Advanced Energy Efficient Automatic Train Operation in Commercial Operation

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Generally about AVV system

Historical introduction

In the 1960’s, Czechoslovak Railways initiated a research of the train driving automation. One of the final aims was saving of energy for traction, among other aims there were better utilization of track and of rolling stock parameters. First successful tests of Automatic Target Braking (ATB) were done in the half of 60's. For a successful operation, necessary peripheral elements like electrically controlled driver's control valve were developed.

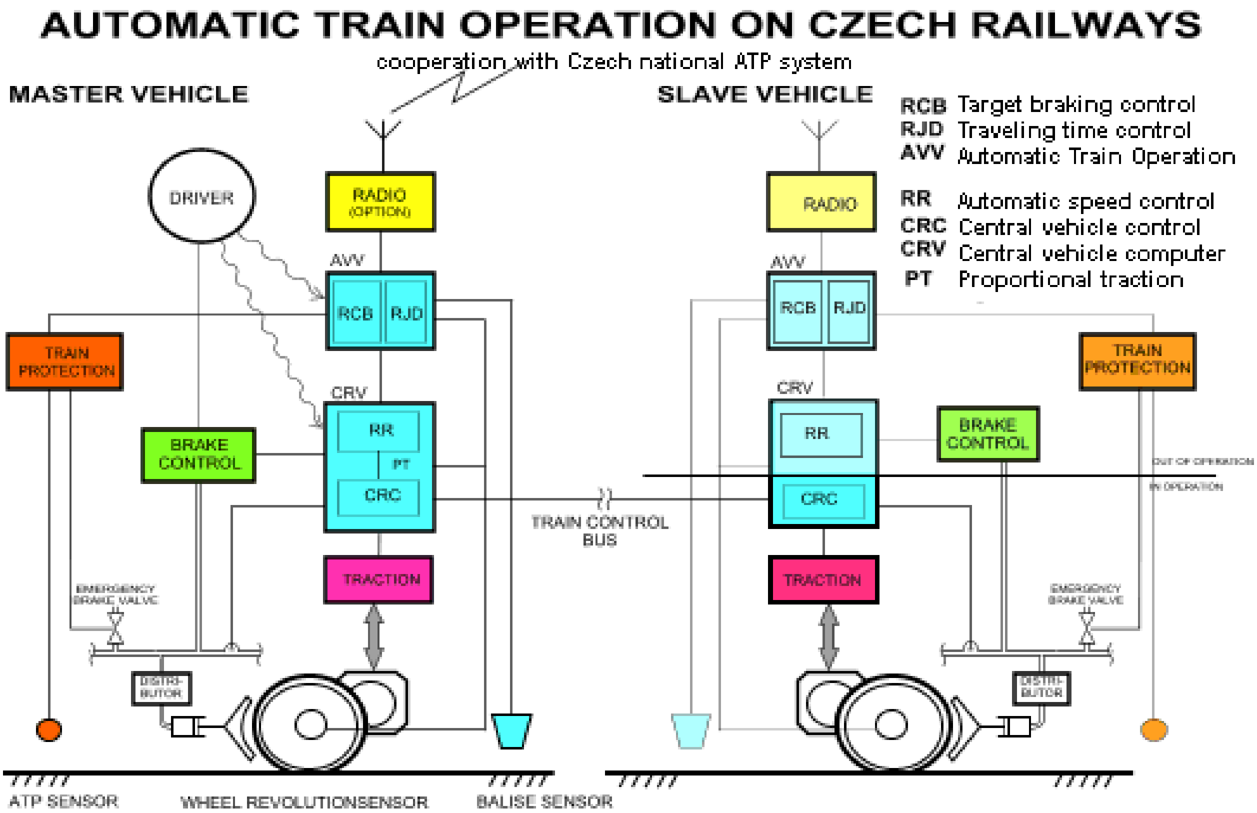
In the early 70’s, first Automatic Speed Control (ASC) Regulators, developed as basic elements of automation, were employed in regular operation (typical precision ±1 km/h). These regulators were capable to control a pneumatic train brake. About 750 vehicles of all tractions (electric, diesel-electric, diesel-hydraulic) were equipped with ASC and most of them are still in regular operation. Also first successful tests of Energy Saving Device were carried out.

