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A SIMULATION OF THE INFLUENCE OF A TRACK CIRCUIT ON SEQUENCE TIME OF UNDERGROUND TRAINS

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In this paper general principles of ATP system operation used on underground lines are described. Next the results of simulations, which show the influence of track circuit distribution on sequence time and commercial speed of trains operated on underground lines are presented. The simulations have been conducted for a 5 km long section of an underground line. They have been conducted for different lengths of track circuits and different changes in vertical profile of a line (-40 ‰ to +40 ‰). Also a proposition of a method for distributing track circuits, which enables to obtain high values of commercial speed with short sequence times, is presented.

1. INTRODUCTION

It is required that the operation of underground trains is safe. For this purpose, automatic train protection systems (ATP), which control driver's operation and in case of his failure to observe traffic conditions correct his action, are used. This system cooperates with devices of train traffic protection incorporated in technical installation of the track. In this paper simulations which will show how the distribution of track circuits influences sequence time of trains moving on a line are conducted. In addition, a proposition of division of an underground line into track circuits is presented.

2. ATP SYSTEMS ON UNDERGROUND LINES

The class of ATP systems is intended to provide safety of train traffic. The basic function of ATP systems is to reduce automatically the speed of a train to a value which guarantees a safe run of a train. This system prevents dangerous situations from occurring, e.g. running into preceding train, brake failure before complete stop, falling out on curve due to the exceeding of speed etc. The ATP system initiates only when the driver exceeds the permissible speed, e.g. signalled by a semaphore. For full functionality the system needs to be provided with some data. Constant parameters of the train and track (e.g. constructional admissible speed, train weight, vertical and horizontal profile) are a source of such data as well as variable information provided by some traffic control devices e.g. changing traffic conditions. For transmission of the information from the track to the train, continuous and intermittent methods are used. In ATP systems, continuous transmission by means of track circuits, radio or balises is applied. For control of track occupancy traditional SOT track circuits or not jointed circuits of traffic occupancy SOT-2U are used while real speed is measured by the appropriate on-train devices.

The principle of ATP system operation is based (after providing appropriate data) on calculating the value of the safe speed V_B and comparing it continuously with the real speed V_R . According to an accepted algorithm, ATP devices do not allow exceeding the safe speed V_B due to controlled power transmission and braking system which prevent exceeding of. Values of given speed steps are obligatory for all trains. In this case, the ATP system determines fixed levels (steps) of speed for a given short sections of the track (Fig. 1). Those steps reflect a braking curve of a train in a relation of the maximum speed on the line to the maximum permissible speed. A train approaching a stop is moving according to multistep braking curve and every step of this curve will be in accordance with track circuit. Every track circuit has a specified fixed value of safe speed V_B called speed step. Therefore, speed steps are laid from the beginning of track circuit along its whole length. In case of such an ATP system, a train on underground line will not approach a semaphore with stop instruction, but it will be stopped at some distance from it. The system is safe since before signalling a stop instruction the sequence of speed steps is generated, [1][2][4][5].

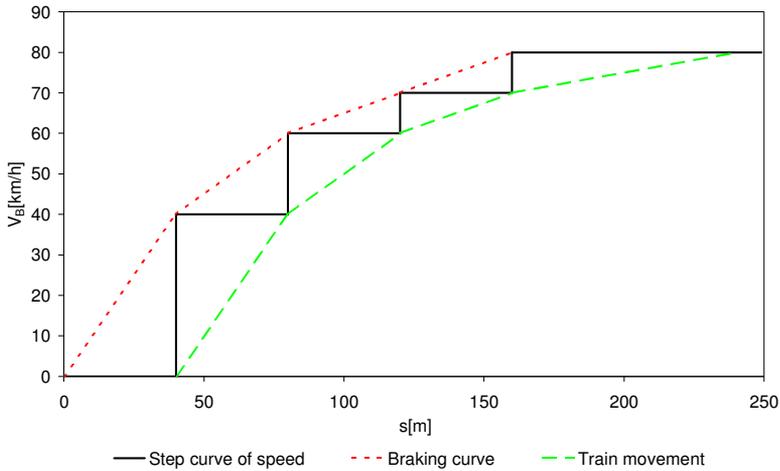


Fig. 1. The step curve of speed

The curve crossing down the peaks shows the way of train operation which will not result in an initiation of ATP system while the braking curve enables the train to stop before a dangerous spot e.g. before the tail of a next train.

