KEY TOKEN SIGNALLING FOR THE 21ST CENTURY

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Summary

This paper outlines the development of the Networked Digital Key Token System, or NDKTS, that couples 21st century electronics with the principles of traditional, physical key token working.

Simple single line railways, for which sophisticated signalling is not an option, may have passing loops but may not have the personnel nor signalling infrastructure to operate them. Even if conventional token machines are available, then these can require cabling between machines and, most importantly, offer no operating flexibility. Thus train running is tied to fixed timetables and cannot react to passenger expectations, or perturbations of rolling stock performance.

NDKTS, having been developed from scratch, has given the opportunity to use as many Components Of The Shelf (COTS) as possible. Bespoke locks are assembled from stock items with just a few specialist components, all of which can be made using conventional machining.

It has been designed for railways with a mixed, transient rolling stock for which permanent in-cab signalling is inappropriate. This paper will outline the background to the project, the key design considerations that have affected it and the process of evolution from prototype to a marketable product.

1 INTRODUCTION

Key token signalling for single lines has existed for many generations. The basic principle is that a train may only enter a single line section if the driver is in possession of a token which details the section involved. Whilst there may be several tokens for the section shared between token machines at each end of a single line, only one token can held by the driver of a train. The others must be securely captured within the machines. If one token is not captured – and, by implication, held by the driver of a train on line - then hardware must ensure that no further tokens can be released.

The system described in this paper retains the principles of key token signalling, but achieves this by using an unconventional mix of software and hardware.

In the following script, the term ‘token’ refers to a plate engraved with the limits of train movement – a movement authority. The term ‘key’ refers to a physical key that is placed in a lock barrel. ‘Key token’ is the term used where a key and a token are combined as a single object and where the key portion is placed in a locking mechanism. The key and the token can be one rigid item or attached to each other with a chain or cable.

2 THE OPERATING CHALLENGE

Very basic railways, away from national networks, face challenges when it comes to running frequent and flexible train services. Modern technological options available today may be inappropriate for a number of reasons.

- Cost. Quite simply, a basic railway may not command the quantity or longevity of traffic to justify any major investment;
- The transient nature of rolling stock. A wide variety of ages and types of rolling stock may rule out the fitting of in-cab signalling.

2.1 The Requirements

To cater for the type of railway undertakings that are so basic as to be ‘under the radar’, it is necessary to recap on why a traditional key token system could be attractive.

It would address

- Cost – although the installation cost of fixed lineside cabling may cause the investment case to fail;
- The transient nature of the rolling stock. No in-cab installations would be required apart, perhaps, for a hook to hang the token;

But, a traditional key token system would not address

- Any aspiration to run more trains, or a more flexible timetable or a service which can repaired after disruption. Conventional key token machines are inflexible;
- Vulnerability. Lineside cabling and equipment may be vulnerable to vandalism and theft;
- Any need to remove the signalling system out of season or between long term traffic flows.

2.2 NDKTS

To overcome the above shortcomings, a new variant of the key token system - NDKTS - has been developed.

It is tempting to compare NDKTS with traditional key token systems. In that they both use a token as an authority to enter a specified section of track they are similar, but this is where any similarity ends.

Traditional key token machines are linked by cable and use polarity detection as a way of ensuring only one key token can be removed from a system at one time. Even modern versions/conversions, which use the internet, emulate the same principle.

Apart from rare and complex traditional systems, there are no ways of introducing any sort of operating flexibility in the form of switching between short* and long** tokens.

*A short token is one that allows train working between token machines at each end of a section and no further. A train running through a railway that comprises only of short sections needs to stop at each token machine to obtain or surrender a token.

**A long section covers a longer distance and will include one or more pairs of intermediate short token machines which are effectively switched out of use. If there is the facility for long section working, then a train needs to stop only at the ends of the long section. Thus journey times through the railway can be shortened.

3. NDKTS MACHINES AND THEIR USE

A traditional key token machine has one escapement – one lock – and several keys, all of which fit that one lock and all of which are allocated to a single section.

An NDKTS machine is stocked with separate locks, each made with a specific key for a specific section.

