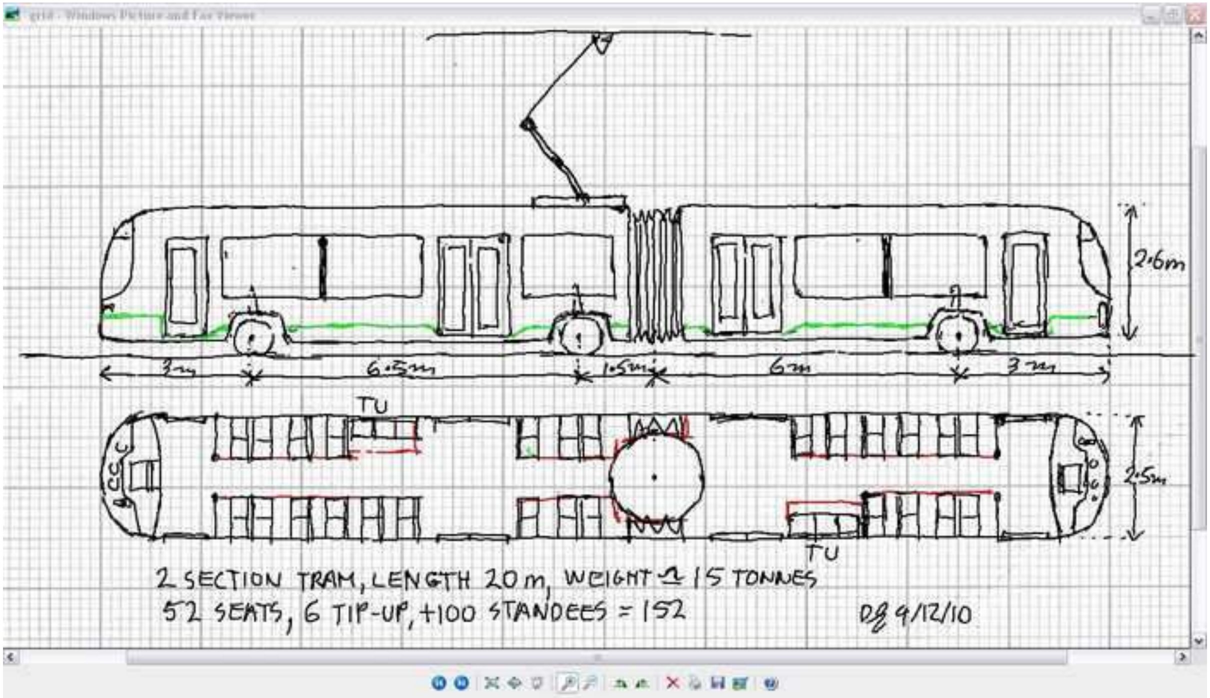
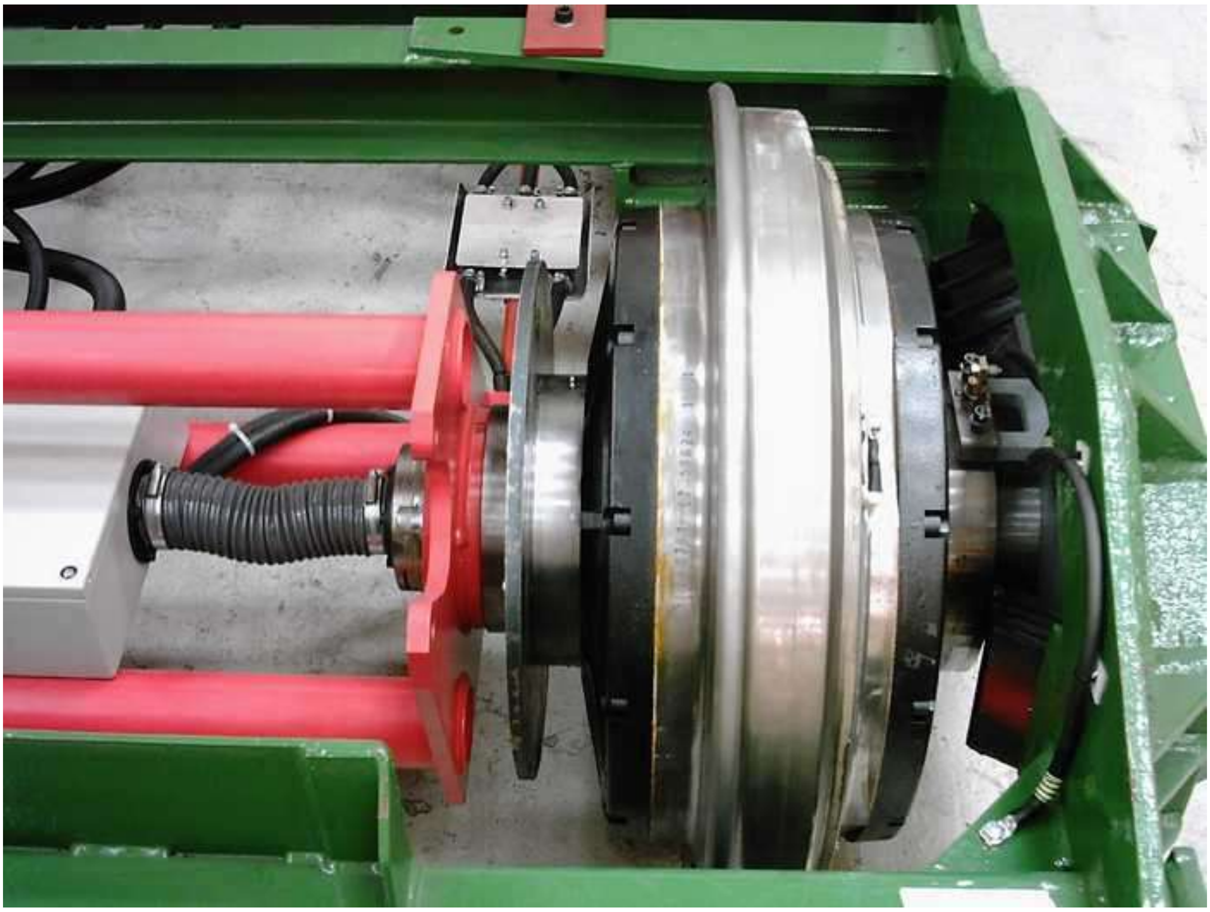
Miniature steerable wheel-motor set.



Proposal for a two section tram. Extra sections can be added, each with two Wheel-motors.



50KW Wheel-motor in Blackpool bogie.