The impact of Indusi technology on disruption of interoperability in European rail traffic

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Abstract. Signalling and safety systems are an essential part of railway traffic that excludes the possibility of wrong reactions of the train driver for different traffic conditions and prevent possible collision of trains. One of the most applicable train protection system in Europe is Indusi system which allows spot transmission of information at discrete points. This paper briefly describes the characteristics and versions of this system developed over time, explores its applicability and its impact on interoperability in European rail traffic.

Keywords: train protection system, Indusi, PZB, interoperability

1 Introduction

Nowadays, great emphasis is placed on sustainability of transport systems in general, and especially railways as massive and environmentally friendly form of transport. Constant development of new technologies enabled investments in creating an open and flexible market in railway transport. The basic precondition for the unhindered running of any form of traffic is a high level of security. This can be accomplished by minimizing the negative impact of human factors on safe and efficient traffic flows with the help of signalling and safety systems and other devices. Signalling and safety devices represent a basic safety system for controlling the movements of trains which must provide timely transmission of information on the state of track and driving mode on locomotive devices [1]. Depending on the national rules, signalling systems based on trackside signals utilise different colour aspects for defining safe movement restrictions and for transferring orders to the driver.

As the train drivers did not always follow the instructions of the signalling system, many railway accidents happened [2]. In order to avoid their unintended mistakes and thereby increase safety, train protection systems were introduced. First train stop systems were mostly mechanical**,** but with development of technology the physical principle of informing the train driver has also changed to permanent magnets and later on to transponders. In the meantime, other systems for train protection were introduced, so for example in 1990 were at least 30 different train control systems in use on European railway network [3].

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2 Train protection systems

When managing a train, the train driver must follow the track signalling and react in accordance with the instructions from the train protection system. From the security aspect, the key part is to provide the necessary information on time. Initially, information was transmissed from trackside equipment to on-board equipment only at selected locations, determined by the trackside equipment. That type of train protection is called intermittent train protection. Contrary to such spot and interrupted linear transmission, there are train protection systems with continuous transmission. Those systems allow a continuous data link (transmitted telegrams in short time intervals) between track and train [4]. According to their functions and the type of transmission, their division is possible even further. Systems with intermittent transmission can be with and without braking supervision. If they are with braking supervision, then differ according to the volume of transmitted data (low and high). Systems with intermittent transmission at high data volume also have dynamic speed supervision. Systems with continuous transmission of signal aspects can be derived by means of track circuits or systems with continuous transmission at high data volume and dynamic speed supervision [4]. Every mentioned type of train protection systems has its application in the protection of trains on the railway network in the country in which it is applied. Some of the observed advantages and disadvantages of applied systems, are solved by adapting the system to their own technical standards and rules that fulfilled the criteria of national requirements.

As mechanical interaction between track and train was replaced by permanent magnets installed in the track, a new type of train protection systems have been developed. Such systems use inductive coupling to transmit signalling information [2]. The German Indusi (germ. *Induktive Signalsicherung)* works on the same way by using tuned circuits trackside and on board. That close coupling between both circuits takes place only at discrete points, so the information is spot transmitted [4], [5], [6]. According to system functions and the type of transmission, Indusi system belog to the group of systems with intermittent transmission at low data volume and with braking supervision. That means they provide for an attentiveness check at the signals which can show „Caution“, trainstop functions and more or less complex supervision functions, but without calculating a dynamic speed profile [4].

3 Inductive transmission system

Indusi system was originally developed in the 1930s [4]. Lot of this system variations have been developed with time and many of them are still in use. Due to its reliability, simplicity and efficiency in stopping the trains, Indusi system soon became the first widely used train control system.