A traditional key token machine administers the release of keys by checking that polarities are aligned between pairs of machines allocated to one single line.

The NDKTS system administers the release of keys by counting *all* keys on a railway and by accounting for *each* key in each line section.

3.1 The NDKTS locks and keys

The NDKTS locks and keys are identified with a particular section or groups of sections. Thus, in the example shown below in Figure 1 below, the machine at A could have three* short nearer section locks and three long section locks. (*The way that the number of locks at a location is decided is covered in section 3.1.1)

Its twinned counterpart at the other end of the long section (D) would have three short section locks for the remote short section and three long section locks. Their twinned counterparts at the ends of the short sections (B & C) could each have three short section locks. There would be three keys allocated to the long section locks and so the long section would be in balance if those three keys were locked in to any of the three long section locks. The same logic applies to the short section locks which would have three keys shared between each of the short section locks. (The dump lock is explained in section 4.2.6.)

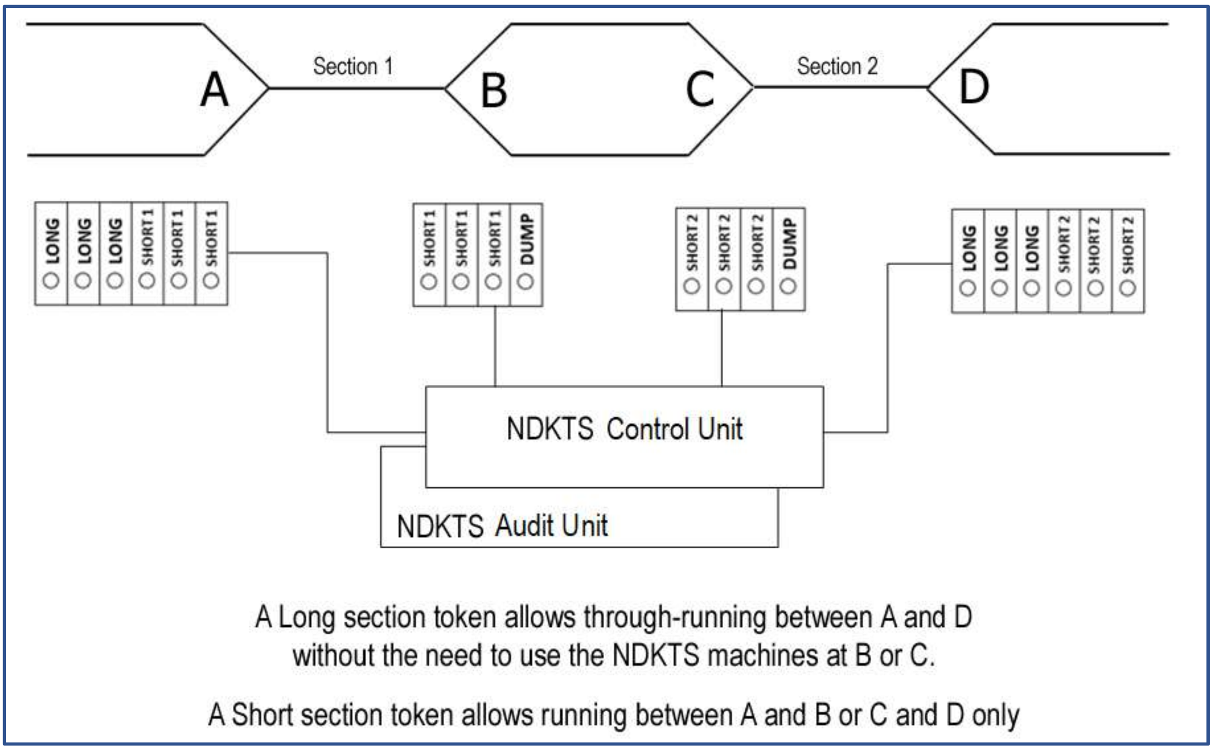

Figure 1: Simple NDKTS arrangement

3.1.1 Lock numbers

Specifying the number of locks in each machine is an strategic train operating design issue and will be determined by analysing the train graph related to the planned timetable with an allowance for service disruption.
The number is also influenced by the amount of rolling stock likely to be in service at any one time. For a very simple railway there would be fewer locks. The lock configuration would be more complex for a railway involving several extended sections. The allocation of locks shown in Figure 1 is therefore for Illustrative purposes only.

