An introduction to intelligent DTS

Graham Penfold, Route On-Track Machine Engineer (Western), Network Rail, details the use of the technology.

Dynamic Track Stabilisation, or DTS as it is also known, has existed in the UK since 1975. It is an integral part of track maintenance regimes worldwide with over 900 machines in operation in 45 countries and is mandatory on many high-speed lines in Continental Europe. Despite this fact, DTS sees relatively little use in the UK, being mainly limited to high output ballast cleaning and tamping associated with high output track renewals. There seems to reside an innate fear and apprehension whenever the acronym DTS is mentioned but, hopefully, this is about to change in the near future with the recent introduction of the Plasser & Theurer Unimat 09-4x4/4S Dynamic tampers, as shown right in Figure 1a, with their accompanying Intelligent DTS systems (Figure 1b).

How DTS works

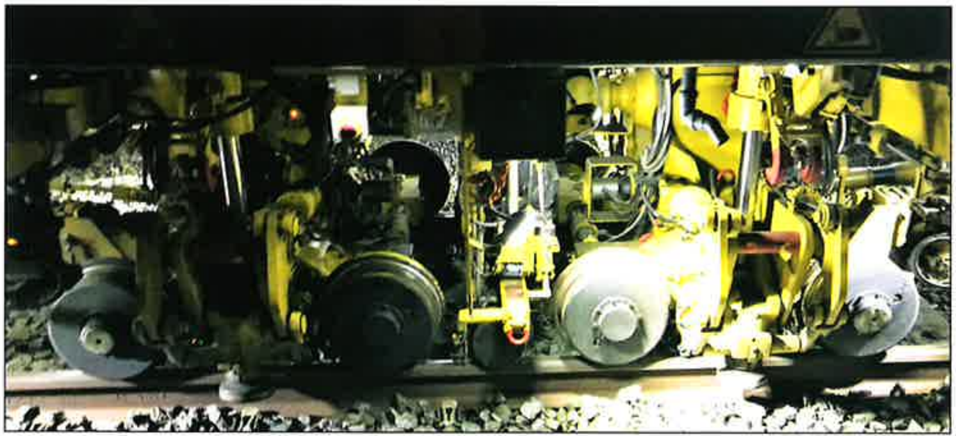
DTS is not a complicated system and, as shown in Figure 2, is fundamentally a vibration drive consisting of two rotating cardan shafts (1). Each rotating shaft has two encased fly-gear boxes containing a toothed wheel with a mass on one side, which is offset, and when rotated at a set frequency creates an eccentric rotating mass. Once in motion, this eccentric mass causes horizontal vibration (2) while simultaneously four hydraulic cylinders (3) apply a static vertical load (4) as the machine traverses the site.

This vibration is transferred by flanged rollers that are tensioned against the running head of the rail while, simultaneously, horizontal rollers are clamped on to the back edge, as shown in Figure 3, ensuring a tight grip on the rail so the vibration is transferred by literally rubbing the sleeper/bear/timber into the ballast.

The frequency range for optimal compaction of ballast should be between 30-35Hz with the chosen frequency the one which resonates the least or keeps the machine most stable. It is not a case of the higher the frequency the better the compaction as higher ranges greater than 35Hz start to liquify the ballast, reducing compaction. The physical displacement or amplitude of the track is influenced by the frequency and can be calculated. These calculations have shown an amplitude range of 2.25mm at 30Hz to 2mm at 35Hz.

Above: Figure 1a - The Plasser & Theurer Unimat 09-4x4/4S Dynamic tamper.

Below: Figure 1b - The machine's Intelligent DTS unit.



Forces of DTS

There are two main forces involved during DTS. These are static vertical load and impact force and can be calculated by:

- Total vertical force = total DTS unit mass + piston force (pressure in bar x cylinder area) x 4.

While the force of the horizontal vibration is:

- Impact force = total eccentric mass x radii x circular frequency (ω) or $(2 \pi f)^2$.

This way, the forces applied by DTS can be accurately observed and recorded.

Why use DTS?

Railway ballast is specified to be 50mm in grade, porous, free draining as well as angular and abrasive to allow tight and robust interlocking for maximum support of the track system. During tamping, track renewal, ballast cleaning or reballasting of the track, ballast becomes less compact and loose with more space between the stone resulting in less surface contact, reduced friction (and weight), promoting an unequal, inhomogeneous state as shown in Figure 4 on the next page.

Figure 2 - Animation of DTS units showing - cardan shafts (1) horizontal vibration (2), hydraulic cylinders (3) and vertical load (4).

