Autonomous power supply of railway automation devices

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Abstract. The throughput of railway section determines the number of trains traveled through it in a normalized time. On such sections of the railway, trains of various lengths are moving. At the same time, existing design methods provide maximum throughput for a railway section for only one train length. To optimize the throughput of the railway section, it is possible to use auto block system with a variable number of block sections on the railway haul. This leads to additional significant hardware and finance costs, including for providing electric power to additional equipment. To use of a low power, autonomous power supply allows the elimination high-voltage power lines for microprocessor optional equipment of block system with a variable number of block sections. The principle of operation of an autonomous power supply uses the mechanical energy of the moving wheelsets of the train cars, which move on section of the railway. Moving the ferromagnetic material of the wheelsets above the permanent magnet of an autonomous power source converts mechanical energy into electrical energy. The organization of electrical power supply of microprocessor optional equipment of auto block system from converted mechanical energy of wheels reduces capital investment and operating costs for the implementation of innovative transportation management methods.

1. Introduction

The most common, though sometimes non-optimal indicator of throughput and carrying capacity of running lines equipped with automatic block signaling is the number of trains running on them per normalized time unit (About approval of Methods for estimation of throughput and carrying capacity of railway public infrastructure. – Russian Federation Railway Ministry Order as of 18 July 2018, № 266). According to these regulatory documents, on single track sections in train pairs per 24 hours the throughput capacity is defined as:

\[ N = \left( \frac{1440 - t_{sa}}{T_{per}} \right) n_a - \left( \frac{1440 - t_{sa}}{\sum t_s + t_a + t_b} \right) n_b \]  \hspace{1cm} (1)

where \( T_{per} \) - train movement schedule period on a limiting running line, min.; \( \sum t_s \) - train shuttle service total time, min.; \( t_a \) and \( t_b \) - time station intervals envisaged by a train throughput scheme, on an adjoining and limiting running line with separate stations “a” and “b” respectively, min.

When several trains with different number of cars are moving on a running line simultaneously, time processes of their movement and estimation of forecast and real throughput and carrying capacity are significantly complicated, equation (1) cannot be properly used for the analysis. A criterion for carrying capacity of track sections is not only the number of trains but also the number of wagons in the train [1].
In practice both freight, in particular, heavy trains and commuter, for example, electric trains run on the same rail tracks. In this case the number of wagons in different trains may be from some units to 100 and more. For accepted normalized wagon length, which is 15 m, the length of a train moving on the running line, may be from some dozens meters to kilometers. It is obvious that in most cases availability of simultaneous movement of two or some trains with similar mini-max linear features on the running line is within the bounds of possibility.

In order to reach running line maximum throughput capacity effect, each train length should correspond to a quite certain block-section length \( l_{bs} \). Its value is realized during standard traction estimates which are made in designing or modernization of track sections and may be expressed by a generalized functional;

\[
l_{bs} = f(l_t, l_b),
\]

where \( l_t \) – a train length which is taken as normalized in designing and further operation of a specific rail section; \( l_b \) – length of braking.

This shows that under existing designing or modernization techniques of railway tracks equipped with automatic block signaling, the running line maximum carrying capacity can be ensured only for a single train length. However, on overwhelming majority of Russian railways both passenger and freight traffic are provided.

2. Materials and Methods

One of the ways to ensure maximum throughput capacity in that case is application of automatic block signaling with variable number of block-sections at the wayside [2-7]. In Fig 1 show one of the implementations automatic block signaling with a variable number of block sections. The pattern operation is described in detail in [8]. Let us consider distinctive features of its functioning related to the issues which are viewed in this article.

![Figure 1. Running line structural pattern with variable number of block-sections.](image)

The pattern shows movement of two trains with respective lengths \( l_{p1} > l_{p2} \) which were dispatched or are being dispatched from station A by signal of departure S. Bilateral information exchange through communications d takes place between signaling control equipment and signal points 1, 3, …, 11, …. Any train entering the running line from station A, receives the data about the train length which may be practically formed with the help of the system of axles count [14] or any other known means. On the basis of the obtained information each signal point S, forms signals for turning appropriate signal points on or off and required from the standpoint of traffic safety assurance color light signal indications.

