ISSN 2457 – 5275 (Online, English)
ISSN 1842 – 4074 (Print, Online, Romanian)

June 2021
Volume 27
Number 2
4th Series

RoJAE

Romanian
Journal of Automotive Engineering

The Journal of the Society of Automotive Engineers of Romania
www.siar.ro
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RoJAE
Romanian
Journal of Automotive Engineering

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Founded in January 1990 as a professional association, non-governmental, SIAR's main objectives are: development and increase the exchange of professional information, promoting Romanian scientific research results, new technologies specific to automotive industry, international cooperation.

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In order to help promoting the science and technology in the automotive industry, SIAR is issuing 4 times a year rIA - Journal of Automotive Engineers (on paper in Romanian and electronically in Romanian and English).

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Volume 27, Issue No. 2 **June 2021**

The RoJAE's articles are included in the ***„Ingineria automobilului"*** magazine (*ISSN 1842 – 4074*), published by SIAR in Romanian.

The articles published in *„Ingineria automobilului"* magazine are indexed by Web of Science in the „*Emerging Source Citation Index (ESCI)*" Section.

RoJAE 27(2) 41 – 90 (2021)

ISSN 2457 – 5275 (Online, English)
ISSN 1842 – 4074 (Print, Online, Romanian)

The journals of SIAR are available at the website ***www.ro-jae.ro.***

RoJAE
Romanian Journal of Automotive Engineering

SIAR

The Journal of the Society of Automotive Engineers of Romania
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Staff: Professor Minu MITREA, General Secretary of SIAR
Subscriptions: Published quarterly. Individual subscription should be ordered to the Production office.
Annual subscription rate can be found at SIAR website ***http://www.siar.ro.***

ISSN 2457 5275 (Online, English)
ISSN 1842 – 4074 (Print, Online, Romanian)

ASPECTS ABOUT DEPLOYMENT OF LEAN PRINCIPLES FOR IMPROVING THE PRODUCTION PROCESS QUALITY IN AUTOMOTIVE INDUSTRY

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(Received 18 December 2020; Revised 11 February 2021; Accepted 03 March 2021)

Abstract: *This study presents the implementation of Lean principles in a supplying company of auto components for two international automobile companies. The deployment of Lean Principles (Standardized work, Visual Management, Visual Check, Kanban) is studied in this research. Lean Manufacturing, or production at minimal cost, is considered a production strategy based on customer satisfaction, which delivers quality products and services when the customer needs them, in the required quantity, at a fair price, with minimal material, equipment, space, work and time. Since 1980's, the Lean Manufacturing methodology in the field of automotive has become a survival practice in order to improve the quality of production. This study started with the process mapping using Spaghetti Diagram as a first useful tool for viewing activities within a process, and it describes the three essential elements Product / Information Flow, People Movement, Processing Work (WIP). It has highlighted the failures and the problems in the process flow, people and equipment movements, and interphase stocks. After determining the required time for each operation and the necessary components to cover a production change, it was concluded that it is necessary to apply some time-based methods to follow the FIFO (First In, First Out) technique. Therefore, after identifying the losses/waste and problems that occurred during the production process, the principles of Standardized work, Visual Management, Visual Check, Kanban were applied.*

Keywords: *Lean principles, Quality, Standardized work, Spaghetti Diagram, automotive components*

1. INTRODUCTION

The Lean Principles were devised, in a structured and integrated manner, in the Japanese automotive industry when Toyota developed the Toyota Production System (TPS) [2].
This Toyota Production System (TPS) represents an example of principles, philosophy and tools for finding and applying ideas for improvement, optimization, step-by-step innovation in workflows (workstations, supply-distribution, production lines, and so on) [1, 10] which was developed in the USA, in the early 90's, by the three major American automakers companies under the name of Lean Manufacturing [9].
Lean Manufacturing, or production at minimal cost, defines the value as "what the customer is willing to pay" [5]. Therefore, internal processes need to be analyzed from the point of view of added value and waste - those actions and decisions that either add value to the customer or increase the cost of production [10][14].
The logical consequence is that the improved performance comes either from maximizing the effects of processes that add value, from minimizing those of processes that cause losses, or from the concurrent action of both categories of processes [7]. Figure 1 shows the 8 major types of waste that occur during the manufacturing process in order to-deliver the final product [4][16].
Lean is a management system, a philosophy or a set of tools, depending on the scale, strategy and level of development of the organization and culture in which it is applied [11]. Each company wishing to become a lean company should apply those tools, methods and specific methodologies to enable efficient production process [15][17]. However, there are some basic methods and methodologies that need to be implemented: Value Stream Mapping, 6S, Total Productive Maintenance (TPM), Visual factory, Standardized work, so that a society becomes lean [3, 6], as shown in the Figure 2.
The application of Lean's philosophy of production and its principles has proven its effectiveness in all fields, especially in the automotive field with outstanding results [18].

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ISSN 2457 5275 (Online, English)
ISSN 1842 – 4074 (Print, Online, Romanian)