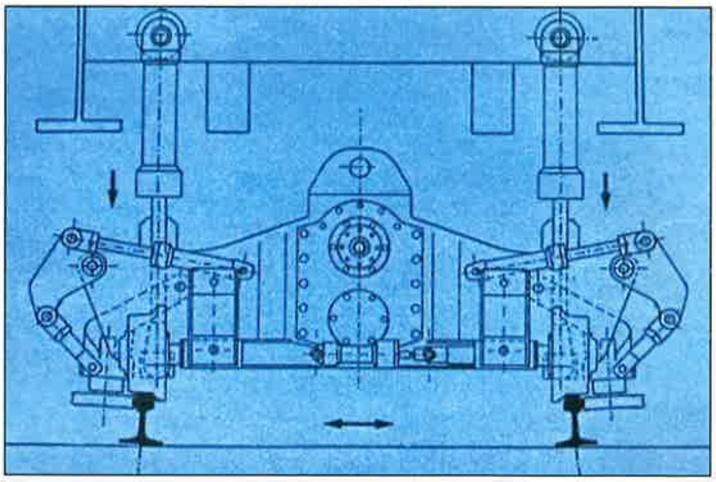


Figure 3 - Frontal cross-section of the DTS unit illustrating tension rollers and clamps.

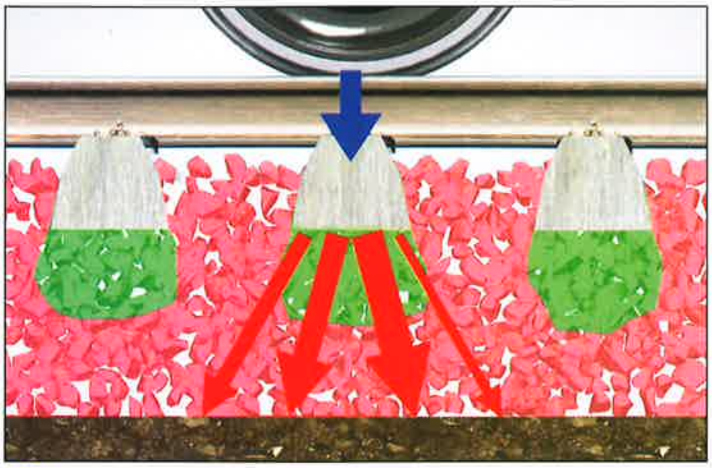


Figure 4 - Ballast compacted only at tamper packing points, resulting in inhomogeneous settlement.

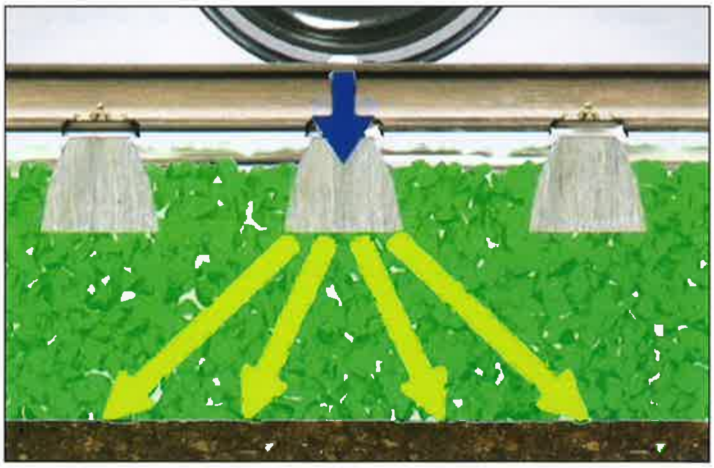


Figure 5 - Controlled compaction of whole ballast bed, leaving stable, homogeneous track support.

This results in less support with lower resistance to dynamic, lateral and longitudinal forces. Settlement then takes place under the passage of trains (vehicles). Different vehicle types have a range of characteristics including fixed wheel sets, bogies with varying suspension/dampening systems, axle weights, maximum speeds and wheel profiles, all contributing to an uncontrolled, uneven, erratic settlement. This reduces the value of the initial track quality achieved post-tamping, causing significant damage to ballast as the angular corners of the aggregates break under loading, leaving fines that reduce the ballast grade, while also adversely effecting longevity. It is widely and incorrectly thought that the tamping process is the primary cause of ballast damage when it is actually this uncontrolled settlement. Critically, this uncontrolled settlement decreases track stability, posing a higher risk of deforming and track buckling, where the permissible speeds will have to be reduced or hot weather precautions applied until the track has sufficiently compacted under traffic.

