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TECHNICAL ASPECTS OF RAILWAY INTEROPERABILITY

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ABSTRACT

Recent technical advances concerning railway interoperability are surveyed and suggested in this paper. For differences in track gauge techniques of variable gauge axles, of powered axles with adjustable gauge are analyzed. Incompatibilities in electric power are overcome through techniques such as the multi-system electric locomotives. For differences in signalization new techniques are investigated. Advantages from the application of these interoperable systems are clarified.

KEYWORDS
Railways, Interoperability, Track gauge, Electrification, Signalization,

INTRODUCTION

In Community Directive 96/48, interoperability is defined as the ability of the trans-European high-speed rail system to allow the safe and continuous traffic of high-speed trains, under achievement of specific performances, [1].

This ability is based on a set of regulatory, technical and operational prerequisites that have to be kept in order to fulfil the basic requirements. Thus, we are referring respectively to:

i. Technical Interoperability Data which comprise all constructional data presenting differences that create interoperability problems, and

ii. Operational Interoperability Data, which comprise problems of administrative, organizational or operational nature that create non-compatibility, affecting inter-operability to an equally significant degree.

The development of a rail network across Europe continues to be impeded by differences in track gauge, loading-gauges, energy systems and more than twenty noncompatible to each other train traffic control systems. Of utmost importance in the attempt to overcome these problems is the co-operation between the rail networks. Technical, as well as commercial interoperability have a long way to go toward the completion of a trans-European network, and shall contribute to the higher goal of the European integration.

The fragmentation of railways by various barriers means that interoperability does not happen ipso facto. Significant efforts have to be made in order to reduce the regulatory, technical and operational differences that could impede the free train traffic without any stops at borderlines, [2].

The technical interoperability aspects that shall be analysed in the following are:

- Track gauge,
- Electrification/Electric power,
- Signalling – traffic regulation.

1. The railway track

1.1. The track gauge

The track gauge is defined as the distance of the gauge-sides of the rails, measured at a distance 14 mm below the rolling surface, [3]. Tracks of various gauge have been built:

♦ Normal gauge, e =1,435m: Most lines have been built with this gauge, which was concluded to optimise rolling stock dimensions. Regular gauge rails are allowed to have maximum deviations of + 10 mm to – 3 mm from a value of 1,435 m.

♦ Metric gauge, e = 1,000 m or e = 1,067 m. Mostly secondary lines have been built with this gauge. The lines of the Peloponnese and of Volos-Paleofarsalos are metric gauge lines. All other OSE lines are of regular gauge (except the rack railway line Diakofto-Kalavryta that has a gauge of 0,75 m).

♦ Broad gauge, e = 1,524 m (Russia), e = 1,672 m (Spain) and elsewhere. Rails of this type were built as a contrast to regular gauge, mainly for political reasons, so that no regular gauge railway vehicles could intrude in these lines.

It is evident that gauge differences do not allow a train or/and a single vehicle that operates at a given track gauge to use the tracks in a rail network with a different gauge.

1.2. The current situation of railways in Europe in regard to track gauge

Maybe the greatest interoperability barrier for the railways in Europe today is due to the different track gauge values that exist in the various networks.

At the beginning of the railway era, that is, from 1830 up to about 1850, the first railways were built in order to meet the transport needs on a regional scale, [4].

It was then impossible to predict the importance and the role that this new means of transport would assume, nor that the connections between the various lines would lead to the creation of a transcontinental network.

As regards the narrow (metric) gauge, it allows for the construction of tracks occupying less ground area and the use of curves with a smaller radius. Thus, metric gauge was used everywhere where a low cost construction was needed, primarily in secondary lines, as well as in mountain regions. Figure 1 depicts the current situation of the various tack gauge values in Europe.

Different track gauge values have been also chosen outside Europe. The Indian network has four different track gauges, two of which (1,676 m and 1,000 m) are dominant. In Australia there are also three different track gauges. In Latin America, Argentina for example, the capital Buenos Aires is the starting point for railway lines with three different track gauges, [5].

Where there is a transport traffic flow on lines with different track gauges, there are problems emerging that have to be overcome in special stations through operations that are more or less time-consuming and costly.

2. Electric power

2.1. Electric power sub-systems

The two electric power sub-systems, that is, the power-supply circuit and the traction circuit have different demands, and depending on the priority that is given to energy transfer (power-supply circuit) or to energy use (traction circuit), different electric power systems have been developed.