In the end of 70's and during 80’s, the development continued with ATB, suitable for commercial operation. First mass implementation of ATB emerged in the Prague underground (Metro line C). On “great” railway, the pilot installations of Energy Saving Device (ESD) were under tests in commercial operation. But analog solution radically limited the further development.

In beginning of 90’s, the digital solution was available also in the Czech Republic. Above mentioned self-standing devices became functions in ATO computer. The track variety was solved using a so called Route Map. Class 470 EMUs additionally equipped with digital ASC, ATB and ESD were set in regular operation, so first complete ATO started its life.

1990’s brought many changes to both economical and social spheres of life. Czech Railways had to face new tasks and challenges (e.g. modernization of neglected infrastructure). Activity in research of train automation was taken over by private subjects. In spite of this, Czech Railways held their course by demanding ATO in new vehicles from their suppliers.

Basic Scheme



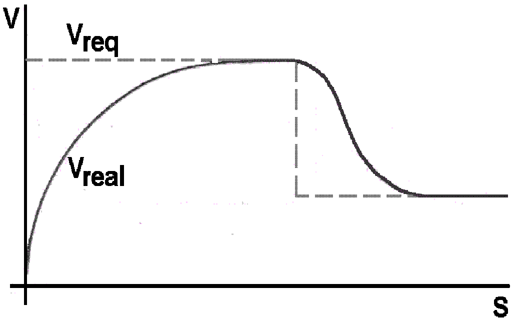
The complete Energy-efficient automatic control system consists of ATO part, that deals with target braking and energy optimization of running, and of Central vehicle control unit that ensures automatic speed control, manual control and multiple traction control on both master and all slave vehicles.

Automatic Speed Control - ASC (type RR)

ASC is the basic stage of train automation. ASC controls the tractive force and dynamic brake (if available) and also pneumatic train brake.

The reaching of new speed value is **aperiodical** (no over- or underrun). Speed is controlled in range from 2 km/h to Vmax (at present, 200 km/h for ŠKODA 109E locomotive), typical accuracy is better than ±1 km/h. If required, special features like control of very low speed (0,25 km/h for shunting loco hauling a train under coal hopper in coal mine) can be provided.

There are some extending functions of ASC: e.g. to check when end of the train passes the end of speed limit (train length is set by driver) and than applying the pre-set value of required speed.



Manual & Automatic Train Operation

Control of tractive force, dynamic and pneumatic brake (including Emergency brake) is realized by one Master controller (6-position control lever with time-dependent control). The time-dependent control enables problemless switching ASC on/off during running or problemless simultaneous manual and ASC brake control - when driver sets braking manually, traction is blocked and his brake request is added to potential effect of ASC-requested brake. So there is no problem what to do if ASC requests e.g. 70% and driver sets 50% ... to decrease braking effort from 70 to 50%, to add both requests and limit to 100%, or to add 50% from the rest after 70% is applied? Next, after applying brake by driver, ASC continues in operation and in case of e.g. greater downhill it still checks the speed and applies more brakes to keep the speed on required value.

The same Master controller is used in Manual and Automatic control.

Setting of required speed in ASC mode is done by keyboard - simple, quick and accurate operation. The key layout is designed so as most operated keys (like e.g. "speed 50") are in the corners so drivers need not to look at the keyboard every time.

Automatic Train Operation - ATO (type AVV)

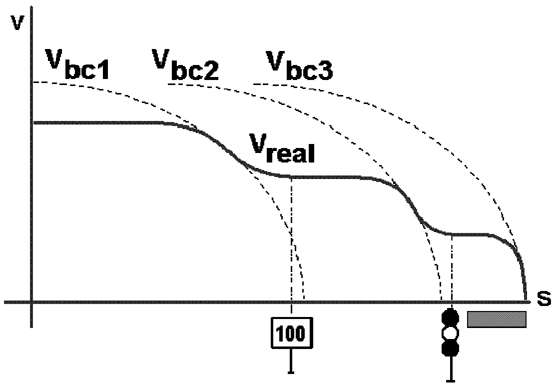
ATO includes Target braking control (TBC) and Travelling time control (TTC) / energy optimization features. Both are based on on-board Route map and Time table. On-track orientation is done using special magnetic information points (see later).