3. EXAMPLES OF SIMULATIONS

For conducting simulations a set of programs for calculation and simulation, which is used for a simulation of the underground line A in Prague, was used. SOP-2P type of ATP system is used there. During the simulations a section of underground line with the following parameters was chosen:

- Line length – 5000 m,
- Number of stops – 5 (*station A, B, C, D, E*),
- Distance between stops – 1000 m,
- Stopping time – 30 s,
- Sequence time of trains – 75-120 s,
- Length of track circuits 100-150 m,
- Line profile – $\langle -40\% \div 40\% \rangle$

The conducted simulations can be divided into two series. The first one concerns the influence of track circuits on sequence time of trains with zero vertical profile. The second series was conducted for different changes in vertical profile and different track circuits with fixed sequence time $t_n = 85$ s; the line was 5 km long. The first station was located 500 m from the beginning of the line and the last station 4500 m. Due to such a solution the train could

accelerate and pull over from the line. The profile range on the line changed from -40 ‰ to +40 ‰. Chosen lengths of track circuits were 100, 110, 125 and 150 m long respectively. Introduced changes were done on 2 km long section of the line before and after station C. In other parts of the line, lengths of track circuits were 100 m long and vertical profile was equal to 0. Speed steps calculated by the programs were changing along the whole line depending on the distribution of track circuits.

Using the obtained times of trains between stations along the specified section of the route commercial speeds, that is the speeds including time spent at the station, were calculated.

$$V_{commercial} \left[\frac{km}{h} \right] = \frac{s}{t} \quad (1)$$

where:

s – distance,

t – run time with stopping time.

3.1. Investigation of the influence of track circuit lengths before and after the station – zero profile

The simulations were conducted for different lengths of track circuits which changed before and after station C. The arrangement and length of the track circuits after station do not influence the results of the investigation of the section before the station. The number of track circuits for every investigated length of circuits for section before and after the station was equal to 4. Therefore, for four circuits 100 m long, each overall length of circuits before station was 400 m and for circuits 150 m long it was 600 m. The braking distance of the train from maximum speed to full stop did not exceed 400 m, therefore, only the investigated section influenced the results (Fig. 2).

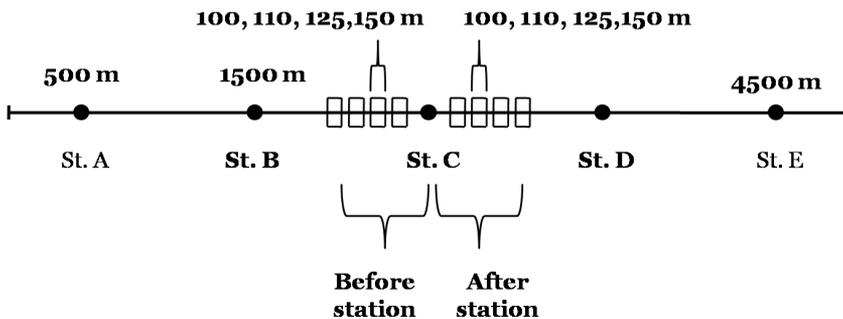


Fig. 2. A model of different lengths of track circuits

The simulations were conducted for 16 cases of track circuit arrangements with division into different lengths: before the station (100, 110, 125, 150 m), after the station (100, 110, 125, 150 m) and for nine values of sequence time (75, 77, 79, 81, 85, 90, 105, 120). Commercial speed in function of sequence time for specified lengths of track circuits (100, 110, 125, 150 m) before and after the station is shown in the graph below.