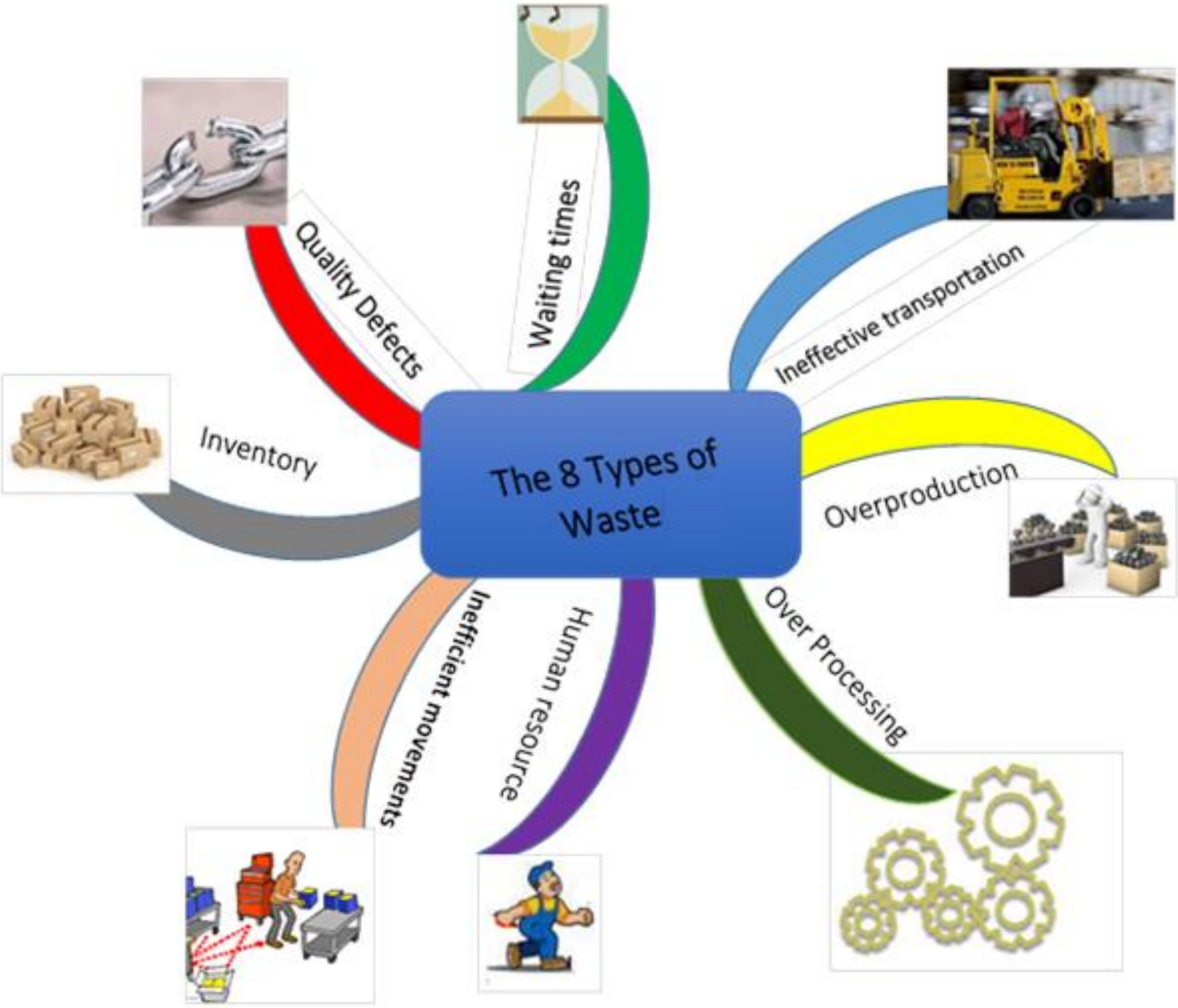

Figure 1. The 8 Types of Wastes

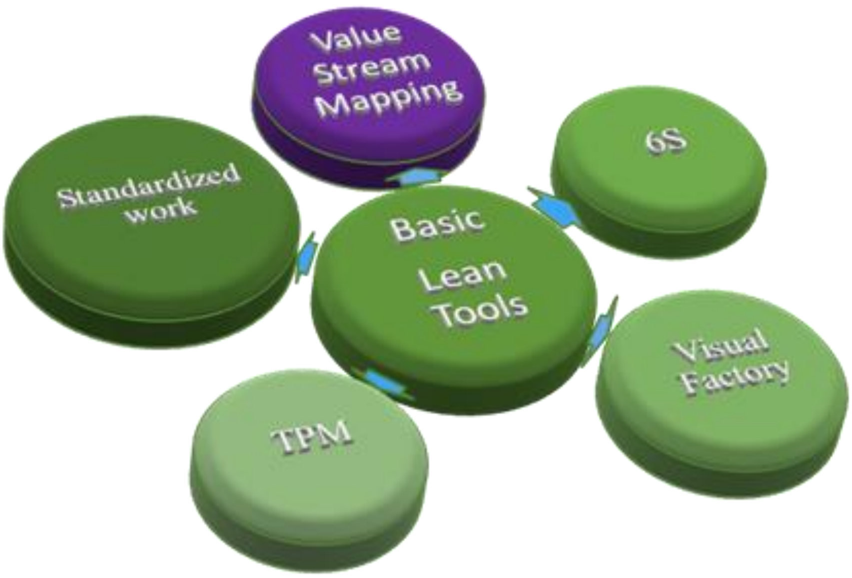

Figure 2. Basic Lean Tools

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2. IMPLEMENTANTION OF STANDARDIZED WORK PRINCIPLES IN A COMPANY

This research has been accomplished at a supplier of fuel tanks for automotive components of two international automobile companies, generically called F1 and F2. The implementation of Standardized work principles has been performed from the beginning of 2014 until now. It is mentioned that, prior to the application of the principles of Standardized Work, the techniques of 6S [12] and Total Productive Maintenance (TPM) [13] were applied in the company. Standardized work reflects best practice and is the basis for continuous improvement. The reference documents required for the implementation of the elements underlying the work standards are made for each operation / succession of work operations, displayed in the workplace in visible places, and will be discussed and developed with the workers. Establishing the precise procedures for each operator in a production process is based on the following three elements: available production time - which is the rate at which products must be made in a process to meet customer demand; the exact sequence of operations performed by the operator during available production time; the standard stock required for the production process to take place properly.
The research methodology, presented in Figure 3, materialized in the initial analysis, from which the application of the basic Lean techniques and methods in Figure 2 began, respectively the mapping of the process to establish the “initial process flow”.
The next step was to establish specific solutions for each area of the company, by determining the different supply times between different areas, transport within the company, unloading, loading, etc. in order to streamline the process flow and shorten the production cycle time.
Applying the methodology at the global level of the company supplying automotive components, the optimal solution for the development of the productive flow and the determination of the overall efficiency of the equipment / process (OEE) will be obtained.

