Braking – precondition for faster movement of railway vehicles

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The paper gives a brief review of development of the braking system of railway vehicles. At the end of the nineteenth and the beginning of the twentieth century, the development of the concept of the drive of the railway vehicles has completed. After the steam, both electric and diesel traction have developed. For further development of railway traffic, it was necessary to develop a more efficient braking system. After the official start of railway traffic, it took almost a hundred years to development the braking system that allows faster and safer movement of railway vehicles. The credit for that belongs Serbian inventor, Eng. Dobrivoje Božić. In an original way, he constructed the brake which solved many problems that until then had been a limiting factor for faster and safer movement of railway vehicles. The aim of this paper is to bring the ingenious technical achievements of Dobrivoje Božić in the field of braking of railway vehicles closer to the scientific and professional public.

Keywords: Serbian inventors, Dobrivoje Božić, Railway traffic, Train braking.

1. INTRODUCTION

People always try to overcome the distance between two places as easily and quickly as possible. The discovery of the wheel had leaded to a revolutionary transformation of land transport. The development of the technology in that period was mostly contributed by the exploitation of ore. Wooden wagons loaded with ore had moved more easily on rails than on macadam roads. With the invention of the steam engine in 1782, the Scottish inventor James Watt had started the new era in industrialization, especially in the development of transport.

During the nineteenth century, almost all over the world, railways rapidly replaced existing stagecoach networks. The railway traffic, in that period of great geographical discoveries and industrial revolutions, became crucial for the development of the economy and society of the whole world. The first railway for public transport was built in 1825. In addition to participating in the construction of the railway, George Stephenson built a steam engine in the same year, which he called "Locomotion". Stevenson personally drove this machine, which was not equipped with a cabin or a place for a machine operator. Due to great successes in development, the year 1825 is considered to be the beginning of organized railway traffic, and the name "Locomotive" came into official use [1].

The first regular railway line Liverpool – Manchester for passenger transport was opened in 1830. Since then, rail traffic has been expanding at high speed all over the world. The limiting factor for further, even faster, development of railway traffic was the unsolved problem of braking.

Along with the development and improvement of railway constructions, the standardization of technical solutions of vehicles, as well as infrastructure and the entire railway traffic took place. This was necessary because rail traffic connected distant cities and states, and even continents.

In addition to many good and useful characteristics, railway traffic enabled exploitation and occupation of certain territories in hitherto unimaginable proportions. That is why some countries, in accordance with their interests (primarily military) - deliberately hindered the free flow of railway traffic and deviated from some established dimensions, such as e.g. track width.

2. THE BEGINNING OF THE DEVELOPMENT OF RAILWAY TRAFFIC IN SERBIA

By signing the Congress of Berlin in 1878, Serbia undertook to build a railway on the route Belgrade - Niš - Vranje. However, even more significant is that the Belgrade - Nis railway was a section of the planned Berlin - Baghdad railway. This would allow Germany access to significant oil deposits, which did not suit other major world countries. The finishing the section Belgrade - Nis marks the beginning of the existence of Serbian railways. The first train passed on this line on October 4, 1884.

For the construction of Belgrade - Niš railway, the so-called Bontu's concession was agreed. In the first contact with large western capital, one of the biggest money scandals in Serbian history occurred. The collapse of the Bontu's General Union was caused the fall of the French government. Regarding this concession, prof. Slobodan Jovanović wrote: "The spoilage of our political natures began immediately under the influence of foreign gold" [2, 3].

3. BRAKING OF RAILWAY VEHICLES

The braking system of railway vehicles regulates the running speed, as well as deceleration and stopping of train. A known joke that trains can move faster uphill than downhill speaks of the greatness of the technical problem of safe braking of variable mass (empty - loaded) of several thousand tons. As in the case of construction of locomotives, wagons and tracks, at the end of the nineteenth century, a race arose in the construction of the brakes of railway vehicles.