However, artificial, controlled stabilisation using DTS evenly consolidates the whole ballast bed and not just at the packing points from tamping tines. This creates denser layers of highly-compacted stone, reducing the space between each stone, whilst at the same time increasing the friction between, thereby forming a significantly stronger interlocked structure as shown in Figure 5. The key factors of settlement using DTS are magnitude of lift, vibration frequency, ballast grade/condition, subgrade/formation condition, vertical load and impact force.

Compaction through DTS is inexpensive and can be executed simultaneously as part of, or following, the tamping operation and has numerous benefits such as:

- An even, homogeneous consolidation of the entire ballast bed.
- Increased stiffness of ballast layers and formation.
- Evenly-distributed dynamic forces on to the formation and surrounding ground.
- Significant increase in lateral stability. Reduced track buckle/misalignment risk.
- Higher critical rail temperatures - 5 degrees Celsius (NR/L2/TRK001 Mod 14).
- Controlled, rapid settlement reducing damage to ballast.
- Increased longevity of track quality.
- Reduced maintenance intervals (up to 30%).
- Lower exposure of staff to unplanned work when reacting to faults.
- Less stress on track components and fastenings.
- Higher handback speeds; reduced need for speed restrictions.

On machines which have conventional or fixed type DTS, the eccentric mass is fixed at a set radius so the only way of influencing impact force is by adjusting the frequency. Critically, on intelligent or variable DTS, the radii of the 43.45kg eccentric mass or imbalance can be varied from 0 to 17.3mm (0-100%), giving control of the impact forces applied. There are also three ways this imbalance can be used:

- Constant - a fixed value from 0% - 100% can be fixed through the site, with the nominal being 80%.
- Automatic lowering - a lowering (settlement) value can be set up to 12mm in maintenance and 30mm for renewal, where the system will adjust the imbalance to achieve the set value.
- Automatic speed - the machine will use the ideal imbalance setting, defaulted at 80%. However, when the machine slows down, the imbalance will automatically reduce to compensate, preventing prolonged high-impact forces in the same area.

Additionally, the static vertical load can also be applied three ways:

- Constant - a selected constant load within the range of the machine is applied to both rails regardless of settlement.
- Standard - each rail is separately measured with the pressure increasing or decreasing accordingly to attain the required preset level and cross-level from the tamping operation.
- High rail variable low rail constant - the low rail pressure will be fixed at the pressure selected and the high rail pressure will vary the set pressure to maintain or achieve the desired cross-level.

All other conventional DTS machines have set imbalance and can only apply the vertical load constantly, apart from the Automatic Finishing Machine (AFM) which also has the standard option. The standard option uses the on-board tamping ALC to generate the target levels for the front and rear DTS pendulums. A microcomputer then compares these with the actual values and generates a correction. The correction is 15 bar/mm with a maximum of 2mm e.g. 30 bar. This is added or subtracted, depending on whether one rail is higher or lower, from the value of downward pressure initially selected. The different machines also have varying vertical load pressure and frequency ranges, along with differing eccentric masses and maximum working speeds, but all have the same piston diameters. Table 1 below shows a concise summary of the UK machines' specifications.

Ramping in and out using intelligent DTS

On conventional machines, only the vertical load can be ramped in or out. With intelligent DTS, both the vertical load and imbalance can be ramped, the minimum and default setting is 15m, which can be done using three different methods:

- No ramp in or ramp out - the DTS starts immediately with no ramp incorporating the nominal settings set by the operator.
- No start delay - the DTS starts ramping in immediately when turned on. The ramp distance is adjustable. When the DTS is turned off, it is ramped down.
- Delay mode - the operator identifies the DTS

Table 1: The various configurations and setting ranges of UK DTS machines.

Machine Type	Frequency Range (Hz)	Eccentric Mass (Kg)	Amplitude (m)	Vertical Load (Bar)	Piston Diameter (mm)	DTS Unit Weight (Ton)	Working Speed (mph)
DGS 62-N	0 - 42	14.26	0.0498	40 - 100	100	2	0 - 2000
09-2X Dynamic	28 - 40	14.26	0.0498	25 - 60	100	2	0 - 2000
09-3X Dynamic	28 - 40	14.26	0.0498	40 - 70 25 - 60(PIC)^	100	2	0 - 2000
09-4x4/4S Dynamic	28 - 38	43.45	0 - 0.0173	40 - 70	100	2	0 - 2000
09-CM*	28 - 40	17.11	0.0498	30 - 70	100	2	0 - 500
09-2X-CM*	28 - 40	17.11	0.0498	30 - 70	100	2	0 - 500
AFM 2000-RT	0 - 42	14.26	0.0498	40 - 65	100	2	0 - 2000

Notes: * These machines only work with ballast cleaners. ***^ These are High Output Ballast Cleaning System 5 machines.***

start position of the tamping by pressing the trigger button and the location is stored by the machine. It continues to tamp until the DTS reaches this position before automatically ramping in. The length of the ramp is adjustable. When the end position (DTS) is reached, the operator presses the trigger button and the ramp-down function is activated.