3.1 Initial versions of the Indusi system

The first known version of the Indusi system was the Indusi I 34. The system had very simple functions offering purely monitoring and prevention of running a red signal by starting emergency braking. There were no indication of observing the lineside signals and react according to their aspects. Supervision was based on speed supervision when passing the magnets or fixed times after that occurrence [2], [5]. After a short period of interruption, in 1954 started a standardization of the vehicle-mounted technology which led to the Indusi I 54. That system had one new frequency generator with a downstream audio crossover, instead of previously used three motors, to emit the three frequencies in parallel. The generator of the vehicle device generates an alternating current and feeds it in a resonant circuit of vehicle magnets [5].

3.2 Indusi system I 60

As a result of minor improvements in the 1960s, a new version of Indusi system, called I 60, was obtained. Like Indusi I 54, the new system had almost no electronic components and due to its simplicity, it has been widely used in many railways for train protection up to today [5].

The basic characteristics of the previous system variants as of I 60 stayed the same. There are on-board and trackside part of equipment. The trackside equipment consists of three types of passive trackside magnets in the form of resonant circuits [2]. Trackside magnets are mounted to the right rail to communicate signal aspect to trains. Each trackside magnet is adjusted to the specific frequency (500, 1000 and 2000 Hz) with the frequency coding the information form the precisely known trackside signal. Depending on signal aspects, the trackside resonant circuits can be switched effective or ineffective. Locomotive's magnet is configured to receive information from the trackside magnet and therefor is placed above the right rail to distinguish the direction of movement. The resonant circuits of vehicle magnets permanently swing in mentioned frequencies. If the switch is effective, when the train passes over a trackside magnet, loss of energy is happened and the on-board equipment registers and processes that. Its executive part triggers the activation of the pneumatic part of the device and effects immediate emergency braking. In the case of ineffective switch (e.g. all signals are clear), the Indusi magnets are disabled and the resonant circuit on the vehicle is not influenced. Since the trackside magnet gets its energy from the vehicle's magnet by induction, the system does not need a local power supply [4], [5], [6].

When train approaches a signal showing „Stop“, it passes three magnets of different frequencies in the track. *The first magnet* (1000 Hz) is placed at the level of the distant signal at a distance of 1,000 m from the main signal. After driving over that magnet, the train driver must press an acknowledgment button within 4 seconds to confirm that he has recognized the distant signal and to prevent emergency brake application. Afterwards, a countdown was started to check whether the train had slowed to a specified speed within a specified time frame depending on the set train type. If not, the brakes will be applied. This magnet is effective when the signal is at „Caution“ or at „Speed Restriction Warning“ of relatively low speed. *The second magnet* (500 Hz) is located between the distant and the main signal, usually at 150 - 250 m before the main signal (450 m before the danger point). Here the speed is checked again against an even lower limit. At this point, when the signal is at „Stop“, the train must already have reduced speed, otherwise the system will stop the train. In that way, even if the train driver acknowledges the distant at caution but does not brake sufficiently or does not break at all, the main signal is not passed at danger. At the main signal there is *a third magnet* with the influence of 2000 Hz. This magnet will always trigger an emergency braking when detected active by the locomotive, and so the train will come to a full stop within the safety overlap after the main signal [4], [5], [6].

Because of different braking performances of trains, a distinction is made between three different categories (freight train, low speed and high speed passenger train) so there are three monitoring programs (U, M, O). Each category has different speed values of the supervision curves based on the maximum allowable speed as is shown in the Table 1 [4], [5], [6]. When the train drives over an active magnet (1000 Hz and 500 Hz), related speed monitoring function is activated depending on the program and belonging type of train the locomotive was hauling. For example, in the train type O, after passing the 1000 Hz active magnet, the train driver must slow the train at 95 km/h within 20 sec. By the 500 Hz active track magnet the train has to move below 65 km/h or the following main signal stops. If a signal is passed at danger, the 2000 Hz control effects immediate emergency braking. This influence can be bridged by operating the so-called command key, for example with signal failure or special command received from the dispatcher. Its use is registered then. The maximum speed of the train is limited to 40 km/h and it will sound a permanent audible warning (beep or voice).