3.2 Counting and Accounting

By knowing the state of each lock (whether a key is trapped in or not) it is possible to count and account for all the keys in all of the system. Counting the keys will identify if a key is out (or potentially out) in a particular section or whether sections are in balance.

Accounting for the keys will reveal *which* keys are in or out. Counting and accounting enables the system to group sections together to allow long section working and it allows long sections to be split into short sections.

In the layout shown in Figure 1, if the long section (A – D) has a key out then a key cannot be withdrawn from either of the short sections (A – B) or (C – D).

If any of the short section keys are out, then a long section key cannot be withdrawn.

If a short section key is out in A – B (for example), it will be possible to withdraw a short section key from C - D.

These are the basic ‘rules of the route’ for the layout in Figure 1.

Accounting also allows the introduction of an hitherto unknown facility - the long section dump shown at B and C in Figure 1 - which enables a failed train to surrender a long token at a short section machine. Its use is detailed in Section 4.2.6.

4 BASICS OF THE SYSTEM IN USE

For the purposes of simplicity, this section describes how a driver obtains a token – if available – on a simple single line such as that shown in Figure 1. The example described assumes that the driver interfaces with a touch screen.

4.1 No Train In Section and the System In Balance.

The system automatically performs a routine census of keys every minute. This is achieved when the control unit requests all the NDKTS machines to give an update on the state of their keys. When all the census data is returned, the control unit compares the state of the locks with the set of rules and declares the line clear (the total number of keys accounted for in the section tallies with the number keys allocated to the section) or occupied (the total number of keys accounted for in the section does not tally with the number keys allocated to the section).

This analysis is applied to **all** the sections on the railway and gives a picture of which sections are occupied and which are clear.

4.2 Running a Train from A to D.

4.2.1 Semi-automatic or manual mode

The system can be run in a semi-automatic or manual mode.

Semi-automatic allows the driver to start the process of applying for a token and is the default mode, enabling the controller to have a hands-off approach. It is used when everything is going to plan.

Manual mode is used when the controller needs to take control and regulate the trains to minimise passenger delays. When in manual mode, the drivers' interfaces are disabled. It is only the controller that can switch the system between semi-automatic and manual – and back.

4.2.2 The census of locks

The driver contacts the line controller to check that the move is permitted (from a train regulation point of view). If the line controller agrees, then the driver taps in the train number, all other inputs are temporarily disabled and the system carries out a real-time census of keys. (In fact, if the previous census had shown that the system was not in balance, the option to initiate the key withdrawal process would not be available in the first place.)

If the result of the census confirms that the system is in balance, then the control unit asks the audit unit for its opinion.

4.2.3 Audit unit actions

The audit unit listens constantly to all the messages that pass between the various machines and also checks that any actions are consistent with the rules.

If the audit unit agrees with the key application, it sends a command to the appropriate NDKTS machine requesting that a relay in the appropriate lock is energised. This command only energises a relay, not the releasing solenoid. The relay contacts close and complete a circuit to the solenoid. After reporting back to the control unit that all is in order and that the relay has been energised, the control unit then sends a command to the NDKTS machine to send current through the solenoid. This will only result in lifting the solenoid plunger if the relay circuit has been closed.

The audit unit is headless. It just works in the background.

4.2.4 Key withdrawal

The solenoid plunger lifts clear of the lock cam so allowing it to be turned by a quarter turn. This is enough to allow the withdrawal of the key and the attached token. After six seconds the solenoid and the relay are de-energised and the plunger is free to drop. If the key has been withdrawn or even if the key has only been turned slightly, the plunger will not drop. The limit switches above the solenoid plunger detect that the plunger is up and that a key is out or is potentially out. This is detected by a key census immediately after the solenoid is de-energised.
If the key remains out, then the system shows the section of line to be occupied – or potentially occupied.