The power-supply circuit comprises, [3]:

- Substations,
- Transmission lines,

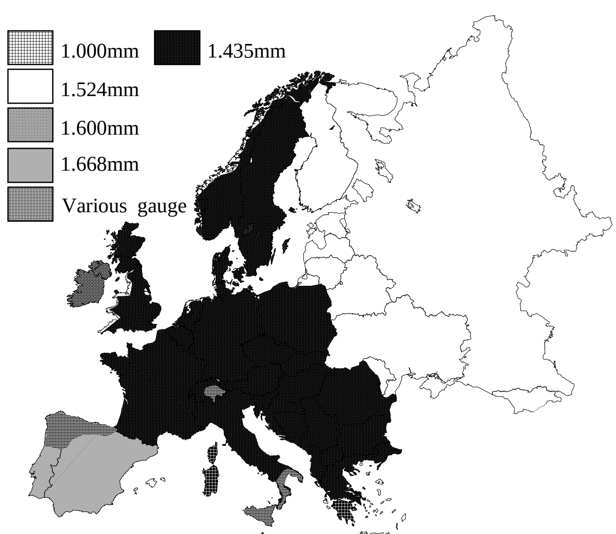

Figure 1. The various values of track gauge in Europe.

The substations can be fed with electrical power, [5]:

- ♦ from the national high-voltage power distribution network with a frequency of 50 Hz, in Europe (60 Hz for the USA).
- ♦ from a special high-voltage network, the frequency of which (usually 16 2/3 Hz) is significantly lower than that of the national network. This special network might be connected to the national network, but it also can be independent, that is it can have its own power generation units.

The transmission line from the substations to the vehicles usually is of single phase. The transfer of power to the electric locomotive can be effected in two ways:

- an overhead line, which is used in interurban and (some times) in urban railways and metropolitan railways.
- A third rail, which is used in metropolitan railways and (some times) in urban railways.

Return of the power is effected through the rails. Either one or both rails can be used.

2.2. Interoperability of electric power systems in Europe

Direct current has more advantages than alternating current in regard to the traction circuit. Thus, for a long time (from early 1900's to 1950) priority was given to better engine performance. Since series direct current engines until recently provided the best conditions for the movement of vehicles, an electric power system that was using direct current was sought.

Voltages that were mainly used, were:

- 750 V, mainly for electric power by a third rail,
- 1,500 V, which was used more than the others,
- 3,000 V.

These voltages are very low compared to the voltage used for transmission (in Greece 150.000 V, 220.000 V). Thus, electric power with direct current results in substantial cross section sizes of the power transmission line (400÷900 mm^2) and placement of the substations at very small distances to each other. Substation distances are 15÷20 km in the case of a 1.500 V voltage and 35÷40 km in the case of a 3.000 V voltage.

Electrification power with alternating 15.000 V, 16 2/3 Hz current is applied in Central Europe (Germany, Austria, Switzerland) where the substations are fed by special low-voltage power generating units and in Northern Europe (Sweden, Norway), where the substations are fed by the national network with a frequency of 50 Hz. This electric power system represents 20% of electrificated lines worldwide, [5].

In Figure 2 the existing electrification systems in Europe are presented. It is obvious that for each system different electric locomotives are needed, resulting in the need to change the traction unit at the respective country's border. Consequently, it has emerged the need for production of bicurrent and of multicurrent (multi-voltage) traction units in general, which can be operated with more than one electric power systems.

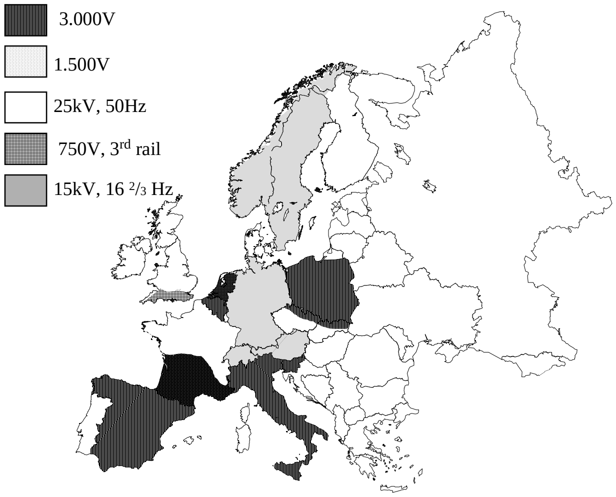

Figure 2: Electrification systems in Europe, [5].