Target braking control - TBC (type RCB)

TBC ensures automatic target braking to:

- track speed limits
- signals with ”Stop” aspect or with speed-restrictive aspects
- platforms of halts and stations (by train’s head, middle or tail to specified stopping point)

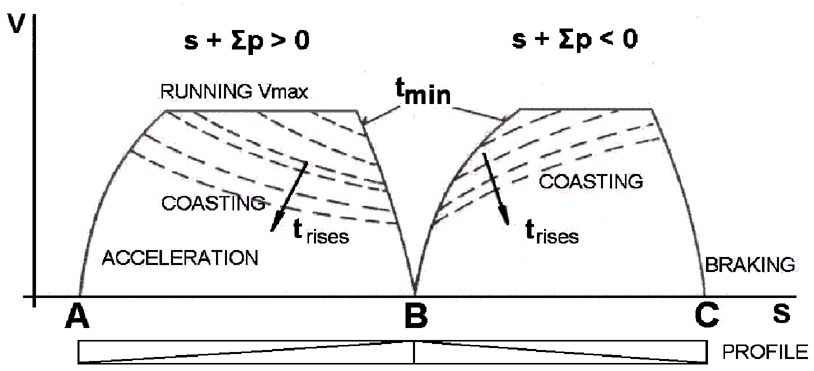
Basic function of TBC is to lead the train to speed restrictions and to achieve a new value not earlier, not later, and with acceleration just sunk to zero (no underrun). The typical accuracy of stopping is ±1 meter.



There are many extending functions, e.g. to check all actual speed limits and not to allow driver to exceed them.

Travelling time control - TTC (type RJD) / Energy saving feature

TTC is used for energy-optimal course of train running, with just-in-time arrival. The typical accuracy of stopping is ±5 seconds. ERRI measuring confirmed the average energy savings between 10 - 30%.



Basic function of TTC is to lead the train to the nearest station just in time (if possible) and with lowest energy consumption. This is ensured by on-board on-line solving of train equations and setting the coasting (power off) when it is actual. There are also some extending functions, e.g. to correct the estimated traffic situation according the actual one using radio data transmission

There exist 2 variant solutions of TTC designed for

- often stopping trains (passenger trains, suburban trains, metro)
- seldom stopping trains (fast trains, express trains, goods trains), which includes also often-stopping variant.

On-track (on-network) orientation – Route map

Route map is a data file stored in ATO's non-volatile memory and it contains all static information about the line:

- positions of track speed limit desks and the value and type (like standard one, fox 6-axle locos, for trains with higher cant deficiency, for tilting trains etc.) of each one
- positions of signals and switches
- positions of platforms, including the attribute of type of stopping (by head, middle, or tail of the trainset)
- positions and values of gradients
- balise positions

Route map must be updated when some changes on the line appear (like new halt opened, track speed changed etc.), but these changes are very rare. Wireless transmission of Route map files is tested. Information from the Route map can be read for any distance ahead the train. The Route map file itself is very compact and small - the map of 65 km double track line in both directions is 6 **kilo**bytes „large“

On-track (on-network) localisation – information points, ETCS balises, GPS

Magnetic information points (type MIB-6) are actually used for on-track localisation. They are placed on track, between the rails. Each information point gives an unique information about position of train on railway network and about direction of running (similar to balise group ID). There exist over 30 000 of unique combinations (excluding symmetric points and symmetric conjugated points).

On the lines equipped with ETCS balises, these balises can be used for localisation. This feature was successfully tested during ETCS Pilot Project in the Czech republic.

For non-corridor, secondary and regional lines, where ETCS installation is not anticipated in near future, the solution using GPS instead of lineside balises (or MIBs) is developed and tested. This solution significantly reduces the initial costs and needs no maintenance of infrastructure part. On the other hand, it needs a little driver's cooperation and provides a bit worse accuracy of stopping, but generally this does not hinder on non-main lines with short trains. The reliability of GPS localisation is very surprising, no problems were detected in narrow valleys or on lines passing through forests...

Time table

Time table is a data file stored in ATO's non-volatile memory and it contains all static information about train schedule:

- list of stations and halts in which the train stops
- arrival and departure times
- prescribed speed for individual line sections

Time table must be updated when changes in the schedules appear, these changes are usually four times a year, but many terms do not concern the trains equipped by ATO.
Wireless transmission of Time-table files is tested.