Table 1. Train control at the I 60 system

Train type	Maximum speed [km/h]	Train monitoring	
		1000 Hz	**500 Hz**
O (Higher)	Over 111	95 km/h after 20 sec	65 km/h
M (Medium)	From 66 to110	75km/h after 26 sec	50 km/h
U (Lower)	Below 65	65 km/h after 34 sec	40 km/h

This train protection system has certain security omissions where not always it is guaranteed that any forced braking ends before the danger point. Especially dangerous situations arise when a train approaches a stop signal after stopping at the platform which is shortly before or significantly further off the 500 Hz magnet, so that influence does not affect him at all or does not stop him at sufficient distance anymore [7].

3.3 Later improvements of the system

Number of accidents have occurred over a time, so there was a need for further improvement of the I 60 system. Increased safety was obtained with the application of microprocessor technology in the new I 60 standard. This enabled semi-continuous monitoring a curve of speed against of time as the train moves toward the signal [5]. The top speed of the train was entered in the train data adjuster before starting the journey, depending on the braking position and braking force. If the train was driving faster than the curve allowed, an emergency braking could be enforced. Automatically releasing again could be possible if the train was going slower than the limit. Considering that, after the 1000 Hz influence, the driver cannot release himself of the speed up to 700 m.

As a result of German division, the Teltow device and control plant from the East-German developed a new intermittent train control. The new PZ 80 supports all existing Indusi I 60 modes, but also has some improved monitoring functions in order to drastically reduce dangerous starting against stop signals with high-acceleration vehicles. The system has continuous braking curves, more restrictive speed monitoring curves and speed is controlled in steps of 10 km/h. So it was possible to drive with a shunting program up to 40 km/h without regard to the oscillating circuits. Also, the permissive mode was implemented, in which it is possible to enter the occupied section at limited and monitored maximum speed (daytime 50 km/h, at night 15 km /h) [5]. After the German reunification in the mid-1990s, there was a need for further increase in safety and the standardization of the East and West German Indusi types. This was achieved by development of a new PZB 90 (germ. *Punktförmige Zugbeeinflussung*) [4], [5].

3.4 PZB 90

As in the previous Indusi designs, the basic principle in the PZB 90 stayed the same. The 1000 Hz, 500 Hz and 2000 Hz trackside magnets are activated on the basis of the signal aspect [4], [5], [8]. The transmission of data takes place inductively from the line to the traction unit, so that a train can be automatically brought to a halt. Since the intermittent transmission is used in traditional signalling, the highest speed that can be achieved to ensure safe and functional operation of the railway traffic is 160 km/h. At that speed the brake distance is about 1 km. To stop the train in time before the danger point and thereby increasing safety, in PZB 90 a restrictive mode was introduced and the monitoring curves were reduced as is shown in Table 2 [4], [5], [8].

Table 2. Train control at PZB 90 system

Train type	**Max. speed [km/h]**	**Normal train monitoring**		**Restrictive train monitoring**	
		1000 Hz	**500 Hz**	**1000 Hz**	**500 Hz**
O	165	85 km/h after 23 sec	from 65 km/h to 45 km/h within 153 m	45 km/h (const.)	25 km/h after 153 m
M	125	70 km/h after 26 sec	from 50 km/h to 35 km/h within 153 m	45 km/h (const.)	25 km/h (const.)
U	105	55 km/h after 34 sec	from 40 km/h to 25 km/h within 153 m	45 km/h (const.)	25 km/h (const.)