At the beginning of the development of railway vehicles, the braking force was changing manually. After that, at the end of the nineteenth century, the American George Westinghouse constructed an air (pneumatic) brake with direct action. During braking, air was released into the main line, and in the unlocked position,

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atmospheric pressure prevailed in the line. When the train was interrupted, there was not possibility for automatic braking, and with other shortcomings, this brake did not meet the basic requirements of a good and safe brake. In addition to Westinghouse's brake, four other technical solutions of the brake competed in America. This competition led to the certain improvements and spreading the Westinghouse's brake both in America and in Europe. In Europe, the Westinghouse's brake was used only for passenger trains. Until the First World War, freight trains in Europe were braked exclusively manually. Each wagon had to have one or two brake operators, which took care of the safe braking of the train.

In addition to Westinghouse in America was also Smith, as well as Hardy in Europe, who designed brakes with diluted air - vacuum brakes. After Westinghouse's brake, several brake variants appeared in Germany, such as Kunze-Knor, Hildebrand-Knor and in Switzerland Drolshamer. All these brakes operated on the principle of a standard two-pressure distributor and did not satisfactorily solve the observed shortcomings.

The idea of brakes with distributor with three pressures was patented in 1892 by the Englishman Humpfrey. The idea remained only on the paper and was never practically realized.

While Watt, Trevithick, Stephenson, Diesel and other inventors set trains in motion with their inventions, Westinghause, Smith, Hardy, Kunce, Knorr, and many others, have been developing the brakes of railway vehicles which had huge deficiencies until the occurrence of Dobrivoje Božić.

The main shortcomings of the then brakes of the railway vehicles were reflected in the following:

The main shortcomings of the then brakes of the railway vehicles were reflected in the following:

- when the train was interrupted, both parts of the train were not automatically braked;
- the brake was exhausting on longer track falls, i.e., the brake was losing its power;
- there was no automation of braking force depending on the degree of loading of the train;
- there was no automation of braking force depending on the speed of the train;
- the brake transmission speed of the braking system was unacceptably low (maximum 80 m/s);
- wheel blocking was very often.

These shortcomings limited the running speed and made it difficult to use the railway on a larger scale. Due to the imperfection of the brakes, frequent accidents and railway traffic interruptions were occurring. Due to the blocking of the wheels during the braking many problems were occurring such as: sliding the wheels on the track; extension of the train stopping distance; formation of flat places on the wheels; damages to both the vehicle and the track etc.

Until the appearance of Božić's invention, the braking of railway vehicles was initially performed manually, and later pneumatically but non-automatically (directly) according to the scheme shown in Fig. 1.

In the case of direct - nonautomatic - exhaustive brakes, the air is fed directly from the main tank through the air line into the brake cylinder. The big disadvantage of these brakes is that in the event of a train break, there will be no automatic braking of any disassembled part of the train.

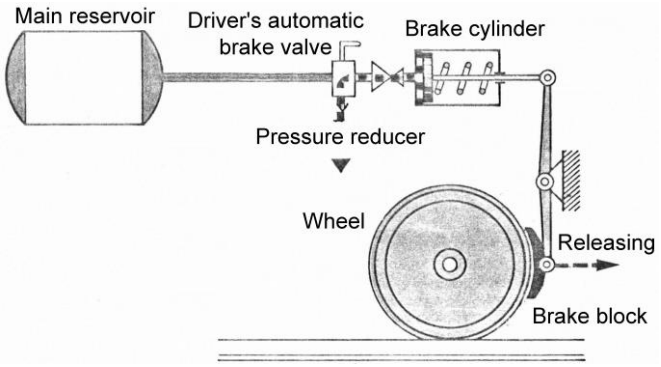


Figure 1: Principle of operation of direct (non-automatic - exhaustive) brake

The exhaustive brakes have a single-stage release, i.e., once started release cannot be interrupted. In this case, the brake distributor has two distribution pressures: the main line - the brake cylinder. If the train is braked to any degree, as soon as the main line is slightly charged, the brakes will fully release. The brake cylinder will not be completely charged because the pressure in the main line did not reach its maximum value. If the braking-releasing process is repeated several times, the pressure in the brake cylinder will decrease more and more, i.e., the amount of compressed air is exhausted, and thus the braking force will decrease more and more (Figs. 2 and 3).

In addition, the huge disadvantage of exhaustive brakes is that they do not have regulation of the magnitude of braking force depending on the weight of the vehicle (with and without load) and running speed. Also, they do not have synchronization of braking (low brake transmission speed) from locomotive to rear wagon, so it often happened that when changing the movement regime (start, acceleration, deceleration) there is a collision between individual vehicles of the composition or the rupture of connections between vehicles.