Operational safety

Although the AVV system is not safety relevant device, it was designed to have certain level of operational safety. For example, if the expected MIB or balise that is placed after branching of the track, has not been read, then full service braking is applied (so called "necessary MIB" - as there are more possibilities of track continuing, the AVV system necessarily needs the information on which particular track it continues the journey, as the position of signals, platforms etc. could be different in particular tracks). On the other hand, if MIB / balise was not read on straight track, there is no possibility to change to other track and system automatically fills in the lost information from the memory (as there exists only one possibility); this may repeat several times up to exhausting specified distance. This feature slightly decreases the accuracy of target braking if MIB / balise is missing (as the distance is not periodically adjusted), but strongly improves the operational reliability (as one damaged "not-necessary" MIB / balise does not cause the operational fault).
Next, in technology part, the requests for traction are given in positive logic, whilst the requests for braking are in negative logic (lost signal = brake command). All important output signals are safeguarded by relay disconnector, that is controlled by independent dual watch-dog signal.
Last but not least, the AVV system must be normally operated with active approved ATP system, that ensures the operational safety of train's running. In case of ATP's failure it is not necessary to switch AVV off, but it can stay in operation (maybe with some driver's manipulations added) and can help driver with this stress situation.

Cooperation with ETCS

The Pilot Project of ETCS in the Czech Republic also contains the ETCS's cooperation with ATO, namely with AVV system. The main points of cooperation are:

- using LRBG for AVV's on-track localisation (instead of MIBs)
- using ETCS's static speed profile (SSP), converting to dynamic speed profile (DSP) and its realisation by respective part of AVV,
- providing TIU functions for service braking and Change of power system.

Cooperation with ETCS was tested on dual-system locomotive 362.166 and single-system EMU 471/971.042. The aims of this testing were to reduce the interventions of ETCS due to overspeed (ATO controls the speed of the train not to overrun the ETCS's service braking curve) and to replace the national on-track orientation by interoperable solution.

ATO as executive system

Why did we design ATO as an executive, not advisory system?

- Driver need not pay any attention to follow any ATO´s instructions
- Braking process is easily predictable, as the executive system performs it by itself
- Thus, time accuracy is better, making the ATO more credible for driver

<u>The ATO everyday commercial operation</u>

During live presentation, the video from the journey with ATO system will be presented.

Start of mission

When starting mission, train data (train number, train length and braking ratio) must be entered. Normally, they are received from EVC or from tachograph (black box, used on vehicles without ETCS). The driver only confirms them. Setting of required speed follows as the last step of data input dialogue.

Now, system is ready for operation. The initial taking off is in speed-control mode only, as ATO has to read lineside balise (MIB) or get the information from EVC (reading ETCS balise) for its orientation. When the first balise is read, full control is provided.

Running and stopping

The train is accelerating and ATO checks all speed limits not to overrun them. The running is very smooth, when approaching maximum speed, the acceleration sinks to zero with constant jerk.
When ATO detects that it is possible to reach next stop without using power, it switches the traction off (very smoothly, again) and the train runs using coasting.
Also the guiding to braking curve(s) is smooth as well as changing between them - it is possible to change from braking curve with lower deceleration (braking to signal in Stop) to braking curve with higher deceleration (braking to platform) in some cases when signal is placed close behind the end of platform.
The train stops in the station just-in-time and having consumed the minimal portion of energy.

Special

If there is a place with restricted speed (track speed limit, signal with restrictive aspect etc.), ATO controls the brakes of the train to achieve the target speed just at the desired place and without underrunning. When leaving the speed restriction, ATO allows driver to preset new (higher) value of required speed, and it stays checking whether the end of train has left the restricted area. Just after leaving it, ATO automatically applies the preset value of the speed. Every speed increasing must be entered by driver, in contrary to speed decreasing that is performed automatically.