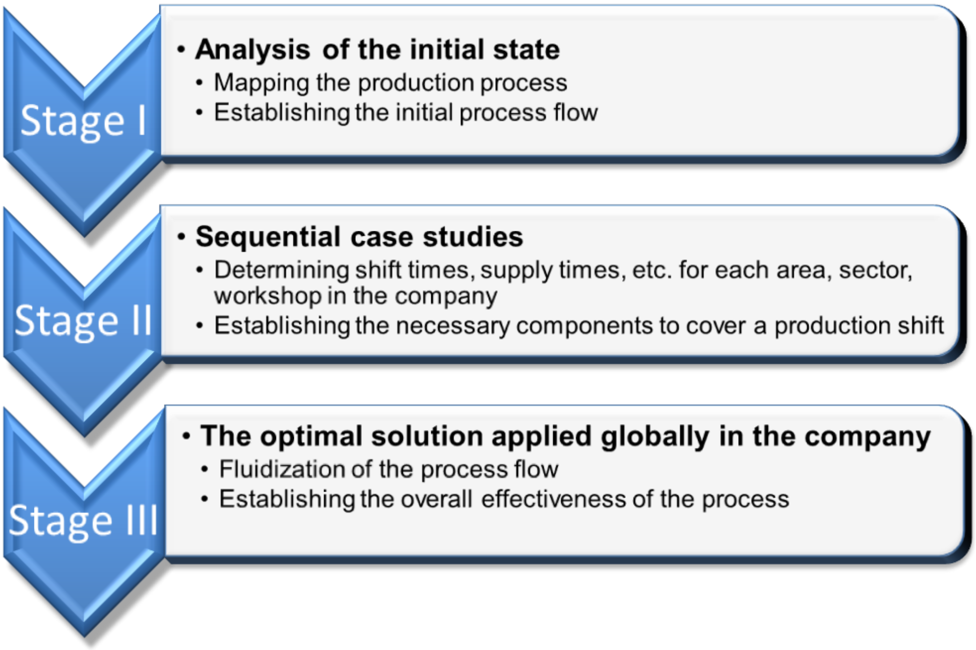

Figure 3. Stages of implementing the Lean methodology, Standardized work (SW)

The following lean techniques were used: Overall Equipment Efficiency (OEE) monitoring, Pareto Diagram, FIFO (First In, First Out), and Kanban. In order to apply the concepts for Standardized work, at initial stage, the 6S and TPM methodology have been already implemented.
The first stage consisted in the use of the Spaghetti Diagram, an important tool for visualizing and accurately mapping the activities within a process, describing 3 key elements: Product / Information Flow, People Movement, Work in Process (WIP). The mapping of the process was done by identifying the activities step by step on the flow of the product / service, allocating measurable indicators to each activity, so as to identify the efficiency of the process, identifying any aspect in terms of equipment, work environment, etc., which can give rise to an improvement solution. In the initial phase, the process of monitoring the operations was carried out, resulting in a Spaghetti Diagram (Figure 4).

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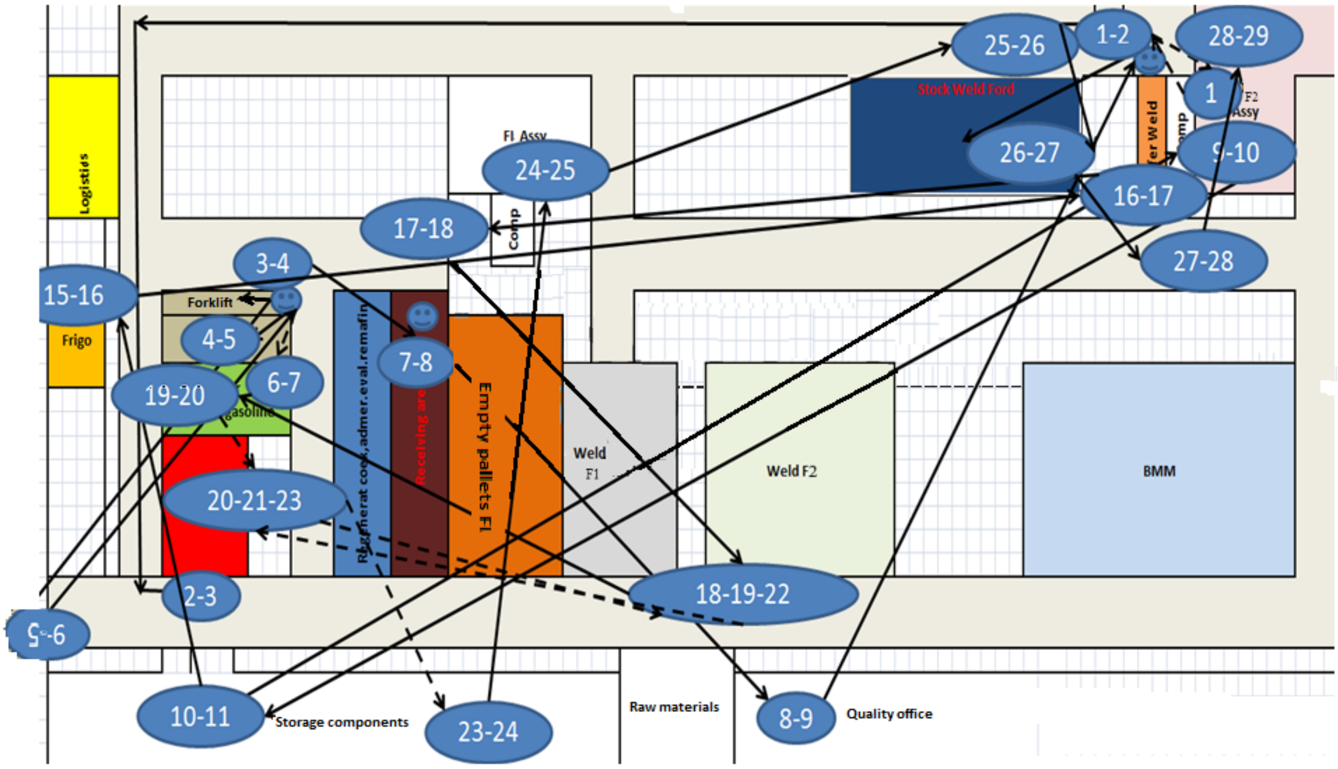

Figure 4. Initial Spaghetti Diagram

As can be seen from the Figure 4, before the application of the Standardized work principles, the manufacturing process was difficult and quite cumbersome, with many overtakes on the route and a lot of waste, presented in the Figure 1, lost time due to inefficient transport, unnecessary moves and many turnarounds on the route, work with stocks, which led to unjustified increase in the production time.
In the next stage, the necessary times for the operations and the correct mapping of the operations were determined. Table 1 shows the process flow and cycle time for periodic work at 4 stations, by timing the time required to perform operations.