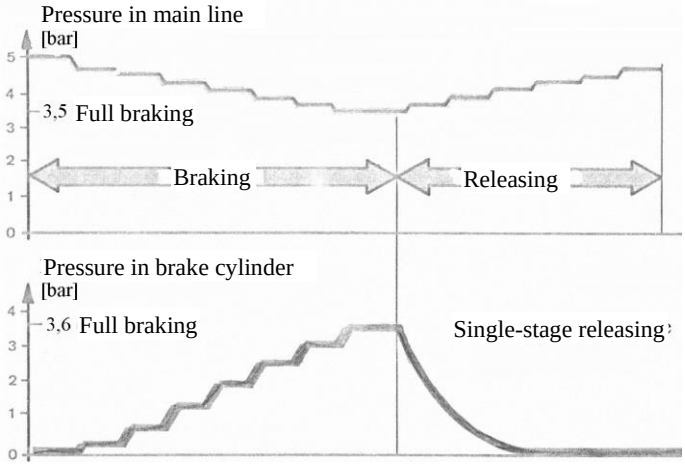


Figure 2: The change of pressure in the main line during braking and releasing at exhaustive brakes

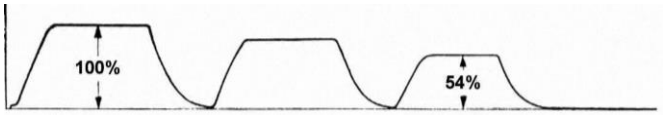


Figure 3: The change the air pressure in the brake cylinder at exhaustive brakes

Although this method of braking had great shortcomings and although many researchers around the world worked on solving this problem, after several decades of attempts, better braking system wasn't successfully developed. The impression is that there was no way out of that vicious circle. The main topic of discussions in the circles of scientists and engineers who developed the brake was whether the braking of railway vehicles should be done with diluted air or compressed air. After many tests with diluted air, no significant progress was made.

4. CONTRIBUTION OF DOBRIVOJE BOŽIĆ TO DEVELOPMENT OF BRAKES OF RAILWAY VEHICLES

In the beginning, English, French, German, and American engineers contributed to the development of the railway. However, the braking of railway vehicles was not resolved in an appropriate way. Further development of the railway (increase of running speeds and weight of transported cargo) was not possible without a quality solution to all previously mentioned problems.

Dobrivoje Božić (Fig. 4) was born, according to the then valid calendar, on December 23, 1885 in Raška, Serbia. Due to the later state transition to the new calendar, some sources state that he was born at the beginning of 1886. After finishing primary and secondary school in Kraljevo and Kragujevac, he was studying at the Technical High School in Karlsruhe and Dresden - Germany, where one of his professors was Rudolf Diesel. After completing his studies, he returned to Serbia. In 1911 he employed in the state railway workshop in Niš where he faced with problems with braking railway vehicles. He developed his invention in the period 1911-1914. He designed and patented the braking system of railway vehicles in which a brake and distributor with three pressures were applied for the first time (Fig. 5). According to Božić's solution, the role of the new braking system is to distribute the air not in two, but in three parts of the braking system - the main air line, the brake cylinder and the auxiliary reservoir [4].

Figure 4: Dobrivoje Božić

In 1922, the American Patent Office accepted his solution of the braking system called "System of continuous braking of passenger and freight trains with compressed air". That was just the beginning because there was still a long way to go before International Railway Union (UIC) approved and recommended Božić's patent for use on railway vehicles.