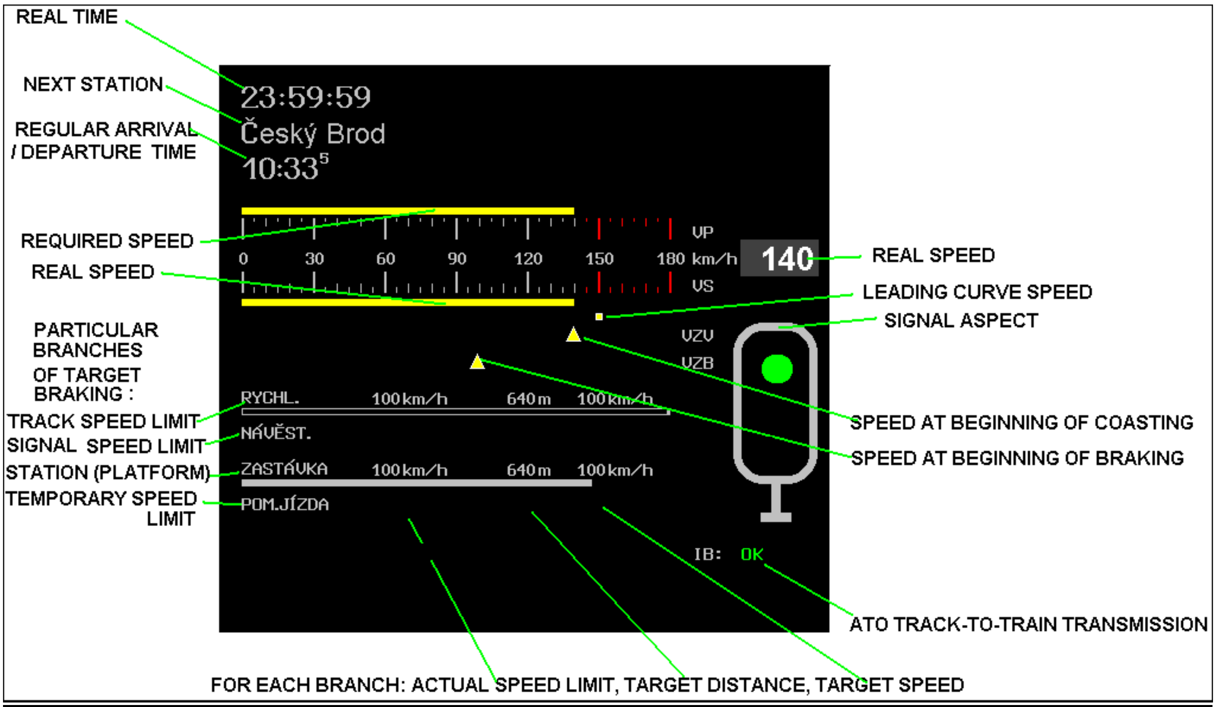
If there are no problems on the track, the driver only opens and closes the train doors and pushes the master controller for departure. All other interventions for train control are provided by ATO.
(Auxiliary devices like horns, lights, pantographs, wipers etc. are still operated by driver - but these do not concern the control of running itself.)

Driver's display

What can the driver see on the display?

In upper part, real time, next station name and scheduled arrival time including correction (driver can set this correction according to actual situation or according to line dispatcher command) are displayed. Next, indicators of ATO's coasting and of preference of manual control of train brake are placed here.

In medium part, required speed, real speed and speed indicators of beginning and end of coasting are shown. In lower part, indicators of 4 branches of target braking are drawn. Only actually active bars are drawn - the value indicates the speed of braking curve of relevant branch and this value can be easily compared to actual speed bar. Next, actually allowed speed, target distance and target speed of each active branch is displayed. The signal symbol indicates "translated" symbol aspect of nearest signal ("translation" means that prospective speed indicating signal aspect is not shown as (blinking) colour light or stripe, but as its numeric value).



Real view of driver's display in ATO mode on EMU class 471.
(The values in the picture may not correspond with real situation)

ATO in numbers

In these days, there are in regular operation with full ATO:

- 83 double-decker suburban EMUs class 471 (2 devices per EMU)
- new-built electric locos class 380 (20 pcs)
- 35 subway trainsets type 81-71M with derived ATO (Prague Metro, line A, 12 km, next pieces ordered for elongation of the line, next installations ordered for line B, 26 km, cca 50 trainsets)
- refurbished diesel locos class 750.7 (19 pcs)
- refurbished diesel railcars class 842 (37 pcs)
- driving coaches class 961 (30 pcs)
- electric loco with modernized control system for cooperation with driving coaches classes 162, 362, 363 (cca 30 pcs, next in manufacturing)
- one loco 362.166 with pilot reconstruction of control electronic system and ETCS equipment
- refurbished diesel locos class 753.6, electric locos class 363.5 and new diesel locos class 744 for cargo operation