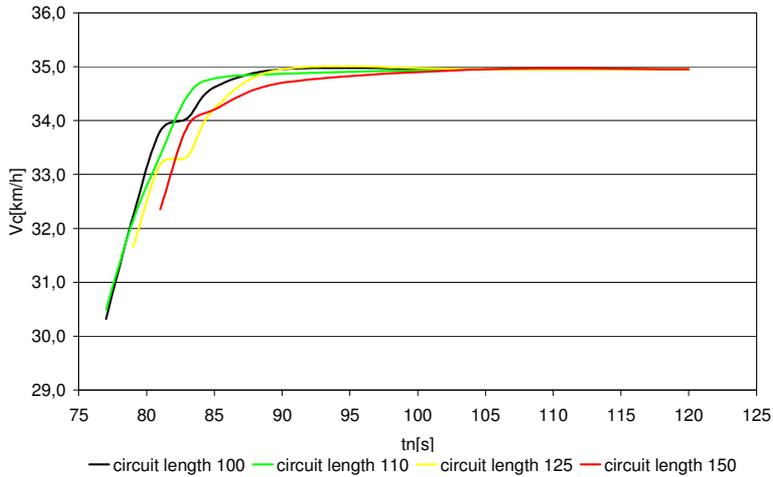


Fig. 3. The relationship between commercial speed and sequence time for extreme lengths of track circuits

When sequence time t_n increased also commercial speed V_c did. Speed increases only to a certain limit value of sequence time and after exceeding it the speed remains constant and further increase of sequence time does not affect it. It results from the fact that there are no speed limits, since for long sequence time trains do not approach each other as they do in case of short sequence time. We could say that for long sequence times (105, 120 s) train traffic on the line does not cause an increase in the commercial speed while too short sequence time (75, 77 s) causes difficulties in traffic operation due to speed limits indicated by SOP system - decreasing the commercial speed. For underground it is important to transport the biggest possible number of passengers in the shortest possible time. It is also important that passengers do not wait for a train too long. Sequence time should be between 85 to 90 seconds. It provides short waiting time and high commercial speed between stations. For longer sequence times it is possible to obtain higher commercial speed on a section of a line. The lowest speed is obtained for short sequence time.

3.2. Investigation of the influence of track circuit lengths with different changes in vertical profiles of the line before and after the station

The conducted simulations included the same sections of the line with different lengths of track circuits before and after the station. The lengths were 100, 110, 125 and 150 m respectively. Additionally the profile of the line before and after station C was changing according to the model below (Fig. 4). Along with appropriate correction, lengths of track circuits increased on the slope and decreased up the hill. What is more, in neighbourhood of the station the profile was changing by $+3\text{‰}$. Such a solution is applied in practice in order to avoid laying water in platform. Outside the area of investigation the profile was equal to zero. All simulations in this series were conducted for sequence time equal to $t_n=85\text{s}$.

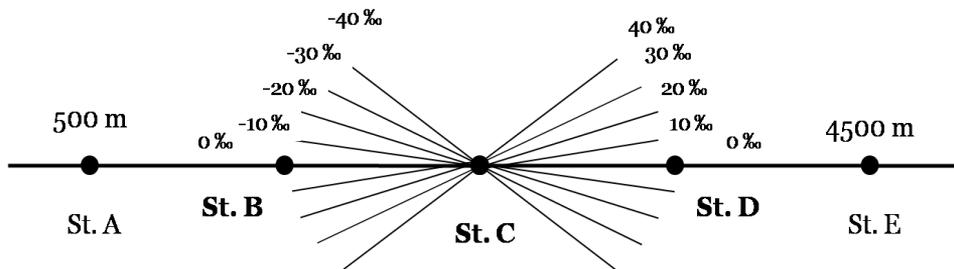


Fig. 4. The diagram of changes in the investigated profile

The simulations were conducted for 81 pairs of line profiles before $(-40, -30, -20, -10, 0, 10, 20, 30, 40\text{‰})$ and after the station $(-40, -30, -20, -10, 0, 10, 20, 30, 40\text{‰})$ and for four lengths of track circuits (100, 110, 125, 150 m). Each change in any parameter required recalculation of speed steps for the investigated line and test run with a simulation of given sequence time.