Table 1.
Process flow for periodic work at 4 stations

Process flow	**Lowest Achievable Cycle Time** [sec]	**Average Cycles Time** [sec]	**Fluctuation** [sec]
Move the forklift to station 4	18	26	18
Stock check station 4 / Update checklist	28	35	23
Components landing	18	26	18
Loading	123	122	6
Move the forklift to station 0	7	155	8
Parking forklift/Loading	104	64	71

Therefore, it was found that the assembling was done in two different places, and the storage was made in 3 other places further away from the assembling area. It passed to the reorganization of the manufacturing process, the timing of the displacement times, the assembly and the storage were set in the same area, close to the loading station. It was precisely determined what stock was needed for the exchange, using the Kanban and FIFO principles. As a result of the definition of the measurements, the Kanban supply route was completed. In the next figure the moving diagram for station 4, as a sequential case study for partial and implicitly general optimization, named “welding components for F2”, after Standardized work principles are applied is presented. In the Figure 6 the new logistic flow process in the company, after applying the Standardized work and Kanban principles is shown.

ISSN 2457 5275 (Online, English)
ISSN 1842 – 4074 (Print, Online, Romanian)

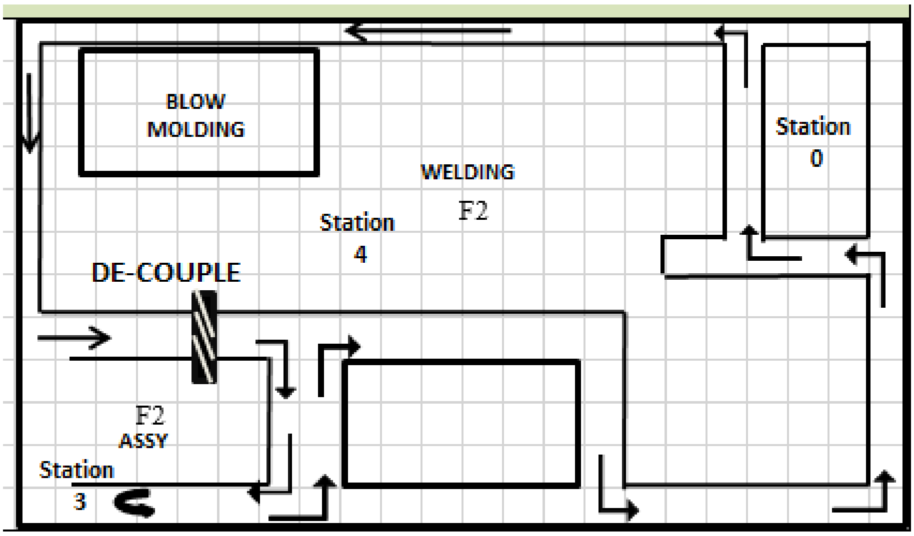

Figure 5. Bringing up of supplies for station 4, welding components

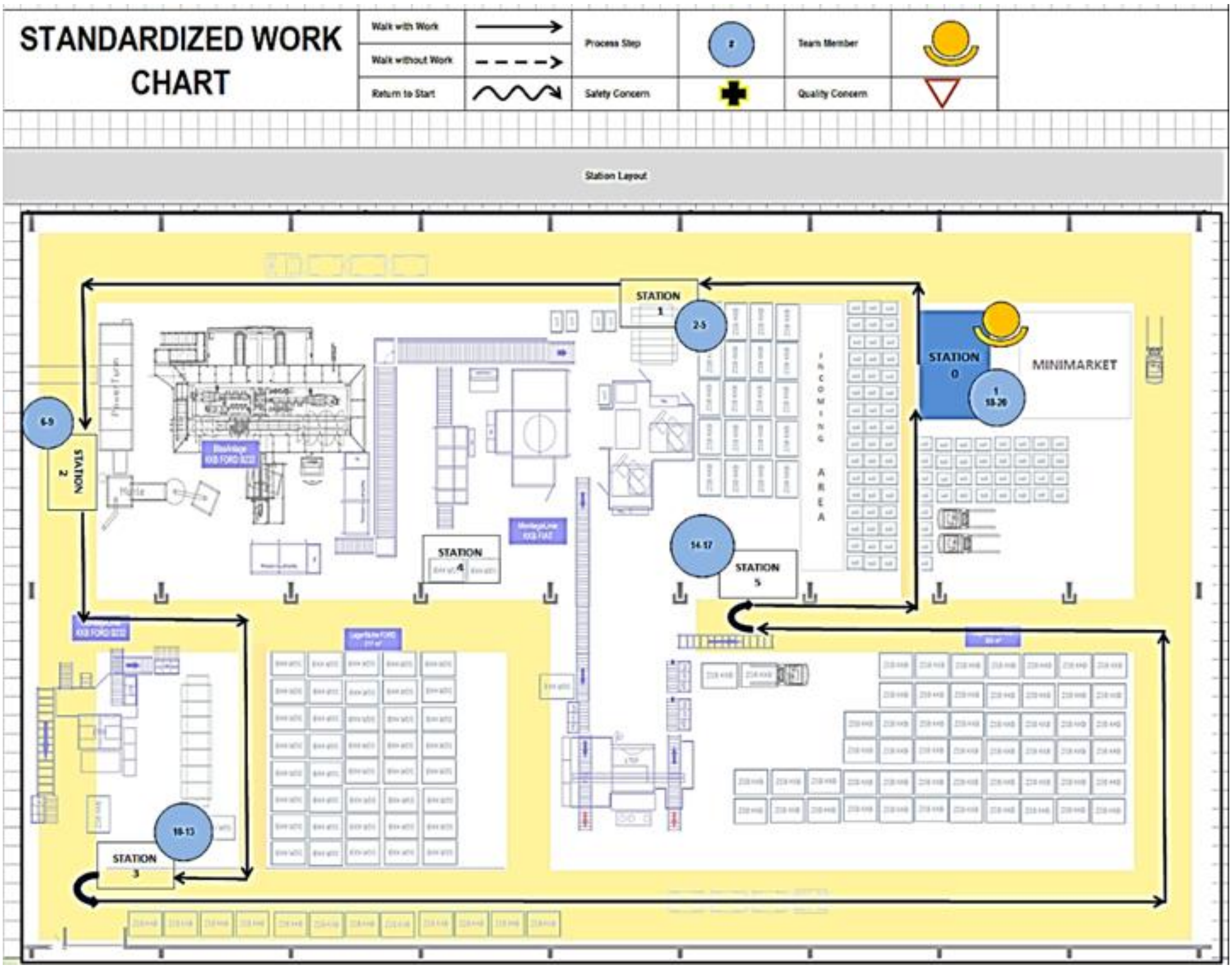

Figure 6. New logistic flow process

ISSN 2457 5275 (Online, English)
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In the last stage, by monitoring the application of the principles of standardized work, the values of the indicator of the efficiency of the manufacturing process, OEE (Overall Equipment Effectiveness), were obtained for the first year of their application. Establishing the OEE in a company is a complex analysis, which is necessary to see faster where productivity losses occur. This analysis begins with *Operating Time*. All planned downtime is eliminated from the *Operating Time*, resulting in *Planned Production Time*. Using these two times, three important general waste can be calculated: *Availability*, *Performance* (*Efficiency*) and *Quality* rate.
The calculation formula is as follows