4.2.5 Key return

If the key is returned without a train movement, then the return of the key is detected as soon as the limit switch state changes when the solenoid drops to trap the key.

If the key is never turned, then the solenoid will drop back to trap the key and the key state is detected.

If the driver completes the journey and is clear of the single line, the key is simply returned to a corresponding lock in the remote NDKTS machine. The machine will detect that a key has been returned. It will prompt a census of all keys and return the system to balance ready for another key to be taken out.

4.2.6 The use of the long section dump lock

The long section dump is a lock located in a short section NDKTS machine. It will have a key combination that will accept long tokens only. It is simply just another lock that is examined in the key census. As a result, it is possible to cater for a train with a long section token to surrender its token in the event of train failure or other disruption. When the long section token is returned to a dump, the system will acknowledge that the system is in balance once more even though there is a train locked in a loop. Being clear of the single line/s, the system will allow another train to obtain a short (or even another long) token and allow the movement of passengers to continue.

When the train recovers, it will be able to obtain a further token to continue its journey. The rules will determine what type of token is allowable. It is in these circumstances that the Line Controller would probably operate the system manually so as to achieve the best train regulation to minimise train delays and passenger frustration.

4.2.7 Recovery

If the process stalls for any reason, then the census routine will clear all commands and outputs. The census is initiated either by the Controller or by the system itself after a minute of inaction.

4.2.8 Logic spinoffs

The token census routine generates enough information for each NDKTS display to show whether a section is occupied or clear, the type of tokens that can be made available, whether a train is inbound or outbound and the identity of the train. Displays can also show the flow (or not) of data, the state of power supplies on the system, the health of the network and any lock malfunctions.

The control unit can have a user interface for the controller that interprets the messages that are exchanged and, as a result, can apply logic to display train positions and identities on a diagram.

4.3 Practical Controller Considerations

On many minor railways Line Controllers have varied duties. Controlling train movements is but one of them. It is probable that other duties would involve selling tickets, announcing trains, sorting out the car park, finding lost children and generally being thoroughly distracted. Certainly, it is probable that the Line Controller would not be close to a control machine.

The system can still operate in these circumstances with the Line Controller having an overview of the line through a remote desktop type application that would replicate any display on the control unit. Being a passive display, the system would continue to operate safely even if this remote display fails.

5 SYSTEM ARCHITECTURE

Right at the start it should be emphasised that the NDKTS breaks no new ground.

There are no new principals of railway working. Even the use of the new long section dump applies normal operating principles.

All the components in the system are already available to the railway industry and beyond. These are:

- A network of computers – this can be a closed system or via the internet connected by phone line or via a mobile phone;

- Instant messaging – this is an established method of communication for the simple codes involved in NDKTS;
- Software to manage the messages, to monitor the states of the locks, to monitor power and hardware issues and to manage the rules of the railway;
- Multiple ways of presenting information. Information can be via touchscreens or by using headless machines through the use of push buttons and LEDs;
- Security systems to safeguard the network and the component computers;
- I/O boards that can note the state of individual locks and which can react to commands – there are many on the market.

5.1 The NDKTS Locks

The hardware interfaces – the mechanical NDKTS locks – do not break new ground because solenoid-controlled, trapped-key, detectable locks already exist - although commercially available versions are bulky, geared to the control of industrial machinery and are relatively expensive. It is rare for more than one commercial lock to be installed at a location.

At the start of the project there was a problem of to how to design a lock without becoming involved with the design of a key and barrel mechanism.

After abortive experimentation with several options, the use of a standard cylinder rim lock was chosen because these have a proven history of reliable performance and, most importantly of all, because keys are securely trapped within the cylinder if they are rotated away from the withdrawal position. This is a normal and fortunate feature of what is recognisable as the ubiquitous front door lock, all varieties of which have standard fixing geometry and are widely available from many manufacturers.

A flat blade – or cam - extends at the rear of a cylinder rim lock. This would normally engage with a door latch, but in the NDKTS it is used to interact directly with a solenoid plunger that is directly above it.