It is evident that the number of signal points \( n_{sp1} = f(l_{p1} = \text{var}, l_b = \text{var}) \) in case of realization of such a method of train movement regulation will differ from \( n_{sp2} = f(l_{p2} = \text{const}, l_b = \text{const}) \) in existing generally accepted automatic block signalling systems. Whereby, according to quotation (2) the more
the difference in real lengths of moving over the running line trains \( l_p \) and requirements to length of braking \( l_b \) is, the more the difference in the number of signal points;

\[ n_{ct1} > n_{ct2}. \]  \hspace{1cm} (3)

It is obvious that this leads to additional, sometimes considerable costly equipment of block signaling system with variable amount of block-sections. Moreover, these costs rise when the difference between lengths of really moving over the running line trains increases.

Normally, running line automatic block signaling points power supply is provided through electric power supply devices \( ED_1, ED_3, \ldots ED_i \), respectively. Their feeding inputs are switched to different phases of three-phase alternating voltage of high-voltage line \( HVL \) 10 kV (or 6 kV). These devices are functionally step down substations having a high-voltage transformer, protection gears and other power elements. A complete power supply system includes a high-voltage line \( HVL \), which must be switched to an alternating voltage source or railway traction substations. Such power functional units and devices are sophisticated and have high material intensity, cost and considerable operational expenses.

Taking into account the above-said and quotation (3), material intensity, costs and operational expenses of automatic block signaling systems with a variable number of block-sections may significantly rise.

A specific feature of up-to-date automatics and remote control systems, including those used on railway transport, is adoption of microelectronic elements and data processing digital techniques. This stipulates radical reduction of not only material intensity, but consumed power as well. For instance, substitution of track circuits [9] for renowned rolling stock axle count system [11] reduces the power consumed by automatic block signaling devices by several scores of times. Analogous positive power indicators are obtained in case of replacement of color light signal filament lamps with LED transducers. This list of power gain may be significantly extended.

These circumstances make it possible to reduce the power consumed by signal point apparatus, from 200-300 to units, several scores of watts. Such potential possibilities of consumed power reduction fail to give proportional reduction of material intensity, cost and operational expenses of electric power supply devices \( ED \), this being provided by complex high-voltage specifications of this equipment and necessity to introduce power protection elements against impulse, for example, thunderstorm overvoltage.

Therefore, there emerge economical and operational disproportions between power supply sources and low-power electronic loads. There is a necessity to design and introduce optimal by energetic and economical features low-power electricity sources of running line electronic equipment of automatics and remote control, which are depleted of economically inefficient high-voltage power lines with corresponding step-down substations. In this case it is necessary to consider the fact that the area of their deployment on railway transport may be sufficiently broadened and is not restricted by automatic block signaling devices.

3. Results
One of the variants of realization of the alike low-power electricity source where drawbacks of existing power supply systems are eliminated is shown in Figure 2.
Wheel pair
Magnetic flux $\Phi$
Permanent magnet
Winding $w$
Rectifier
The storage of electrical energy
Load

Figure 2. Low-power electricity source circuit.

The Figure 2 circuit mode of action lies in the fact that it is basically a converting device where displacement of wheel set ferromagnetic mass of a moving train provokes emergence of heteropolar voltage impulses on coil leads $w$, placed at the permanent magnet core with N and S poles. The function of this voltage by electromagnetic induction law is defined by the generalized equation:

$$e_w = kLw \frac{d\Phi}{dt},$$

where $e_w$ – coil $w$ voltage; $k$ – conventional coefficient, defined by magnet circuit geometry, its ferromagnetic specifications, permanent magnet induction, wheel set movement speed and other; $L_w$ – coil $w$ inductivity.

When there is no wheel set above a permanent magnet, magnetic resistance $R_m$ of device magnetic circuit by Figure 2 circuit between its poles is large. This provides small magnetic flow in the circuit: $d\Phi \rightarrow 0$ and $\Phi \rightarrow 0$, shown in Figure 2 with a dashed line. Then according to (4) we have: $e_w \rightarrow 0$.