As results from Figure 2, even within the same country, often there are more than one electric power systems. It is not possible for an electric locomotive to pass through a different electric power system on a neighbouring rail, and for this reason the traction unit with its personnel has to be changed at the border. This change generates time delays that encumber railway transports in relation to competitive transport means.

3. Signalling – Traffic regulation

3.1. Role and functions of signalling

Until few years ago signalling, was effected only with steady traffic signal lights that were placed along the line. But with increasing speeds, the danger increases that the engine driver does not apprehend some signal. Thus, for high speeds there is also used cab signalling, which provides continuous information regarding traffic conditions.

In regard to the need of a safe braking distance, signalling is of utmost importance.

Braking distance is 1.300÷1.400 m for a speed of 160 km/h and becomes 2.500÷3.000 m at a speed of 200 km/h. Thus, protection from the existence of an obstruction in the route of a train should not be left to the engine driver and his reaction, due to long braking distances. So it is necessary to notify the engine driver timely, which is done by the necessary signing and signalling.

Finally, in regard to security, railways are a mass transport means and should provide the highest possible security to their passengers. During the movement of a train there are three security problems:

– protection from other trains that are moving on the same line and with the same direction, before or after the train in question. Given the long stopping distances, a security distance between successive trains should be put in, which should not be shorter than the braking distance.

– in case of single-track or double-track railway, where, however, each line can be trafficked toward both directions, protection from a train that moves in the opposite direction and prevention of a frontal collision. Thus a train is allowed to enter specific section of a line, only when it has been ascertained that the line will remain free.

– protection from another train that moves on another line, which however intersects or merges (by means of a track transition) with the specific line.

3.2. The interoperability of the European network in regard to signalling and traffic regulation

In Figure 3 the existing in Europe signalling systems are given. There are 16 types of system throughout the entire European continent. It is evident that this poses a major obstacle for the realization of the idea of a train that departs from one end of Europe and without a change of the traction unit arrives at the other end. At high speeds, where (cab-signalling) is necessary, it renders the solution to this problem very expensive.

Throughout the European Union there are thirteen different signalling and traffic regulation systems installed on-line and operating, which are incompatible to each other. This means that a train in order to depart from Holland and to finally arrive in Italy will have passed through three to five different signalling and traffic control systems, and therefore will have to replace the traction unit, as well as operating personnel. These changes are creating delays that accumulate disadvantages to rail transports. In modern signalling, the driver receives the signal within the cabin (cab signal), which ensures the safe train movement in regard to natural and traffic obstructions that are located within a distance of some kilometres from the approaching train. Each cab signalling is adapted to the current signalling - traffic regulation system of the specific network. This is a very important problem that needs to be solved.

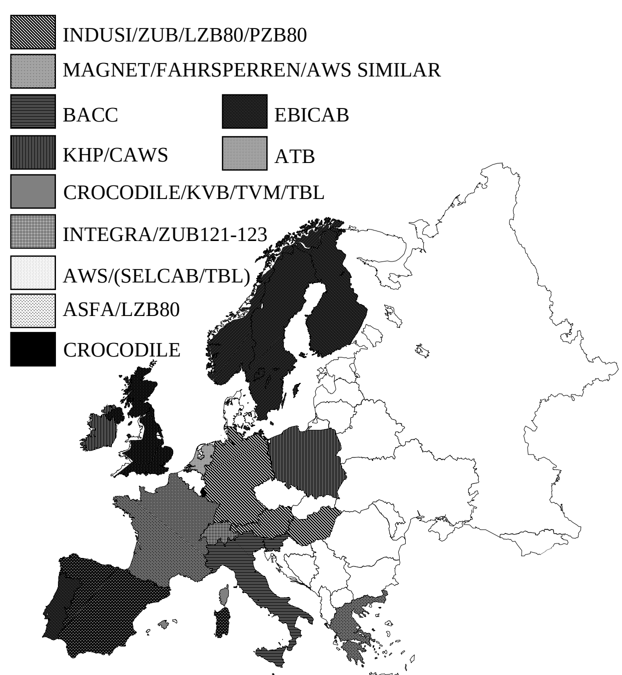

Figure 3: Train control systems - Existing European systems, [5], [7].