NDKTS locks indicate to a control unit, via two limit switches, that a key is trapped **in** when a slot in the solenoid plunger drops around the cam of the cylinder lock so preventing its rotation. When a key is **in**, the cam is vertical. The position of the solenoid is detected by two limit switches that are in contact with the top of the solenoid.

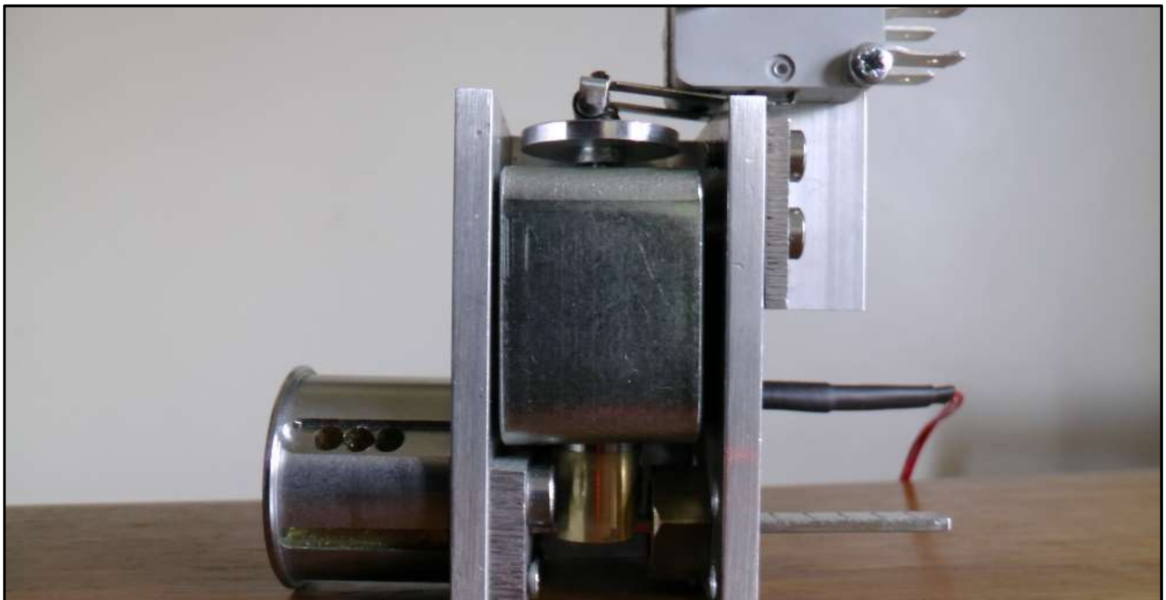

Figure 2: The NDKTS lock at an early prototype stage showing the basic components and their arrangement.

The locks indicate to a control unit that a key is **out** – or potentially out – when the solenoid plunger is above the cam, which is then able to rotate 90º to a horizontal position - the point at which the key can be removed. The solenoid plunger is above the cam either because the solenoid has been energised or when it cannot fall back past the cam, because the cam – and key – have been rotated away from the **in** position. The cam then prevents the solenoid plunger from dropping – a position detected and reported by the limit switches.

Another fortunate feature of the cylinder rim lock is that when the key is out, the cam will not rotate of its own volition and allow the plunger to drop.

5.2 Summary of the Software Architecture

The software sits within three distinct types of machines.

There is a controller machine that controls the flow of instant messages/commands between NDKTS machines and checks that the reported states of the locks is consistent with a pre-determined set of rules of the railway. Solenoid commands to release a key can only be sent to a particular lock if all the rules are satisfied and if two machines (the controller and the audit machine) are in agreement.

There are the NDKTS machines – or slaves - that contain the locks, and there is an audit machine that listens to all the messages flowing between machines and which is involved in a two-part command to energise a lock solenoid. The NDKTS machine software only reports the states of each lock and interprets commands. It is not party to the rules of the railway. Contained within either the control or audit machine there are server programs. These simple programs do not warrant a separate machine.