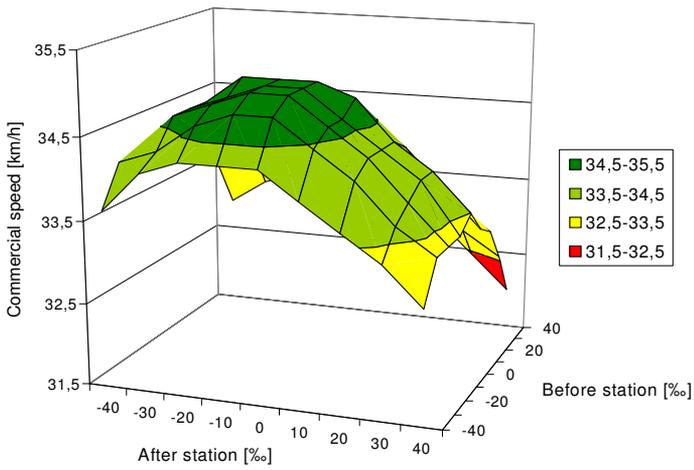


Fig. 5. Commercial speed for 100 m track circuits

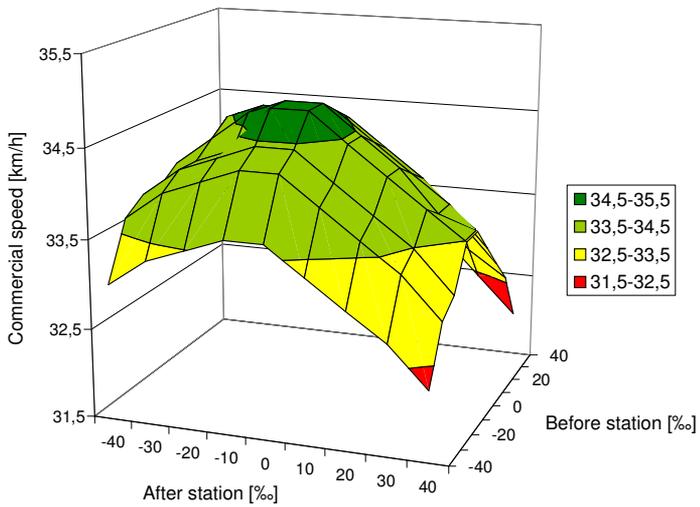


Fig. 6. Commercial speed for 110 m track circuits

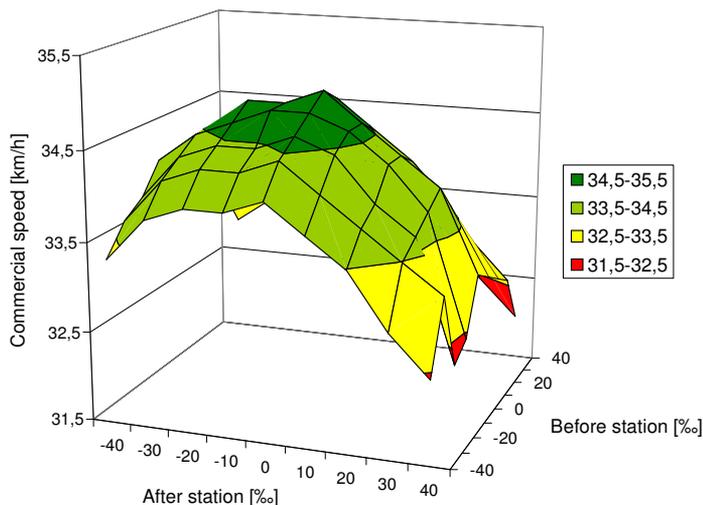


Fig. 7. Commercial speed for 125 m track circuits

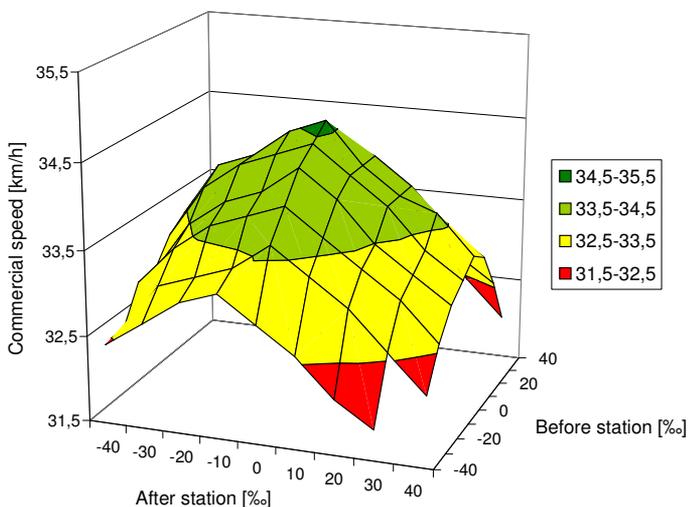


Fig. 8. Commercial speed for 150 m track circuits

The influence of track circuits on commercial speed is shown on the graphs. As shown the speed depends on both profile and applied lengths of track circuits. The highest commercial speeds were obtained for short track circuits after the station. The lowest commercial speeds were obtained for long track circuits in particular on slopes (for negative profile). Commercial speed decreases proportionally to the hill profile. After analysis of the results obtained from the simulations it can be said that application of short track circuits after

a station is most efficient. However, in practice, track circuits shorter than a train itself are not used. Only in case of holding tracks, 100 m long sections are used to provide safe run of a train with low speed. A bigger number of speed steps exists on slopes than during an up the hill run, [3].

4. METHOD OF TRACK CIRCUITS DISTRIBUTION

A proposition of distribution of division points of a line into track circuits is presented below. Before a station it is best to distribute track circuit in such a way that their beginning is in place where a given speed step was calculated by SOP system. However, such a solution, in particular in vicinity of a station, determines the application of very short track circuits e.g. 40-50 m long. Application of such short track circuits is certainly inefficient. Therefore such track circuits are lengthened before a station. In most cases the use of very short track circuits is not recommended since one track circuits should not be longer than the