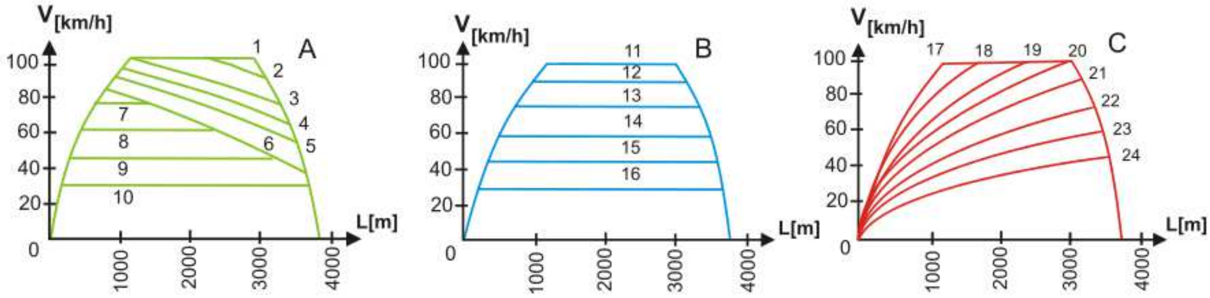
There are over 300 km of lines equipped with lineside part of the AVV system on the Czech railway network. Next lines are planned as well as exploitation of lineside part of ETCS.
The data descriptions of over 1000 km of non-corridor and secondary lines can be utilized for ATO with GPS localisation.

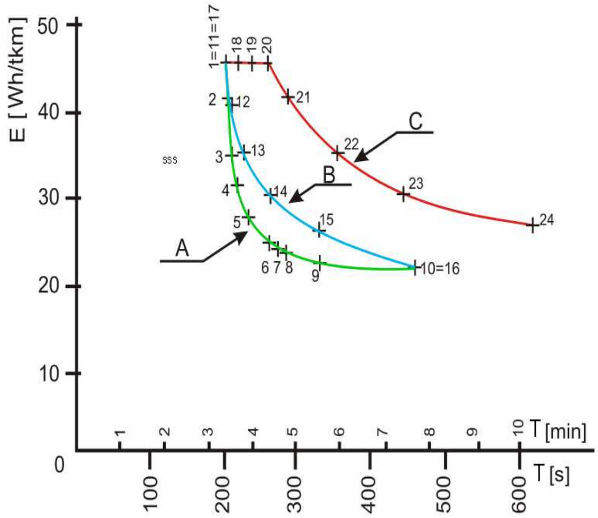
<u>Concrete results of Energy optimization</u>

Energy optimization - One section results

There are 3 possibilities how to enlarge travelling time (comparing to the lowest reachable value) and, at the same time, how to decrease the energy consumption:

A) using coasting
B) limiting of Vmax
C) decreasing of acceleration





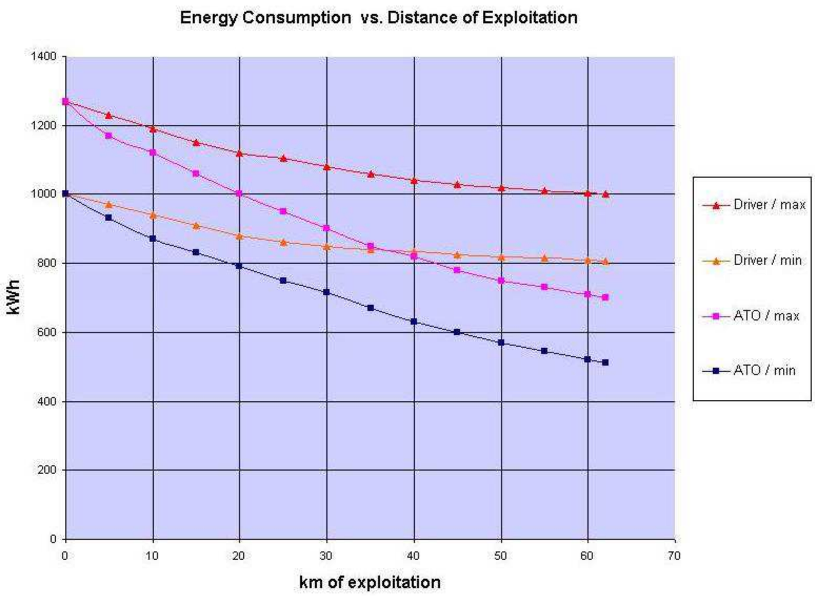
Real measuring of energy consumption of often stopping train in Wh/t.km