6 CODING DEVELOPMENT

6.1 Basic Twinned Machines

The basic concept of slave NDKTS machines controlled by a control program and monitored by an audit program was initially tested with just two slave units. In the early stages, the locks were mock-ups with manual switches mimicking the actions of the solenoids. Separate programs were written on each physical machine and testing was close to a real life setup. Programming required concentration as any code alteration in one slave had to be mirrored in the other slave and may have required code alterations in the control and audit units also.

Early versions of the process involved the interacting programs talking to each other in sequence. This was straightforward to code, but meant that the final routine – from a driver requesting a token to final clearance - took around ten seconds to complete. This seemed a long time, but was accepted by drivers as there were changing indications on the touchscreens with each stage in the exchanges.

6.2 Multiple Sections, Multiple Machines

When the concept proved to be viable, the project then addressed the issues involved in managing a railway with five passing loops. This involved twelve virtual NDKTS machines, fourteen server programs, an audit program and a control program. This complexity needed a new approach, not only to the coding but to the checking, amending and testing of the entire operation.

For example, the simple matter of opening the programs for testing had to be 'mechanised' so that **all** the programs could be opened in less than 30 seconds and opened complete with a knowledge of where each was meant to represent. An 'opening' program was written which fed each standardised slave program with an identity and thus the attributes of a particular location.

The sequential nature of the original programs was clearly unacceptable with twelve slaves. The problem was overcome by opting for parallel reporting, and once all messages had been accounted for, the relatively short process of verification could begin. This has cut the time taken for a token to be released down from ten seconds to less than three seconds – and this is with twelve slaves rather than just two.

7 LOCK PROTOTYPING

7.1 Early Versions

Very early versions of the locks were crude. They involved an arrangement of solenoid and rotor that was effective, but which was too wide. The lock cam – the blade behind the cylinder barrel – drove a rotor that normally held the solenoid plunger at its high point. The rotor had a hole in it that aligned with the plunger so that, when the key was turned through 90º to the point of entrapment, the plunger dropped into the hole and locked the rotor, which locked the key.

7.2 Subsequent Developments

The second generation of lock also operated with a rotor, but was much narrower, with the rotor and limit switches being in line front-to-back.

The current version of the lock is sealed, and has been miniaturised so that several locks can be used in a single machine without unreasonable weight, bulk or cost. The miniaturisation has been achieved using straightforward machining techniques from readily available stock material. There are no special castings or bespoke electrical components. Apart from the solenoid plunger, limit switches and the cylinder lock itself, there is only one moving part and this rotates through only a quarter turn. There are now no rotors nor rotor support assemblies, all of which added to the cost, weight and bulk of the locks.

Figure 3

The lock is now the form of a plain, sealed cartridge (Figure 3) that can sit behind a front plate with artwork that is relevant to the railway involved.

7.3 Lock Security

The overall lock security is achieved by using standard Dormakaba 20 high-security cylinder locks straight-out-of-the-box which have keys that can be interchangeable with padlocks or other locking mechanisms based on the same cylinder lock design. The keys have unique identifier codes and cannot be forged using high street locksmiths.

7.4 Scrap

The prototyping process, both for the coding and for the physical locks, has produced a great deal of scrap material. The coding is just retained on a hard drive; the aluminium scrap is much more tangible! (Figure 4)

Figure 4 The results of experimentation!

8 SITE TRAILS

The NDKTS has been trialled for approximately two years. The first year proved the general system with basic prototype equipment. The second year saw the use of the next generation of lock design and industry standard hardware.

The current cartridge form of lock has undergone endurance testing and showed no sign of wear after 30,000 cycles. A patent for the system was granted in March 2017 number GB2523100.

10 CONCLUSION

The NDKTS is just an exploitation of systems and components that already exist. Granted, there is software to be written, but this is straightforward so long as the overall system architecture is sound.

The system locks are unique, but not impossible to replicate giving a reasonable amount of machining skill.

All the computing hardware is off-the-shelf. Risks can be minimised by splitting tasks between duplicated components.

In summary, key token signalling has been propelled into the 21st century and should not be relegated to the history books.

In its NDKTS form, it can deliver a measure of operating flexibility on simple railways that can match that of much more sophisticated counterparts.