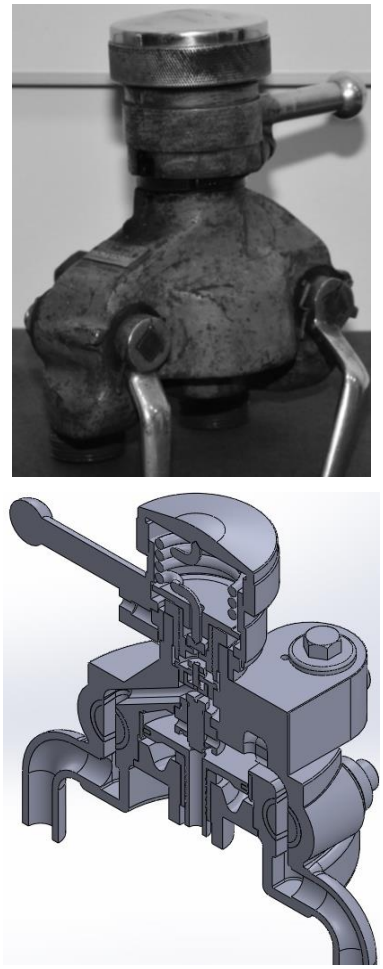


Figure 5: Božić’s three-pressure distributor

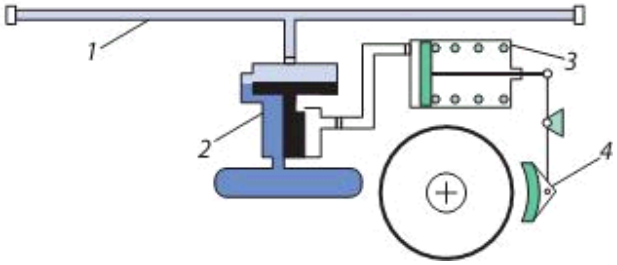
At the conference of the victorious countries of the First World War, in 1923, France submitted a proposal in which it recommended the use of the direct, exhaustive Westinghouse's brake for braking railway vehicles. Since the Knorr's brake came from a country that was a loser of the Great World War, it did not have a great chance next to the Westinghouse's brake in that period. The Knorr's brake was just one of the modifications of the Westinghouse's brake. In that time, these brakes used a standard two-pressure distributor. At the same conference, the representative of the Kingdom of Serbs, Croats and Slovenes recommended the general reception of the Božić's brake, as a better and more perfect solution. The great success of that representative is that the French proposal, i.e. Westinghouse's brake, was not automatically accepted. Instead, a certain period of time was left for Božić and other constructors to practically prove the quality of their solutions to the International Railway Union.

In 1923, Božić also applied for a patent called "Quick-reacting triple valve", which was recognized in 1926. His solution of brake of railway vehicles, Dobrivoje Božić officially submitted via the railway of the Kingdom of Serbs, Croats and Slovenes in 1925. The third patent "Distributor for brake systems with pressurized fluid" was adopted in 1928.

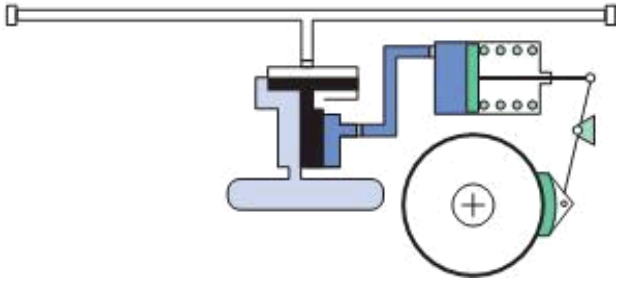
Since they represented a completely new, revolutionary solution, these patents initially faced with a lot of resistance, but after numerous tests on the Zagreb-Rijeka line, they were accepted by the International Union

of Railways in 1928. The complete solution is registered as a Božić brake.

With Božić's automatic - indirect - inexhaustible brakes, there are three pressures: constant pressure in the working chamber of the main reservoir, variable pressure in the main line (1) and variable pressure in the brake cylinder (3). The air from the main reservoir, through the main line (1) is indirectly via the distributor and the auxiliary reservoir (2) introducing into the brake cylinder (3). Conversely to direct brakes, at the Božić brake in the unlocked position, the main line is under pressure and the brake shoes (4) are not in contact with the vehicle's wheel (Fig. 6a). In case of braking or rupture of the railway composition, the main line is emptied, atmospheric pressure prevails in it then, so the pressure from the auxiliary reservoir acts on the brake cylinder and braking occurs automatically (Fig. 6b).



a) Unlocked position



b) Locked position

Figure 6. Simplified scheme of operation of Božić automatic - indirect - inexhaustible brake

The role of the distributor is to distribute the air into the parts of the braking system such as: the main air line, the brake cylinder and the auxiliary reservoir. Božić's three-pressure distributor was designed in a such way that it solved the issue of gradual unlocking of railway vehicles for the first time in the world (Fig. 7). Also, it eliminated the danger existed at the previous brakes with two pressures, that due to the emptying (exhausting) of the auxiliary reservoir on the long falls of the railway track, the necessary braking force will not be realized (Fig. 8).