O.E.E.= Availability x Performance x Quality (1)

Availability is directly dependent on the unplanned stops of a line and represents the ratio between the *Operating Time* and the *Planned Production Time*:

$$Availability = \frac{Operating\ Time}{Planned\ Production\ Time}\ x\ 100 \qquad (2)$$

Where:
Planned Production Time [sec] = (Operating time + Overtime) - (Planned downtime + excess capacity);
Operating time [sec] = Planned Production Time − Stop Time

It is observed that the availability decreases due to the time in which the production line does not work, although it could be available. *Performance* (*Efficiency*) is the operational indicator that shows what capacity the production line is working on.
It is strictly dependent on the cycle time of a product (*Ideal Cycle Time*), its calculation formula being:

$$Performance = \frac{Ideal\ Cycle\ Time\ \ x\ Total\ Pieces\ Produced}{Operating\ Time}\ x\ 100 \qquad (3)$$

Where:
Ideal Cycle Time [sec] is the time required to produce a product.

The quality rate, the third indicator by which the OEEO is determined, shall be calculated in relation to:

$$Quality = \frac{Good\ Pieces\ Produced}{Total\ Pieces\ Produced}\ x\ 100 \qquad (4)$$

Given the complexity of determining the efficiency of the process (OEE), there are dedicated sites that allow the understanding of the calculation methodology [8].
Figure 7 shows the OEE estimate within the company producing automotive components, observed, and determined during the first year of implementation of Standardized work.
It is recalled that the application of the principles of standardized work was made after the implementation of 6S and TPM techniques at the company producing automotive components, presented in [12] and [13], this being one of the factors that allowed high OEE values, in fact, being a sum of the improvement of the quality of the manufacturing process in the company through the contribution of all these three basic Lean methods.
It is also possible to observe the upward trend in the efficiency of the manufacturing process, efficiency indicator, OEE, after applying the principles of Standardized work for both production lines in the company, for both F1 components and F2, which are well-known automotive manufacturers.
It is also noted that, during the year, the company target set for that year was constantly exceeded, for both F1 and F2 production lines, being a categorical proof of the improvement of the quality of the manufacturing process in the company supplying components auto.
In fact, at present, all auto companies require their suppliers to become "Lean companies", being a sine-qua-non condition in the automotive industry.

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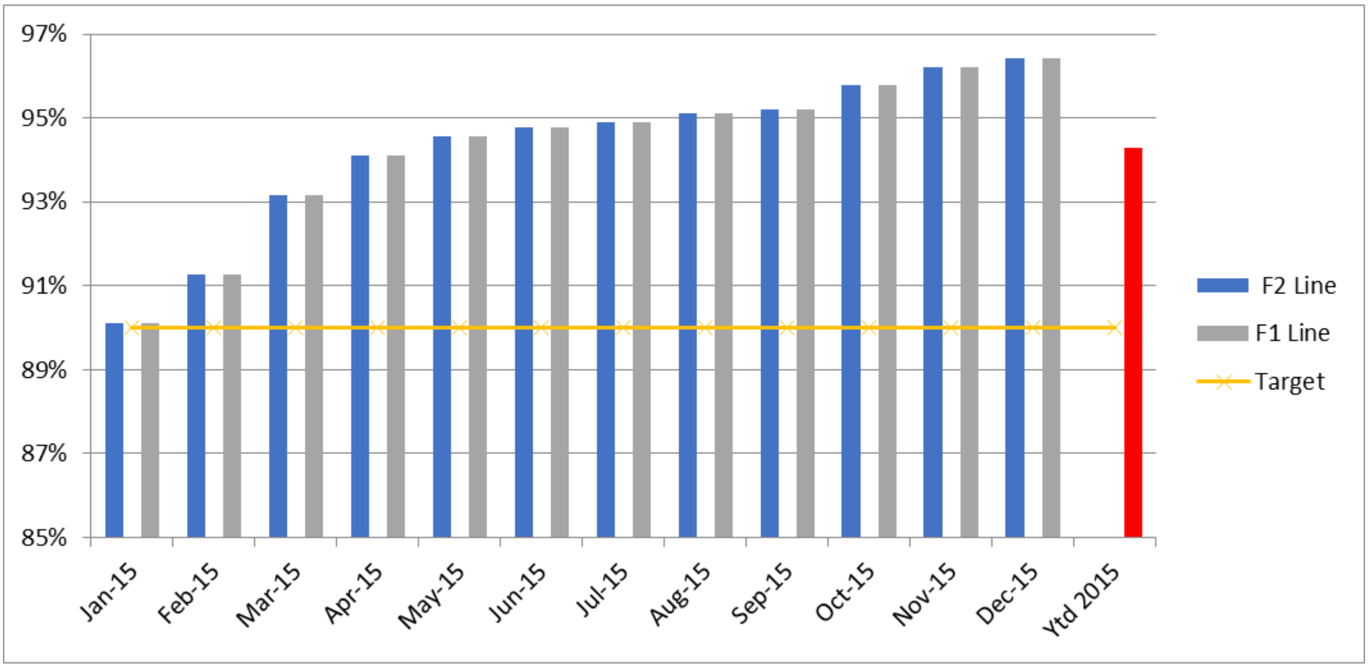

Figure 7. The trend of OEE after applying the Standardized work principles

In Figure 7 it can be observed that the OEE values obtained for November were 96.2%, and for December 96.4%, for both production lines of the components of companies F1 and F2, the desideratum initially established being 90%, thus highlighting the fact that the solution adopted generates higher values.