All these adjustable parameters make intelligent DTS incredibly flexible, controllable and highly compatible for many different types of site with varying track construction, earthworks, track types, configurations, structures, etc. For example, on a renewal site where three passes are planned, the first two passes could be in constant vertical load with a high imbalance to achieve maximum compaction of the ballast layers, while the final pass could be standard vertical load with lower imbalance to achieve the desired cross-level and track quality. While on a maintenance site, which almost always equates to one pass, only the lifts applied require consolidation so standard vertical load with a constant imbalance set to a lower imbalance would suit.

DTS with structures

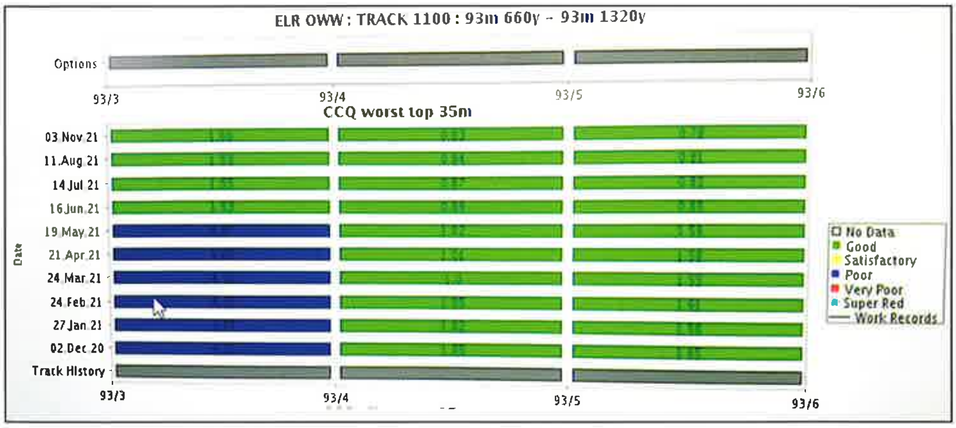
This seems to be the area that attracts the most concern. However, as structures and buildings tend to resonate around 23-25Hz if the DTS is kept between 30-35Hz, the risk is very low with the exception of structures incorporating cast-iron elements and tunnels which are avoided. DTS vibration does travel further laterally than trains or tampers but studies have shown these are very low and, after two metres, around 85% of the forces have dissipated. Studies have also shown that tamping can generate five-to-six times as much force vertically than DTS and generally, on the continent, the rule of thumb is if tamping is permitted then DTS is also acceptable. That said, caution must be exercised when using DTS in these areas and currently there is a trial where each planned mileage is entered on to a specific form, which then automatically populates the mileages of all buildings and structures, along with their associated risk category, ready for endorsement by the relevant department. There is also a detailed register of all DTS sites with all modes and settings accurately recorded for reference.

DTS with S&C

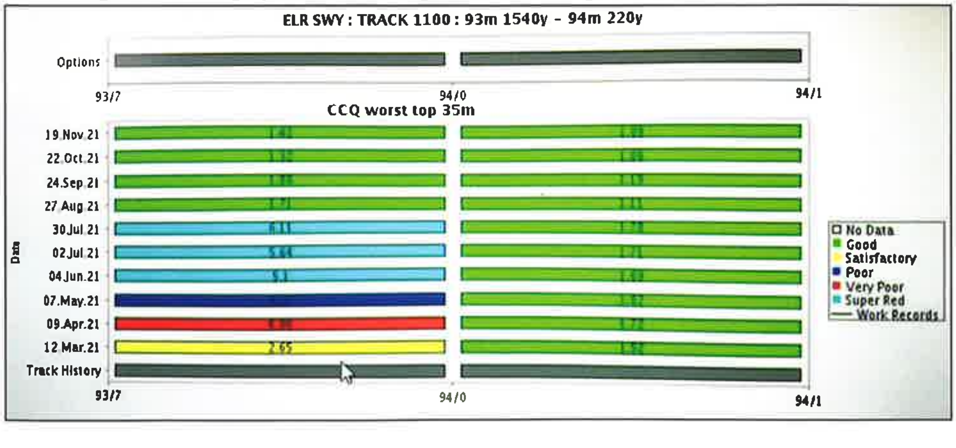
DTS is currently being trialled on Switches & Crossings (S&C) which have modern Point Operating Equipment (POE) such as Hy-drive, In Bearer Clamp Lock (IBCL) and High Performance Switch System (HPSS). So far, results have been encouraging, both in terms of longevity and performance.