Unlike the hauled vehicles, traction vehicles (locomotives) also have a braking control device which is the central device of the train braking system. The Božić's braking control device gives commands for:

- braking and unlocking all brakes in the train
- filling the brake system with compressed air
- compensation of losses due to unsealed brake devices, i.e. maintaining the working pressure in the main line
- discharging of the main line into the atmosphere and rapid braking.

Before the Serbian inventor Božić, no braking control device could automatically maintain a constant air pressure in the main line during the braking. Compared to earlier solutions, Božić designed the pressure adjustment in the relay chamber in an original way. Guided by the same principles according to which Božić designed his braking control device (Fig. 5), all modern braking control devices have the property of maintaining the working pressure in the main line during the braking and unlocking. In this way, brake exhausting is avoided, i.e., no matter how many times braking is performed, the braking force will have approximately the same value.

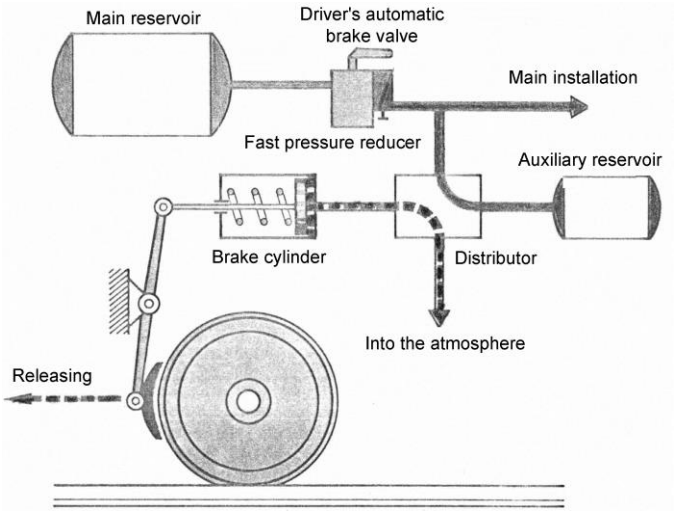


Figure 7. Principle of operation of indirect (automatic, inexhaustible) - Božić brake

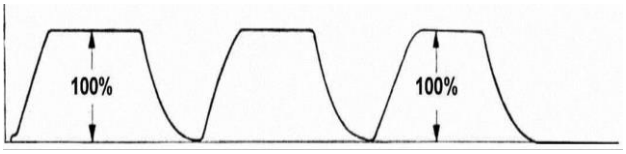


Figure 8. Change of the air pressure in the brake cylinder of Božić brake

These brakes are also called inexhaustible, because the auxiliary reservoirs are filled for all the time of braking and unlocking, so that the pressure in the brake cylinder remains constant. With Božić brakes, the reduction in the braking force can be done gradually. Gradual unlocking is enabled by a distributor with three distribution pressures: main air line - working (auxiliary) chamber (reservoir) - brake cylinder.

Therefore, brakes at which gradual braking and gradual unlocking are possible, i.e., in which the auxiliary reservoirs are replenished for the entire time of braking and unlocking, while maintaining the maximum value of the braking force at any time, regardless of the repeated braking, are called inexhaustible (Fig. 9).

The Božić distributor is designed so that it automatically adjusts the pressure in the brake cylinder for each load. This was achieved with special device that changed the value of the braking force depending on the deflection of the vehicle suspension. In this way, empty or lightly loaded railway vehicles are braked with smaller, and more loaded with greater braking force. Other countries at the time were developing brakes with two brake cylinders. In the case of an empty wagon, only one brake cylinder would work, and in the case of a loaded wagon, both brake cylinders would work.