3. CONCLUSION

After the implementation of Lean principles, there were substantial improvements in both the time required for the supply production line, and in the elimination of the no-value added work of the logistics team members, succeeding in the elimination of sources causing waste for the company.
Also, the most logical, economical, and fluent process flow has been achieved, which minimizes the product's execution time, adds value, and increases the OEE in the company.
At the same time, in the developed studies, there are almost similar values obtained for both production lines of the components, for both the company F1 and F2, which denotes a correct, impartial and dedicated monitoring.
Another indicator that enshrines optimization is the average annual value of the efficiency of the manufacturing process in the company producing automotive components, which increased to 94.30%, compared to the proposed target of 90%.

ACKNOWLEDGEMENT

This work was supported by the grant POCU380/6/13/123990, co-financed by the European Social Fund within the Sectorial Operational Program Human Capital 2014 – 2020.

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ISSN 2457 – 5275 (Online, English)
ISSN 1842 – 4074 (Print, Online, Romanian)

STUDY ON GEAR RATIO OF BATTERY ELECTRIC VEHICLES

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(Received 23 November 2020; Revised 22 January 2021; Accepted 03 March 2021)

Abstract: *In a world increasingly polluted with declining fossil fuel resources, researchers in the automotive industry are looking for new solutions. ICE (internal combustion engine) cars are an important source of pollution and one of the main consumers of hydrocarbons. The need of replacing these cars is obvious, and at this time, the best solution seems being the use of all plug-in electric vehicle, but especially so-called battery electric vehicle (BEV), which represent vehicles with electric motors energised from batteries. These electric cars have usually a single gear ratio (G.R.), and this is the main subject approached in the paper. To carry out the study, the Simulink program and the US06 driving cycle included in the Federal Test Procedure - together with the city driving (FTP-75) and highway driving (HWFET) - from the USA, have been used.*

Keywords: *gear ratio; motor; battery electric vehicle*

1. INTRODUCTION

The first electric machine (a generator with permanent magnets) was made by Antoine-Hippolyte Pixii in 1832 just one year after the discovery of the phenomenon of electromagnetic induction by Michael Faraday [1]. It is considered that the first electrically propelled vehicle was the one made by Thomas Davenport in 1834, the direct curent (DC) motor, built by him, being powered by a battery system [2]. Probably the first vehicle usable for public transport was the one made by the Russian engineer (of Jewish origin, born in Germany), Moritz von Jacobi, who in 1838/1839 propelled a boat, also with a DC motor powered by to batteries, and the boat carried 14 passengers on the Neva River, against the current, at a velocity of three miles/h [1]. Although electrical engineering had only begun a few decades ago (we can consider the year 1800 when Alessandro Volta made the first DC source), the interest of scientists in this field was very high, so that in 1859, the Italian physicist Antonio Pacinotti made the first DC machine with notches and collector, very close to the today DC motor. An important role in the development of electric traction was played by the German engineer Siemens, who experimented in Berlin the first tram line in 1879. In the following years, both urban electric traction and electric propelled vehicles, experienced a rapid development. Such that, out of the total number of cars sold in 1900 in the US, about 40% were battery electric vehicles (BEV), 20% with gasoline and 40% were steam driven vehicles [2]. But the situation changed rapidly in just a few decades. The main reasons why BEVs lost supremacy were the following: they were expensive and had limited driving range. Since the last decade of the 19th century, engineers have noticed the potential of ICE (internal combustion engine), which has known a continuous development from its appearance the inventor being considered G. Brayton in 1872) [2]. Transportation, as a large energy-consuming branch, has been at the forefront of electricity use.
After Lenoir used the electric spark to ignite the fuel in the ICE in 1870, an unknown mechanic in Brussels built an electric car. Its energy source was the zinc plate batteries, and the traction was provided by an electric motor. The four-wheeled vehicle was designed for two people and was equipped with a parking brake with wooden clogs and had an autonomy of 20 kilometres, the distance after which the batteries had to be replaced.

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ISSN 2457 – 5275 (Online, English)
ISSN 1842 – 4074 (Print, Online, Romanian)

In 1875, an electric tricycle was built in France, also by an anonymous manufacturer, on the same principles as the Belgian one. Finally, the third prototype allows us to leave the anonymity of the manufacturer, because history has kept his name: the engineer was called Trouvé. In 1881 he built a three-wheeled vehicle equipped with two electric engines that ensured the transmission of the engine effort through a gear wheel. The speed reached 15 kilometres per hour and the autonomy had already reached 40 km. But the one who established the prestige of the electric car and opened its way as a means of transport with a large public presence, was the Belgian Camille Jenatzy. For a decade, Jenatzy developed a car with the body shape of an artillery projectile, on two axes with two sets of batteries and a single seat. The suspension on lamellar springs, the stability of the vehicle determined by the judicious placement of the batteries, the steering, and the braking system sufficiently stable for the functional parameters of the car are noticed. The Acheres competition, on May 1, 1889, rewarded Jenatzy's work. He was ranked on the first place and by achieving the speed of 105.9 kilometres per hour, he was the first man who exceeded the 100 kilometres per hour speed on a road. We can appreciate that at that time the ICE was practical. Most observers were inclined to believe that its time had passed. Incidentally, in 1889, in the U.S. there were 1575 electric cars operating, compared to only 936 equipped with ICEs. The "Tudor" plants in this country, manufactured battery packed with lead plates and electrolyte consisting of sulfuric acid and water. After 1900 the "Studebaker" Company expanded the manufacture of electric cars in series production-always more improved for example, "Wolverhamton" - American production or "Electromotion", of French construction [3]. The best performances obtained by the electric series cars were at 70-80 kilometres per hour traffic speed, at 10 hours the battery life between two successive recharges and at 6 passengers the transport capacity. All these features represented quite much for the stage of technique of the early twentieth century. Other qualities that required its use were: very fast and smooth start, quiet operation, achieving an unlimited number of traffic modes by manoeuvring the controller and, finally, but not at least, increased safety by using the additional electric brake if needed. Only one major shortcoming was the decisive element that made it be taken out from the public roads for almost half a century: the small action range determined by the limited capacity of the batteries. When the ICE managed to surpass it in this field, at the end of the first decade of this century, its short supremacy in road passenger traffic came to an end. When everyone thought that the use of electricity in transport was finally over, new possibilities of use were found, where we would have expected less, in the railway and naval transportation.
After the Second World War, it would spectacularly return in the road transport, especially in the conditions created by the global energy crisis [3]. The large autonomy given by high value of energy stored in fossil fuels (diesel or gasoline) but also the low price of ICE vehicle, especially after the implementation of the mass production system by the inventor Henry Ford (his cars were at a quarter price compared to existing EVs), caused EVs to be rapidly marginalized. The low efficiency of ICEs has been accepted by automakers and society, while growing environmental issues, especially in large metropolises, being still disregarded. After a century of continuous increase in pollution due to ICE vehicles, using almost exclusively diesel or gasoline [4], major increases in health-care costs due to urban smog and a strong environmental degradation, the concept of highly efficient, clean, and even smart transportation became the new rule (starting with the last decade of the 20th century). More stringent standards regarding engines efficiency and fuel economy became the major factor of designing more efficient engines and increasing the “electrification level” of the vehicles. At this time, the best ICEs (diesel) can reach a real maximum efficiency of a little more than 50%. An electric motor, of every type, reaches a minimum 90%. Besides this, an engine consumes fuel regardless of whether the vehicle brakes, runs on a slope or stays still, while an electric machine generate energy when vehicle brakes or descends, and it is easily stopped when the vehicle is stationary. In this context, the wheel is turning slowly but surely, and we are turning again our attention to "more electric" vehicles [5]. Starting to micro-hybrid (only a stop-start function and regenerative braking) up to hybrid range extended electric vehicle and full electric vehicle (BEV), all these use “more electrification” to increase the total efficiency. This increase in "electrification" is also a trend [6] due to the increase of batteries performances, the world research is focused on this direction [7], but also due to the decreasing price of electric vehicles [8].
A major difference between an engine and an electric motor is the rotational speed range. While an ICE has a useful 1000 - 6000 RPM range, some electric motors used in vehicles traction have a range of 0 - 20000 RPM. What this mean? An ICE vehicle requires multiple gears (4 – 6) to be properly driven, while BEVs usually have only a simple gear. Of course, currently, both for technical reasons but also for economic reasons (cars with lower price), there are few exceptions to this rule.