Loco 242.256,
Train 300 t,
Section Valy u M.L. - L.Kynžvart,
Ls = 3770 m
Gradient = + 5‰
measured in 1989

Using coasting (case “A”) is the most efficient way for energy optimization. This method is used by AVV system.

Energy optimization - the whole line results

The real consumption depends on many conditions. The most important one is the possibility of exploitation of energy efficient running - the train must not be late.
Following picture shows real consumption vs. possibility of exploitation of ATO,

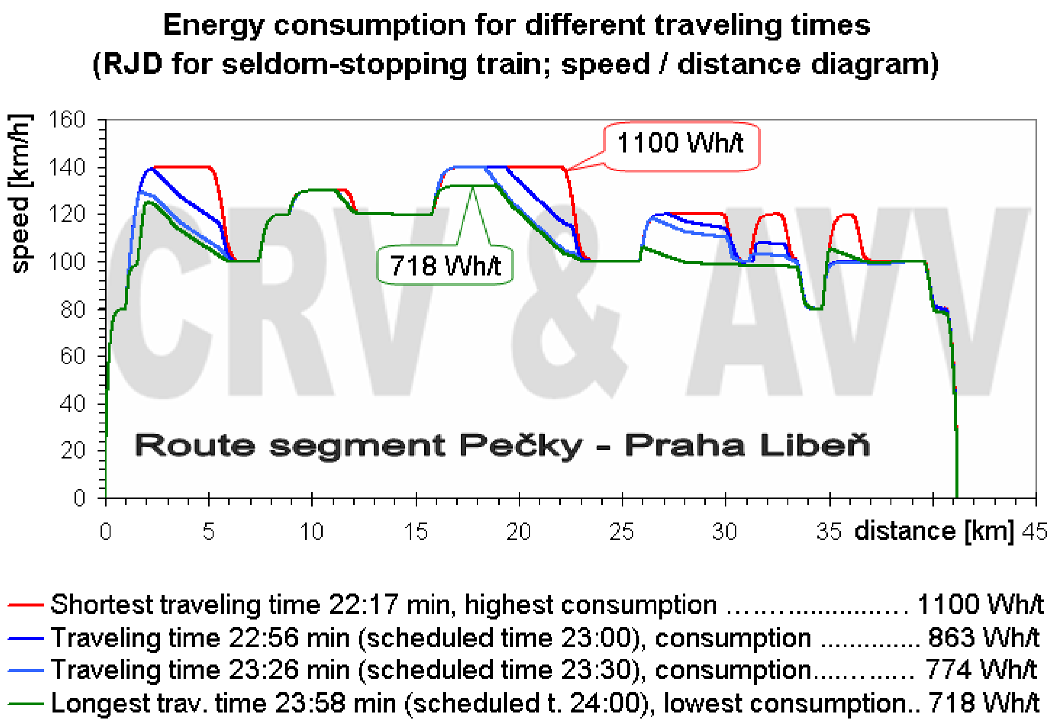


Real measuring of energy consumption of often stopping train in kWh

Loco 163.034
Train mass 400 t,
Line Praha - Kolín (62 km)
measured in 1992

When it was possible to use ATO on the whole line, the average saving was about 30% of energy.

Simulation results (seldom stopping trains)



In January 2011, Travelling time control / Energy saving function for seldom stopping train was successfully tested in commercial operation on 104 km long line between Praha and Pardubice (which also includes the route segment Praha - Pečky, presented on above shown picture). The achieved results fully confirm the results of simulations.

Conclusion - ATO's future

Energy saving feature reduces the operational costs of the railway transport. Now it is operated also on diesel vehicles which use diesel fuel that goes more and more expensive. When saving fuel, the production of CO_2 is reduced, too. Also from this point of view, the Energy Efficient ATO will be more and more senseful device...