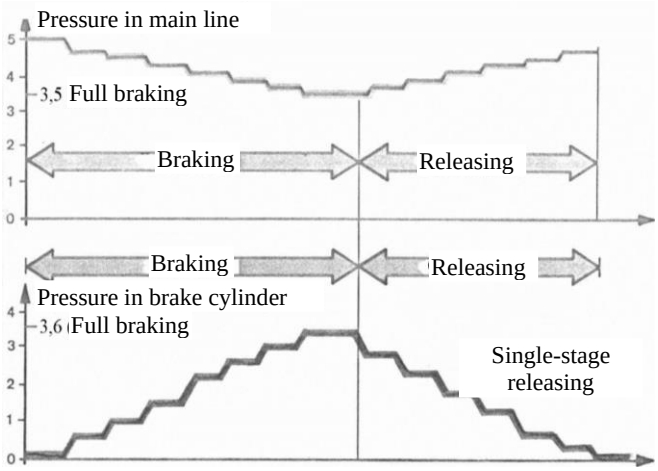


Figure 9: The change of the pressure in the main line of Božić brake

Because of their interests, large companies tried to criticize Božić's patents through their representatives. Despite, all later constructions of the braking system are based on Božić's (simpler, safer and cheaper) solution. Božić's brake system of railway vehicles have remained in an essentially unchanged form until today. In this way, the genius and superiority of Božić's solution was proven, and all the criticism "fell into the water" over time, because they were technically unfounded and encouraged only by the desire for profit and fame.

In addition to previously realized and internationally accepted patents, Božić designed and proposed a device based on the principle of a centrifugal regulator which, at lower train speeds, would reduce the pressure in the brake cylinder to an appropriate measure and thus reduce braking force. This solution would prevent blocking the vehicle wheels during braking. In this way, the problem of changing the braking force depending on the speed of railway vehicles is solved [5]. Although Božić's solution preventing blocking the wheels, forming a "flat place" on the wheel and significantly shortening the stopping distance of railway vehicles, his proposal was not accepted at the time.

This Božić's attitude was understood and accepted by science and profession only many years later and is used in modern railway brakes. Božić sold the license for his patent to the Czech company "Skoda". After the Second World War, Božić was unjustifiably declared as an enemy of the state by the new authorities and arrested on charges of collaborating with the occupier. He was released from the prison at the insistence of the Russians. Fearing that, in those troubled times, he would be arrested again and shot, and that he would be prevented from further work on perfecting the brakes of railway vehicles, with his family he secretly left Yugoslavia in 1948.

In 1954, a special commission of the General Directorate of the Yugoslavian Railways considered the issue of the type of brakes that should be approved for use. Even then, the "Metalski zavod Tito" in Skopje had purchased a license of the brake from the then little-known Swiss company Oerlikon and was just waiting for the decision of the commission to start production. Of course, the Collegium of the General Directorate, ignoring Božić's results, adopted the Commission's view that the Oerlikon brake is most suitable for Yugoslavian Railways and made the decision that in the future only that brake will be installed on all railway vehicles on Yugoslavian Railways. By unnecessarily spending money on a license, any further serious development of the brake of railway vehicles in Serbia was also prevented.

5. CONCLUSION

With his inventions, Dobrivoje S. Božić solved the hitherto unsolvable problems of braking of railway vehicles: he was the first who constructed and applied a distributor with three working pressures. He constructed the most efficient braking control device. Božić's designs of braking control devices and distributors solved the problems of automatic keeping of constant air pressure in the main air line during braking and unlocking, and at the same time increased the brake transmission speed of air in the main line from 80 to 150 m/s. His braking control device enabled the gradual braking and unlocking of the train and solved the problem of inexhaustibility of the train brake during braking. For modern brakes, the UIC prescribed a mandatory examination of the inexhaustibility of the brake, which was not obligatory in previous regulations. With his inventions, Božić solved the problem of overcrowding of the working chamber, as well as the problem of automatic change of braking force depending on the load of the railway vehicle. He was the first who solved and proposed the automation of passenger train braking as a function of speed, and for that he constructed a centrifugal regulator. Although this solution was not accepted at that time, today it is used in all (both passenger and freight) railway vehicles.