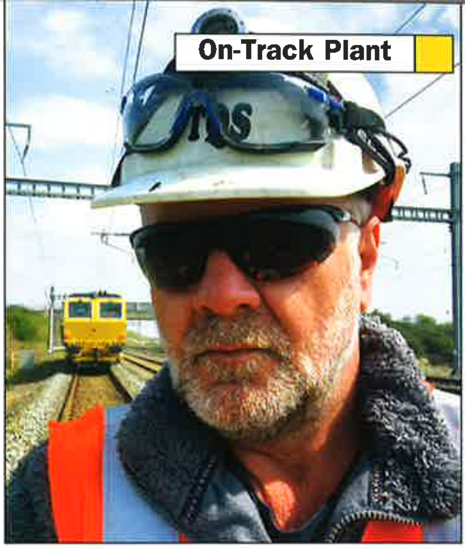
Richard Philips, Track Quality Supervisor, Swindon, Network Rail, said: 'The DTS looks to have an excellent ironing out effect and is very good over non-tampable bearers as, once manual packing with orbital tamper packers is complete, the additional DTS consolidation is considerably more consistent than when left by conventional S&C tamping. I use the DTS after parallel tamping as the constant, non-stop movement again lends to a more even and consistent compaction. It generally only takes around an additional 15 minutes to complete.'

Again, there are a number of detailed post-DTS site checks tailored for each type of POE although considerable time must be given to removing and reinstating the break-out devices on Hy-drive systems. Richard also used the imbalance auto-speed mode tamping on a turnout at Appleford on the Didcot and Chester line. This mode lowers the imbalance and, therefore, the impact force as the speed of the machine reduces and he concluded: 'The way the machine compensates the DTS when the speed fluctuates, as is the case during S&C tamping, is ideal. I have been back to Appleford and Tackley several times since the DTS tamps and the historical voiding issues have significantly decreased and, in some cases, been eradicated.'



Above: Figure 6 - CCQ graph for Aston Magna. Below: Figure 7 - CCQ graph for Heyward Road.





Richard Philips, Track Quality Supervisor, Swindon, Network Rail.

Summary

It is early days for Intelligent DTS but its flexibility and advantages are beginning to show. Figure 6 below, shows a CCQ graph illustrating track quality for the 35m worst top for Aston Magna on the Oxford, Worcester and Wolverhampton line. This site has a tight curve of maximum 150mm cant running at maximum 110mm cant deficiency. The intervention was on 14th June 2021 using low rail constant high rail variable vertical load, which has so far shown to be the best method on high canted track. The results show a very slow degradation of track quality, which was particularly impressive on the 'blue coloured 'Poor' eighth' as these sites tend to deteriorate quicker due to ballast memory (prolonged weaker consolidation at track geometry faults), which has been significantly reduced by the thorough DTS compaction.

Another excellent example is the multiple slurried (wet) bed site at Heyward Road, Westbury, shown in Figure 7, where there were two passes. The first, on 26th August 2021, using constant vertical load with a high imbalance setting of 95% designed to achieve maximum compaction, improved the quality band from 'Super Red' to 'Good'.

The second pass on 7th October 2021 was used with standard vertical load and 85% imbalance, a lighter pass adjusting for cross-level, which resulted in further improvement.

Along with this, the Resistance to Lateral Displacement (RLD), which is also being analysed, involves complex formulae regarding equipment function, efficiency, trackbed resonance, applied lifts and DTS settings to calculate the force required to move a sleeper post-work by 2mm. From this, we can then gather more information regarding critical rail temperatures (the rail temperature could mandate certain actions, including a speed restriction, to be applied until the track has settled post-tamping). The RLD can also produce valuable data pertaining to the opening speed of a line after renewal or reballast.

So, at the moment, these are exciting times for DTS, particularly with the multi-faceted intelligent DTS system, which could have a growing influence on future track renewal and maintenance work. There is still much work to be done analysing how amplitude, applied lift, working speed and imbalance all contribute to settlement, but with numerous benefits DTS could play an integral part in reducing whole-life costs for the railway in the immediate and long-term future. ●