But they are important because, probably, they show the new trend in BEV's transmission. Among these exceptions, we can mention Tesla Roadster, which initially had a multi-speed gearbox, not for they desired, but because they had reliability and durability problems. After switching to a one-speed transmission, now they use a dual-motor transmission (model S), each of the motors having a different G.R., so every motor (with different power) will be used such the efficiency being maximum. The car can use one of the motors or both at a time, depending on the needed power. Another BEV with two-speed transmission is Porsche Taycan. In fact, one of the two motors on the Taycan has two-speed gearbox and the other has only a simple G.R. The first step has an approximate 15:1 G.R. while the second has an approximate 8:1 G.R. Even though not many BEVs use a multi-speed gearbox now, researchers have anticipated and say that in the future all pure electric cars will have two- or multi-speed transmissions, [9][10], and some authors dealt with the issue of shift gear optimizing, so that the drive to be performed with maximum efficiency [11][12].
In this paper we will analyse not the motor efficiency at different RPMs, but how the G.R. influences the manoeuvrability of the BEV using only regenerative brake. Why? Because in this manner we can appreciate how efficient the vehicle drive is. The longer you can follow a driving cycle without using mechanical braking, the more you will recover from energy. Some comparisons with ICE vehicle, with four speed gearboxes, will be made.

2. OBJECTIVES

The paper objectives are focused on the dependence between G.R. and the electric drive efficiency, so a high-level manoeuvrability of the BEV to be fulfilled in different scenarios. We considered high efficiency electric drive, if a driving cycle is followed as rigorously as possible (high-level manoeuvrability), using only regenerative brake. Three scenarios have been studied: vehicle runs on ramp, horizontally and on slope. The BEV has a simple gear [13]. We started with a G.R. of 11. Which is the optimum G.R. for these scenarios? We will see. For the same vehicle (mass, wheels, etc.) and in the same conditions (driving cycle, wind, and road incline) an ICE with four speed gearboxes, with controlled gear selection and mechanical brake, we considered to make comparisons regarding the consume and manoeuvrability. Of course, we can anticipate some of the results of the comparisons. But what is wanted, is to show that the degree of energy recovery, or the efficiency of a BEV, depends also on the G.R. The simulations have been made in Matlab Simulink.

3. METHODOLOGY

The vehicle speed has been imposed according to US06 driving cycle, which sets the speed-time relationship for 600 seconds. It is one of the three driving cycle defined by the US Environmental Protection Agency (EPA) and included in Federal Test Procedure – together with the city driving (FTP-75) and highway driving (HWFET); it refers to aggressive driving. We decided to consider this driving cycle because of the specific issues regarding regenerative braking [14]. The Simulink model of ICE vehicle transmission and vehicle model are shown in fig. 1 and 2. The inputs for driver are imposed speed (driving cycle) and the car speed. The driver compares the speeds and accelerates or brakes.
The accelerating signal is sent to the motor for increasing the torque. When the signal for breaking is sent to the vehicle, mechanical braking occurs. The logic control of the gearbox depends by the accelerating signal and vehicle speed and based on these, imposes to change up or down the steps. The ICE has a maximum power of 150 kW at 4500 RPM and can reach a maximum 6000 RPM.
The BEV system model and the vehicle model are shown in fig. 3 and 4. BEV is propelled by a DC motor, energized through a controlled (PWM) H-bridge, which allow regenerative braking.
The system of batteries is also modelled, and based on the electric current value, current direction and batteries capacity, the state of charge (SOC) is calculated and shown. DC motor has no load speed 10000 rpm, nominal speed 5000 rpm, rated voltage 300V and rated power 100 kW.
In the case of BEV running horizontally, seven values of the G.R. were considered to observe when the driving cycle is respected properly using only the regenerative brake. The low values of the G.R. (5-8) are inappropriate in this case, when fast accelerations and braking are required, especially at low speeds. In this case, a G.R. of 11-12 seems to be more appropriate regarding the driving cycle concordance. Even higher G.R.s are not very inappropriate, but they are less good.