whole train. The length of the platform at which a train is supposed to stop is most often 100 meters . It is most efficient to distribute track circuits through the station in such a way that one track circuit ends in the middle of the platform or the track circuit of the station is shortened. It improves traffic capacity of a line and efficiency of the traffic operation.

In static profile of speed imposed on a section of the investigated line with zero profile is shown. Moving train leaves behind speed step curve so the following train should be driven in such a way that it does not exceed new permissible speed steps. A train which is standing at the station creates speed step curve which is obligatory for the following train. Additionally the braking curve which reflects braking distance from $V_{\max} = 80$ km/h without ATP system, is presented on the graph. Vertical dashed lines (A, B, C) mark dislocation of given speed steps before the station; in other words track circuits should begin between dashed line A and B, if we look in the movement. direction The best situation, from a point of view of covering speed steps, will occur when track circuit begins between line B and C.

Before the station, track circuits without joints are used for control of SOT track occupancy. Due to their principle of operation in areas of electrical isolation two neighbouring circuits are laid one on another (mostly at a distance of 5 m). It is the so-called blind spot. In practice, to provide safety, resonance track circuits without joints are determined in such a way that when a train comes to a blind spot the occupancy is signalled by two neighbouring circuits. In this case it is difficult to determine the beginning of a track circuit. If application of short circuits is required (e.g. holding tracks), the so-called axle counter is used for precise determination of the beginning of a track circuit.