4. Operation of trains between lines with different track gauges

4.1. General

Railways that have a problem of more than one track gauge values can improve the situation for passenger traffic either in one or in two ways: either to convert all of their permanent ways to one single track gauge, or to adapt the trains so as to operate with different track gauges, [8]. The adaptation of a network's gauge to that of the neighbouring network is the most effective and at the same time the most expensive solution.

Another transition technique from one gauge to another is the transfer of passengers and the trans-shipment of the vehicle payloads. This way is technically the most simple one, however, the most time-consuming and expensive in regard to the carriage of goods. If the goods are easy to reload, for example goods in bulk that are reloaded by means of gravity, or allowing organized reloading, like containers, there are no significant problems. Conversely, the trans-shipment is rendered very expensive for other types of goods, for instance the shipments of retail goods, while often a reduction of rail freight transport is noted, which is due to mandatory trans-shipment. A large number of narrow-gauge networks, due to this disadvantage, were led to cease their operation.

4.2. Vehicles with the ability to switch from one gauge to another

It is more effective for a vehicle to switch from one gauge to another than the trans-shipment of its load, and currently there exist many solutions toward this direction. The existing possibilities are:

i. *Wagons or carrying bogies*. These are small running gear (carrying bogies) that are placed under the axles of the vehicle that has a different gauge or vehicles (carrying wagons) that are equipped with rails at their substructure in order to carry wagons of different gauge.

ii. *Replacement of running gear*. Here the running gear, single axles or bogies, are replaced at the border between two networks that have different track gauges. The vehicle continues its route on the other side after the change of its running gear. This technique necessitates equipment, mainly cranes, in a sufficient number for the replacement of the axles and bogies.

iii. *Axles with variable gauge.* Variable gauge axles are the ideal solution to the problem. Their wheels, which are assembled at the centre-line of the axle, are capable of moving in longitudinal direction and wedged at a position that corresponds to the desired gauge.

iv. *Variable gauge axles technique*. The wheels move in longitudinal direction on the centre line of the axle, or of a half-axle in the case of independent wheels. The wheel is secured at the position corresponding to the desired gauge in order to avoid any undesired slipping and displacement. The assembled axles dispose over a security-locking device that prevents the rotation of the wheel in relation to the axle in such a way that the mechanical tension is given, like in an axle that is assembled with fixed wheels. This mechanism is not necessary in the case of independent wheels. On its arrival at the border between the two railway networks with different track gauges, the vehicle is taken to the conversion installation. This is a section of the tracks that is suitably equipped, where the following functions are performed toward the direction of movement of the car:

- Unlocking of the wheels or the axleboxes,
- Movement -by means of sliders-of the wheels toward the centre or the edge of the axle (depending on the track gauge at the exit of the installation), locking of the wheels or axleboxes at the final position that corresponds to the new track gauge.

These installations have to adapt to any axle system. The ease of conversion of track gauge during operation of the train depends on the reliability of their securing and wedging in their new position, ready for operation and especially during the passage through the conversion installation (locking, unlocking).

4.3. Variable gauge axles

4.3.1. Application of variable gauge axles in passenger traffic

Articulated "Talgo" trains are equipped with independent wheels placed on transverse half-axles, which are placed between the bodies of sequential vehicles of the train. The wheels and their ball bearings move axially along a plane in order to switch from one gauge to another (Fig 3). During the gauge change, at first the wheels are released from the load of the body of the vehicle, which body is moved upward by means of rollers-auxiliary rails, (phase 1). Guiding profiles "grab" the heads of the two locking bolts of each wheel, lead them downward and release the axle translocation (phase 2). The wheel, together with the wheel's half-axle, is placed, by means of guiding rails, in its final position, corresponding to the other gauge (phase 3). In the following (phase 4) the running gear is secured in its new position and the vehicle continues its route on the other gauge (phase 5). A train passing from one gauge to another

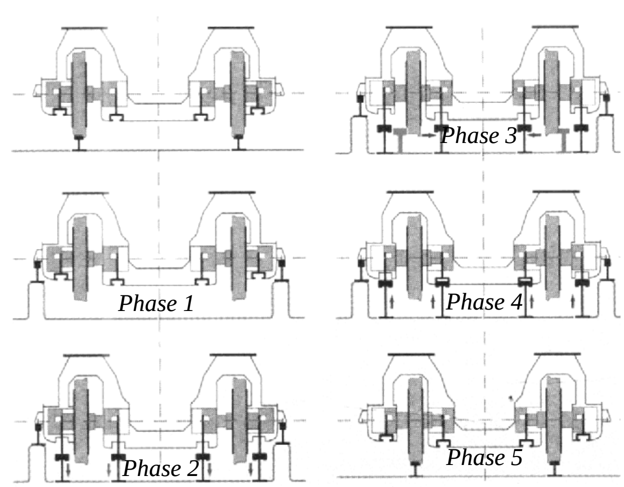

Figure 4. Variable gauge axle – System for articulated trains

needs a few minutes of time for this at a speed that is slightly higher than the pace of pedestrian.