Availability of a moving train wheel set above a permanent magnet causes reduction of magnetic resistance $R_m$ and appearance and further increase of magnet flow $\Phi$. Voltage $e_w$ starts on coil $w$, its polarity depending on derivative sign $d\Phi/dt$, that is, whether a wheel set is approaching or leaving a permanent magnet. Consequently, running of each wheel set of the moving train above the permanent magnet causes voltage impulses on coil $w$. It is evident that in case of a great train length with a large number of running wheel sets, the energy transmitted from the coil to the rectifier increases respectively.

After rectification the direct current enters the energy storage unit, for which either conventional large electrolytic capacitors or ultra high power intensity capacitors (super capacitors) may be used. Next the DC accumulated energy enters the load, providing its functioning.

Therefore, as each wheel set is moving above the permanent magnet, the average value of impulse energy further used for load electrical feeding, enters the energy storage unit. The capacity of accumulated electrical energy, and, consequently, the power returned to the load, depends on the number of train wagons which have passed above the device by Figure 2 circuit on the running line, namely, on train movement intensity.

Consequently, the device under consideration makes it possible to have an electric power source on the running line, which does not require external power supply source, realized at present by high-voltage lines with appropriate power elements. This ensures expulsion of functional elements ED1, ED2, ..., EDi and HVL, shown in Figure 1 structural pattern, from the structure of running line electronic systems and equipment, with realization of corresponding economical effect.
It is known that running line automatics, remote control and communications devices for ensuring reliable operation have backup power sources with expedient switching from the main power supply to backup supply. Normally for this in existing systems two high-voltage lines are used. It is obvious that making use of the proposed structural methods enables expulsion of not only main but also backup HVL, replacing them with additionally introduced analogous low-voltage power supply sources. In each case there is a necessity to install two low-voltage sources at each signal point or another electronic device with switching of their output voltage with the help of emergency relays.

It should be pointed out that there is a certain limitation for the use of described Figure 2. Circuit operation principles. The energy gain in the energy storage unit must last for functioning of load equipment over the time period when there is no train movement with appropriate number of wheel sets. Therefore, application of the described principles of electronic equipment operation is possible under adequate train movement intensity at track sections. However, this limitation may to some extent be compensated through application of appropriate energy storage capacity accumulators as storage units. It is apparent that evaluation of possible use of the power device under consideration is determined by train running intensity at track sections. Application of such devices at low-density lines is intricate, but not for main-line service.

The functioning arrangement system of electronic devices, which is considered in this article, is related to not only running line automatic block signaling devices. The realized self-sufficiency and independence of the electricity supply source of sophisticated external power supply systems may be required for other railway transport equipment.

4. Discussion
This refers, for example, to equipment of operative or other service communications of various railway subdivisions, maintenance crews etc. Recently there have been developed rather important electronic devices for identification of internal mechanical tensions in rail lengths [11] or definition of track geometrical spatial features, traction electric rolling stock overhead catenary etc. The issue of electric power supply for them, as well as for automatic block signaling, is crucial.

Availability of an impulse signal on winding leads enables to use Figure 2 circuit for fixation of passing of a wheel set above a signal point installation site. This is required, in particular, in case axle count systems [12, 13] are used on the running line which have been broadly applied recently in up-to-date movement safety systems and train running regulation instead of rail circuits widely distributed on railways [14, 15]. Thereafter, the circuit under consideration realizes functions of an axle count track sensor which, as in previous examples, does not require a special electricity source with appropriate technical and economical effect. In that case the power source under consideration will be a unified functional unit solving several problems.

Consequently, the automatic block signaling structure arrangement device under consideration with variable number of signal points on the running line makes it possible to achieve technical and economical effect through expulsion of step-down high-voltage substations, containing complex and material-intensive high-voltage elements and equipment which requires considerable operational expenses. Concurrently, possibility of a complete refusal from track high-voltage lines is the evident and most vivid advantage. Another advantage of the considered low-power electricity sources is realization of additional functional possibilities of their usage at the rail net.

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