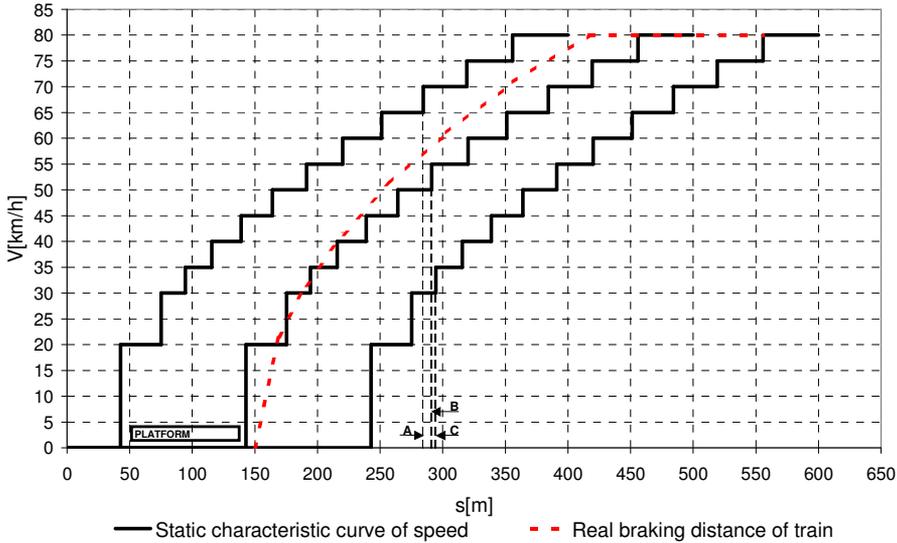


Fig. 9. The step curve of speed - zero profile

It is most efficient to apply 100 m long track circuits along the section before the station. Application of such a solution provides fast release of the section by the coming train improving traffic capacity of the line. Application of longer track circuits after station will lead to a longer time of train occupancy which will delay departure of a train located before the circuit decreasing capacity. Division of section for short track circuits is troublesome especially in case of traditional track circuits since it requires frequent cutting of rails to isolate them from one another decreasing mechanical strength of rails, [3].

5. SUMMARY

The conducted simulations indicate that it is most efficient to use short track circuits of approx. 100 m length especially after a station. Such a solution provides quite high commercial speed and efficient traffic capacity. Moreover, it is possible to obtain relatively short sequence times of trains of about 85-90 seconds. The investigations showed that it is not efficient to use very long track circuits. It leads to a decrease of commercial speed and an increase of sequence times. It can be said that the way of distribution and determination of track circuits has a considerable influence on commercial speed on a line and affects the effective traffic operation.

According to worldwide standard sequence time should be equal to 90 seconds with 30 second for stopping at the station. When choosing sequence time it is most efficient to assume 10% margin and assume that trains may move with 80-82 second sequence time. Such sequence time enables to meet 90 second standard in case of a traffic disorder on the line.

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SYMULACJA WPLYWU UKŁADU TOROWEGO NA CZAS NASTĘPSTWA POCIĄGÓW W METRZE

Streszczenie

W pracy opisano ogólne zasady działania systemów klasy ATP stosowanych na liniach metra. Przedstawiono wyniki badań symulacyjnych, które ukazują wpływ rozmieszczenia obwodów torowych na czas następstwa i prędkość handlową pociągów poruszających się na liniach metra. Symulacje te były prowadzone na 5-kilometrowym odcinku linii i zostały wykonane dla różnych długości obwodów torowych i zmian profilu pionowego linii od -40 % do +40 %. Przedstawiono też propozycję metody rozmieszczania obwodów torowych, która pozwala na osiągnięcie przez pociągi metra wysokich prędkości handlowych przy krótkich czasach następstwa.

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