4.3.2. Powered axles with adjustable gauge

The Japanese Railway Technical Research Institute (RTRI) has built a prototype triplet train (EMU: Electric Multiple Unit), with variable (adjustable) gauge bogies, [8] which was tested at speeds up to 100 km/h with narrow-gauge tracks of the western Japanese railways, in order to be put to service in the high-speed regular gauge Shinkansen tracks (1.435 mm), as well as on the narrow-gauge tracks (1.067 mm). Its bogies underwent dynamic testing at a simulated highest speed of 500 km/h, [9]. Japanese Railways have powered bogies with variable-gauge, which they consider to be more efficient from a cost point of view, in order to extend the advantages of high-speed rail transport to the whole network.

The new train that was developed by the Japanese Railway Technical Research Institute (RTRI) auto-matically changes the distance between the wheels of each axle during travel on track section that is called gauge-changing section, which has a length of 22 m. A prototype ground installation for the gauge change has been constructed for evaluation and the new prototype bogies have performed more than 1.000 passes through this installation. Because the new train is self-propelled, with powered axles distributed along the entire length of the train, it has the ability to pass from one gauge to another by its own traction power. Parallel to the track and to both of its sides there is one rail respectively that supports a railway vehicle and functions as a conveyor belt. While the support rail remains at the same level, the rails that comprise the narrow-gauge track are gradually declining in the transitional section, until they terminate 55 mm below their level at the point of entry. The regular-gauge rails are also lowering within the transitional section.

As the train passes through the approaching part of the track (which has a specific gauge) the lowering of the regular rails gradually conveys the weight of the vehicles to the carrying support rails, which function as a conveyor belt. At the point where all the weight of the vehicle is conveyed and supported by the support rails, the rails that comprise the regular track come to an end, and the wheels are getting in contact to the guiding rails in the transversal direction. With the axleboxes fully supported in the transitional section where the regular rails are at the lowest point, a locking pin at the edge of the axles goes down in order to release the wheels. With the train's forward motion the guiding rails are exerting pressure laterally on the wheels in order to change their distance to each other. Then the wheels are led to their new position, which is compatible to the new track gauge as the train is continuing on. The track rails reappear at the point where the new wheel distance has been achieved. As the wheels begin to rise again, the weight is conveyed again to the axles, while the locking pin is returned back up to the axlebox and secures the wheels for the remainder of the journey, while the weight of the train gradually is raised by the support rails and conveyed to the regular rails, [9], [10].

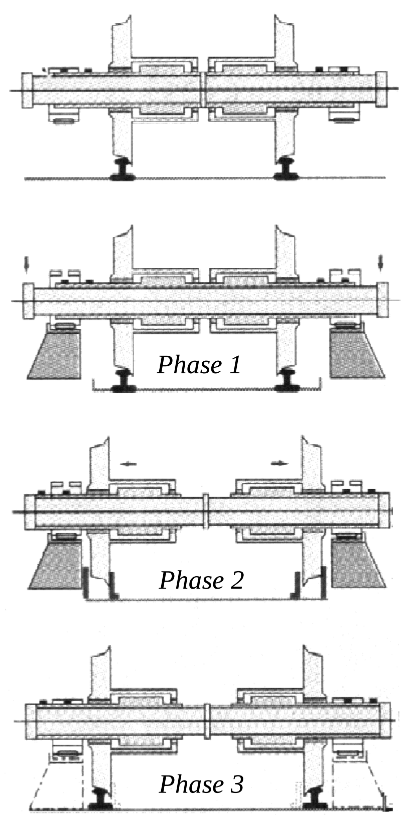

Figure 5. Gauge-changing procedure for a powered axle (EMU), [10].