In a completely new way, Božić significantly increased the degree of automation of the braking process and prevented frequent blocking and the formation of "flat" places on the wheels of railway vehicles. Božić's inventions enabled safer, better quality and more economical braking of railway vehicles. It was no longer necessary to employ a large number of braking operators who, in addition to train drivers, were obligatory participants in the movement of railway compositions. After Božić's discoveries, concept of diluted air brakes was definitely abandoned and it was decided to use brakes with compressed air. Also, the issue of two-distributed and three-distributed brakes has been resolved. The three-distributed concept has been adopted as a more perfect, which enables gradual unlocking and ensures the inexhaustibility of the brake. Increasing the brake transmission speed enabled calmer and safer braking. Automation of braking depending on the load and speed of movement also contributed to more efficient and safer braking. This influenced the further, even faster, development of railway traffic in the whole world. The best judge of these conclusions is always immutable and impartial time, because all other developed systems of braking of railway vehicles have long been out of use. All later solutions of air brakes in the world are just improvements of Božić's inventions. His braking principle is unsurpassed and is the basis for all types of air brakes used to date.

From all the above, we conclude that Božić's contribution to the development of brakes of railway vehicles is of planetary proportions, and in many cases, he was far ahead of the time in which he created [6]. We can

rightly say that Dobrivoje Božić was even a forerunner of the development of the ABS (anti-lock braking system) with which road vehicles are equipped today.

After the Second World War, Dobrivoje Božić was unjustly accused for cooperating with the enemy. All his property was confiscated, and he, fearing further and more drastic measures, emigrated with his family from Yugoslavia to the North America. He remained in exile until 1961, when, without a family, he returned to Belgrade permanently with a great desire to start the production of the most perfect brake of railway vehicles in the world. Having been left without a family and without property, he failed to fulfil this wish in the new state system, exposed to huge obstruction. The state government of that time, for reasons known only to them, was not ready to accept this invaluable gift. He died in Belgrade on October 13, 1967, at the age of eighty-two.

As an illustration of the positive influence of Božić, the words of Josip Švagel from Zagreb should be cited, who in the preface of his book "Brakes of railway vehicles" points out [7]: "... I should especially emphasize my gratitude to Mr. Dobrivoje Božić, who interested me in this important branch of railway technology with his brakes and personal influence, and is thus the real initiator of this book." "The extraordinary development of conduction brakes in the last decade, the great success in that field of our compatriot Eng. Božić, is looking for its interpreter."

In the end, it can be concluded that the development of railway traffic is not the merit of one man, but it is the continuous improvement of many inventions of several generations of engineers and technicians of several countries, among which Serbia has a significant place thanks to mechanical engineer Dobrivoje S. Božić. Studying his work and life, it can be seen that Dobrivoje Božić is an example of a world inventor - a sufferer, although he did everything to enable everyone a safer, easier and better life.

The life destiny of inventors like Dobrivoje S. Božić should not discourage future researchers. The greatest Serbian inventor Nikola Tesla also spoke about this in 1919, emphasizing [8]: "It is a difficult task for the inventor, who is often misinterpreted and not rewarded. However, he finds enormous compensation in the satisfaction that comes from his powers and the cognitions that he belongs to the class of extremely privileged people without whom humanity would have long ago disappeared in the difficult struggle against the ruthless forces of nature".

Among other, in an interview with Nikola Karanović in 1963 in Belgrade, Dobrivoje Božić said:

- "... all foreign copies of my brake are very complicated and therefore unreliable, and at the same time very expensive. For example, while my distributor has 70 parts, foreign copies have even 200 parts."
- "Until recently, my brake was the only one with automatic adjustment of braking power according to the load of the wagon, which was done with a single part, while all similar brake systems had only manual adjustment, and even very limited - only for empty or partially loaded wagon".
- "Only when UIC prescribed my automatic adjustment of braking power according to the load of the wagon as obligatory in 1953, an attempt was made to apply it to foreign copies, but the device was incredibly complicated. That's why it works poorly on the one hand, and on the other - it's very expensive."
- "The production of my last universal type of brake is obstructed in our country ... it was not enough for them that foreigners earned billions by copying, but they want foreigners to sell licenses for making those bad and expensive copies to my homeland." The Swiss company Oerlikon already succeeded in that several years ago, and now the West German company Knorr-Bremse is also trying to do that. "(Price Božić - 330000 dinars, Erlikon - 530000 dinars).
- "So my country, instead to use my brake, which is why I came here and whose improvement I am now working on, has already issued a billion foreign currency dinars to buy a license to produce a bad and expensive copy of my brake!"

ACKNOWLEDGEMENTS

The authors wish to express their gratitude to Serbian Ministry of Education, Science and Technological Development for supporting this research (contract no. 451-03-9/2021-14/200108).

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