In the first train category (O) are the fastest trains with maximum permitted speed up to 160 km/h plus a tolerance margin of 5 km/h. After influence of the first magnet at the distant signal, the train driver has to push the acknowledgement button within the four seconds. In case of failing, emergency brakes are applied. Then he has to reduce the speed from 165 to 85 km/h which is monitored over a distance of max. 1250 m. If within this distance no 500 Hz-input follows, the systems assumes the signal having cleared in the meantime and the supervision speed is released to the maximum of 165 km/h. Considering that a large distance is monitored and it is possible that the next signal was cleared after passing the distant signal, the train driver can release himself from the monitoring manually with the "PZB free" key no earlier than after 700 m if he is able to recognize the infilled signal aspect (optical infill) without any doubt. Before a release is not possible despite signal enhancement, since the system receives no information about the revaluation. Emergency brakes are applied in case of exceeding the supervision speed [4], [5], [8]. The release is not possible for a 500 Hz magnet, where further reduction of speed from initially 65 to later 45 km/h is supervised, as the train is already close to the Stop signal. In restrictive train monitoring, trains are limited to 45 km/h when stopping after an active 1000 Hz inductor or to 25 km/h when stopping after an active 500 Hz inductor (up to a point 250 m after the 500 Hz control measure) as well as after changes of direction. Therefore, a stopping place is placed at platforms either in front of a 500 Hz magnet or close to the end of the monitoring distance [4], [5], [8]. An active 2000 Hz magnet results in an instant emergency stop within the overlap because of the previous speed reduction at a maximum of 45 km/h. To pass a Stop signal in degraded mode operation, the locomotive’s cab is equipped with an override button [4], [5], [8].

4 Application of Indusi/PZB system

Except for Germany, the Indusi system cradle, it is a standard train protection system in Austria, Slovenia, Croatia, Bosnia and Herzegovina, Serbia, Montenegro, Macedonia, Romania and Turkey. The system is also partially used in France, Poland, Great Britain, Denmark, Czech Republic, Israel, India, Indonesia, USA and Canada [5], [9]. Looking at the equipment of the track with the Indusi/PZB system in relation to the total size of the railway network, mainly the main lines are equipped with the trackside part of train protection system in the railway networks all mentioned countries in Europe. For instance, Austria has total 63 % of route kilometre protected with PZB, and in Germany PZB is implemented on 86 % of route kilometre of main lines and 65 % of secondary lines, which is a total of more than 96 % of the total network [10], [11]. It is evident from this that even today there is still a problem of absence of adequate protection.

In order to operate on Indusi/PZB equipped lines with an adequate level of safety, all vehicles driving on them must also be equipped with this system. For instance, in Slovenia a total of 118 vehicles operated by national passenger and freight railway undertakings on main lines are equipped with 157 security devices and 146 vehicles with 215 security devices on regional lines [12]. Some countries go a step further and legally regulate that all vehicles on the tracks must be equipped with train protection system regardless of whether they operate or not on lines with an implemented protection system. This is the case in Croatia with Indusi I 60 [13]. Similar is regulated in Germany and Austria where except Indusi/PZB system also exist sections with LZB system (type of continuous train protection system) in parallel (PZB then serves as a fallback), so all vehicles must be equipped with PZB on-board units [14]. According to 2003 data, 1140 vehicles in Austria were equipped only with PZB system and 260 vehicles had PZB and LZB systems. At that time in Germany, 6900 vehicles had only a PZB system, 1800 PZB + ZUB 122/262 (train protection system in neighbouring rail networks) systems and 305 LZB + PZB systems [15]. These data have changed so far, since both of these countries have introduced the ETCS system on some of their track sections.

Although the basic task of the Indusi/PZB system is the same in all countries were applied, there are certain differences in their application, such as speed limits depending on the maximum allowed speed supported by the railway infrastructure and the maximum speed that can be achieved by the railway vehicles that run on it. When it comes to the highest permissible speed which can be achieved with traditional signalling using the PZB protection, it is limited to 160 km/h to give a safe braking distance for a train running at maximum line speed and that the train driver can observe track and signal states and timely take appropriate actions [1]. At higher train speeds, other train protection systems should be used. Also, due to the specificity of individual track, the maximum permitted speeds are not always equal to the entire length of the line.