4.3.3. Variable gauge axles in freight traffic

In freight traffic the variable gauge axles can produce significant savings in time. In practice freight reloading/ trans-shipment makes necessary an average delay of 2,5 days, which can not be reduced except in the case of freights that are easier to reload: goods in bulk, fluids or containers, [10]. To this delay the risk of losing or damage to the goods during reload is added. Due to this the percentage of axle or bogies change is rising, since it takes only a few hours.

However, with variable gauge axles the change from one gauge to another needs only 20 to 30 seconds, while the wagon is moving at the speed of pace of a pedestrian. One should not be surprised by the fact that the Central European countries with major freight transports traffic to and from former Soviet Union countries, commenced studies in the direction of this solution, which remains interesting, given the fact that in 1994 25,5 million tons have been trans-shipped between regular-gauge and 1.520mm-gauge networks (excluding Finland).

4.3.3.1. The Rafil V variable gauge axles system

This axle (Fig. 6), was developed by the former East German network and has been recently perfected by the German railways (DB AG), [4].

4.3.3.2. The SUW 2000 variable gauge axle

This axle was developed by the Polish railways (PKP), (Fig. 7).

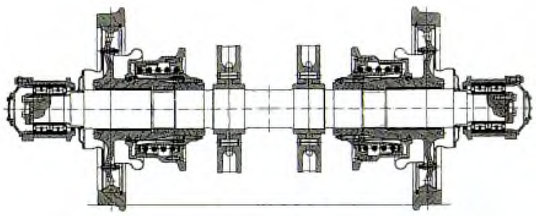

Figure 6. DB AG/Rafil type V Variable gauge axle (locked position to the right, unlocked position to the left), [4].

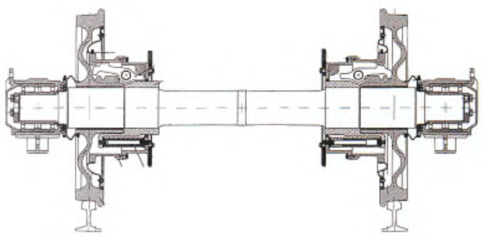

Figure 7. SUW 2000 Variable gauge axle, (version for vehicle bogie with disc brakes), [4]

4.3.3.3. The Talgo variable gauge axle

The Talgo company operates since thirty years successfully and fully reliably a variable gauge axle system with which they equip their articulated trains, [4].

4.3.3.4. The PKP variable gauge axle

This axle was developed by the Polish railways (PKP), (Fig. 8). Their wheels and ball bearings are placed within a housing that moves axially along a plane. The locking mechanism is situated on the outer side of the wheels, [4].

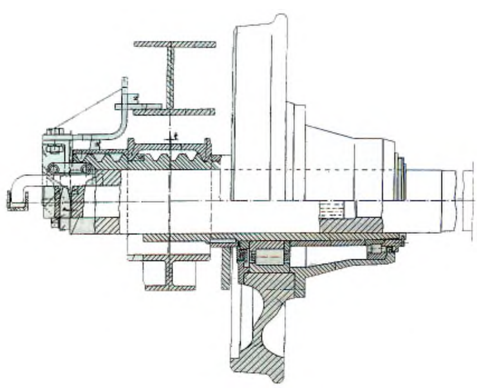

Figure 8. Variable gauge axle **-** *PKP system, [4].*

5. Electric power systems incompatibilities

An electric locomotive necessitates special design and construction, which allows multicurrent or multisystem operation in order to run on more than one network. Currently the first quadricurrent (four-voltage) electric locomotive is being built.

In all countries of South - East Europe, the electrification systems are the same, the technical data being a voltage of 25.000 V and a frequency of 50 Hz. In Austria, as well as in Germany, the electric power system runs with a voltage of 15.000 V and at a frequency of 16+1/3 Hz. In Italy, as well as in Slovenia electrification has a direct current voltage of 3.000 V. It is obvious that traction units that can cover all three electrification types should be used.

In this way the delays for the change of electric locomotives at the border, which results in a delay of at least 15 minutes, could be avoided.

5.1. Multi-system electric locomotives

Very recently electric locomotives which can operate under three different current systems have been developed in Belgian Railways (SNCB), [11]. The technical data of these electric locomotives, which derive directly form those of the SNCF's series 3.000 are the following:

- Weight 90 tn,
- Maximum speed 200 km/h,
- Feeding voltage 3 kV DC, 1,5 kV DC and 25 kV, 50 Hz AC,
- UIC 505 – 1 gauge,
- Length including bumpers 19.11 m,
- Bogie axles distance 3 m,
- Distance between centres of bogies 10,4 m,
- Continuous output to the wheel at 3 kV and 25 kV: 5.000 kW between 80 and 200 km/h and at 1,5 kV: 2.100 kW,
- Equipment with two-axle bogies.
- These machines are designed by the company GEC Alsthom.

Recently the firms Siemens and Krauss - Maffei, [12] have designed and it is currently being built, the first four-system electric locomotive, BR 189 type. The main technical data of this electric locomotive are:

- Weight 86 tn,
- Maximum speed 230 km/h,
- Feeding voltage AC 25 kV 50 Hz, AC 15 kV 16.7 Hz, DC 3 kV, DC 1.5 kV,
- Power 6.400 kW for AC 25 kV and AC 15 kV, 6.000 kW for DC 3 kV and 4.200 kW for DC 1.5 kV,
- Equipped with two-axle bogies,
- UIC 505 – 1 gauge,
- Length including bumpers 19,58 m,
- Bogie axles distance 3 m,
- Distance between centres of bogies 9,9 m.

6. Harmonisation rules for signalling systems interlocking

6.1. Harmonisation rules for signalling interlocking

The recent technical changes in the sector of safe electrical calculations and telecommunications, allow for new approach that has to be determined for the traditional component of the rail interlocking system. The microcomputer generation based on interlocking is in operation for more than ten years. Nevertheless, operating conditions still depend on classic operational rules, which are based on traditional technology. Having that in mind, in 1993 the UIC assigned to ERRI (European Rail Research Institute) to conduct a special budget program (ERRI A 201) regarding the "harmonization of operating conditions of signalling systems", [13].

The work of the ERRI A 201 program, which focused on interlocking signalling was accomplished at a time where European railways and the European signalling industry were concentrating their efforts mainly on issues of interoperability with the draft of a specification for the ERTMS system and within that the ETCS system. This development was a good reason for thorough examination of the role of interlocking within the new structure of the signalling system. Therefore, with the harmonization of the operational rules it would be possible to redetermine the role of interlocking within the entire signalling system.

After intensive analysis that was documented with several reports, the A 201 program worked out a mutual centre of operational specification for interlocking, which is a good basis for the further debate between railways and industry.

A number of railways contributed to this work. Analysis did cover the practice of European railways, as well as of Japanese railways.

The European Railways are making efforts to improve the service (operation) and safety and to increase capacity (ability) and effectiveness. These efforts are brought into line by two important directives of the European Union: 91/440/CE – which refers to the free access of any rolling stock operator to the Railway Network and 96/48/CE – which refers to the interoperability of the trans-European high-speed railway system.

6.2. Reliability, Availability, Maintainability, Safety Issues

The specifications of the ERTMS system in regard to safety are closely related to the CENELEC (European Committee for Electrotechnical Standardization) standards.

The relation of RAMS characteristics with railway reliability, is given in the pr EN 50126 specification of the CENELEC committee. The specification determines the need to establish a RMAS program and a safety plan based on a system life cycle approach. Acceptance of the safety of an interlocking system should be achieved through the preparation of a safety case, as determined in ENV 50129.

A noteworthy characteristic of the Japanese guidelines is that the guidelines provide information to the railway Authorities and to the industries, in order to decide on safety measures and procedures for themselves, while the European countries are aiming at CENELEC specifications with legal force.

Special documentations are necessary. Experience shows that these approaches are difficult and it is estimated that the safety control level of the train, as well as the safety systems that follow the guidelines will be enhanced. Notwithstanding of some differences (especially organizational) even between European countries, we believe that it is possible to harmonise in the future the European and Japanese safety specifications. Japanese guidelines are taking the compatibility of international specifications into account, and the guidelines will have to be revised in the near future, accumulating valuable applied experience.

7. Conclusions and further research

Interoperability is the key for the railways in order to offer continuous and uninterrupted flows and compete efficiently in the transport market. A synthesis of the most important recent achievements concerning technical interoperability has been presented in this paper. However, major research efforts are furthermore needed, particularly in the traffic control systems. As application of these interoperable systems is new, railway companies are encouraged to adjust their investment programs having in mind a more wide world environment. Last, it should be not omitted that special efforts should be made in the human field; scientists, technicians, administrators and all involved people are a prerequisite for an efficient application of the achievements of interoperability.

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