While there is no major difference in the trackside of the Indusi/PZB equipment, the vehicle equipment for train control can be used in different designs depending on the vehicle. For this reason, it is difficult to determine for each country the exact applied version of Indusi system, especially since vehicles can be equipped with two or more systems, as mentioned previously for Germany and Austria. This of course depends on the type of train and their brake characteristics, so different monitoring limits are also imposed because every train must be able to stop when necessary. Therefore, locomotives with existing on-board equipment from previous PZ80 or I 60R must additionally have an electronic recorder for appropriate monitoring of the speed curves [14].

5 Obstacles to running unhindered rail traffic

In addition to the Indusi/PZB system development, over the years various systems of train control and protection are developed that are independently and incompatible with each other. The reason is that most of them are adapted to technical standards and operating rules at the national level. The problem arises when cross-border rail traffic is carried out because it often increases complexity and total cost of delivery thus reducing the competitiveness of rail transport in the long run. Therefore, a critical precondition for efficient cross-border railway traffic is harmonization and standardization of national railway networks. This has been recognized by Europe, which has been intensively supporting development and strengthening of multinational railway transport over the past few decades.

In order to allow the safe and uninterrupted movement of trains, it is necessary to start standardization from the lowest level (individual parts for railway vehicles and lines) to the highest level which implies standardization of procedures, rules of railway traffic and the legal conditions of rail [16]. Interoperability in railway will be able to navigate rail infrastructure of the individual countries without taking activities by drivers and stopping at the borders in order to exchange drivers and/or locomotives. In this case, train drivers can drive by consistent signalling principles, according to signals interpreted on the basis of information received from the infrastructure systems, and displayed in the cabs of the vehicle.

Indusi system is in use for almost nine decades and in all that time it has been constantly upgraded, but even if PZB 90 has more restrictive monitoring curves than its predecessors, it still does not meet today’s expected level of safety (SIL 4). Its supervision of speed is limited on certain critical points and cannot offer a continuous monitoring of the braking curve. Also, lack of signal commands displayed inside the vehicle’s cab substantially decreases operational performance. Although it is trying to expand the PZB system features to meet specific requirements and to overcome technological obsolescence, the Indusi/PZB system could not be made interoperable at the higher level.

Accelerated development of new technologies in the area of train protection offers a solution in the form of a unique European Train Control System (ETCS). The base of this system that ensures interoperability is application of mandatory “Technical Specifications for Interoperability” [15]. ETCS system consists of three layers with different technical requirements and applications, so it can be easily retrofitted and configured for specific country simultaneously allowing unobstructed train traffic. Its application has already started in many countries, but it will require a long migration period to fully equip both infrastructure and rolling stock and completely replace all existing national train protection systems.

6 Conclusion

In order to make the railway system safe and efficient, signalling and train control means are required. They help prevent driver mistakes, monitor their actions, and act as needed to prevent unwanted train collisions. As technology evolved, initial mechanical interaction between track and train soon was replaced by permanent magnets and the development of the future most applicable system for train protection in Europe has begun. Since then, Indusi system had several upgrade phases, many of which are still in use today.

Other train protection systems were also developed in parallel offering different functionalities, from simple warning, intermittent or continuous speed supervision to full cab signalling. Each of them has been adapted to specific national needs and without common technical and operational standards. In addition to this, the growing need for expansion and global trade accompanied by market liberalization leads to problems in cross-border traffic. The current architecture of Indusi system is not fail-safe (does not comply with SIL 4), does not offer a continuous supervision of the braking curve and is not suitable for cab signalling which is all essential for full automatic train protection when traveling to more than one country.

To achieve interoperability the solution lies in new regulatory, technical and operational conditions equally applied on everyone. ETCS system with its different technical requirements and applications allows unobstructed train traffic, but also requires time for the complete switching from the legacy train protection systems. It is the future of the train protection system in Europe and the world, which certainly contributes to increasing rail competitiveness as a sustainable transport, and remains to see how it will be realized. The obtain information from this paper indicate the necessity of further research on the issue of train protection systems to increase interoperability and rail traffic protection.

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