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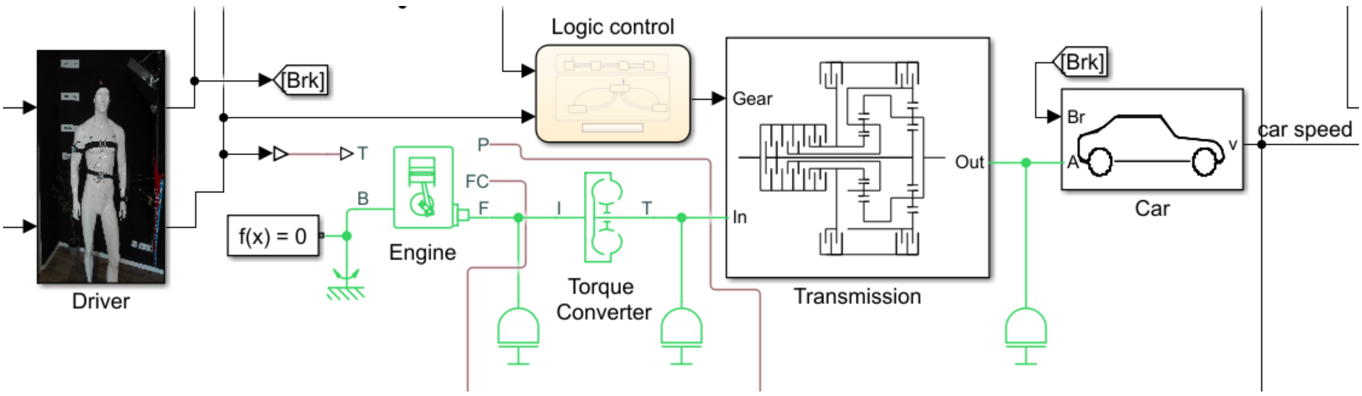

Figure 1. Simulink ICE vehicle transmission model

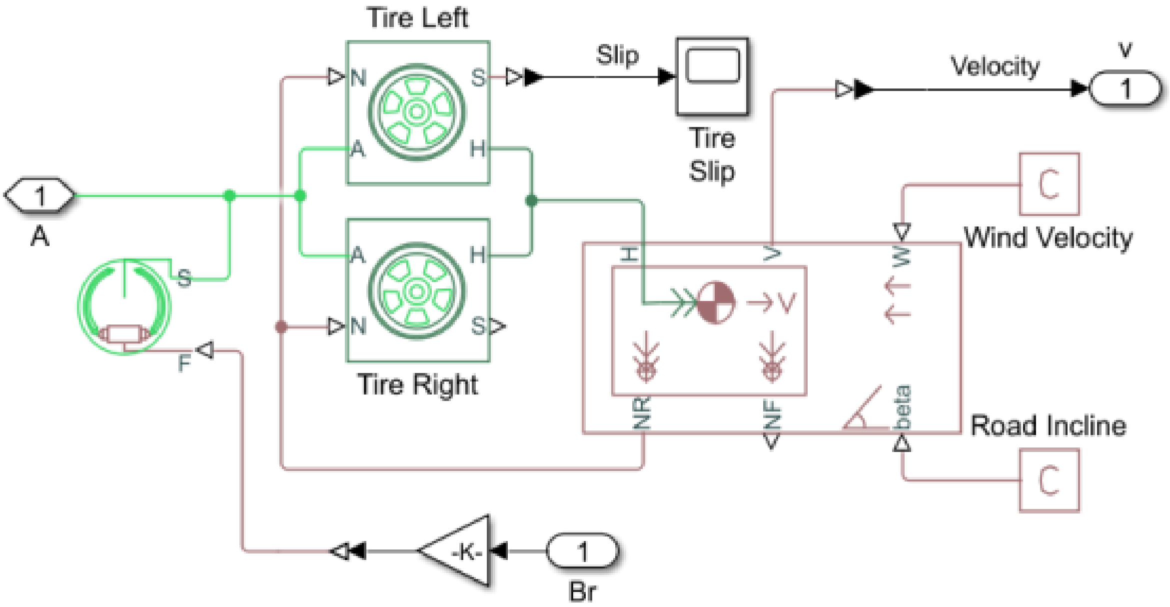

Figure 2. Simulink vehicle model propelled by ICE

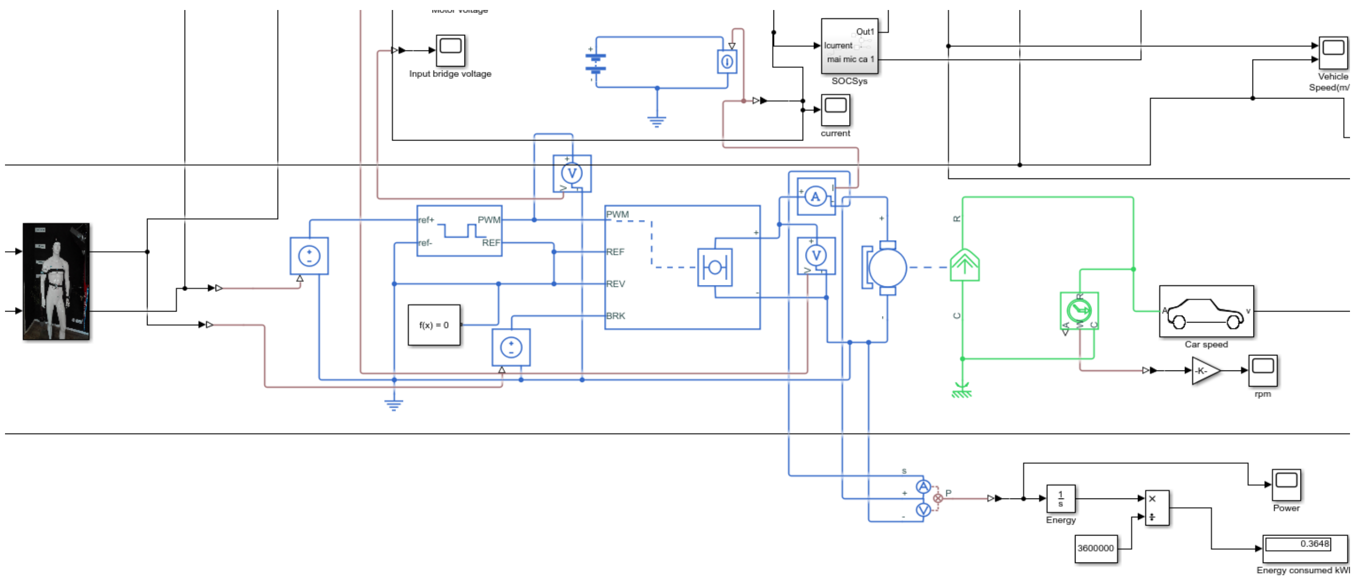

Figure 3. BEV system model

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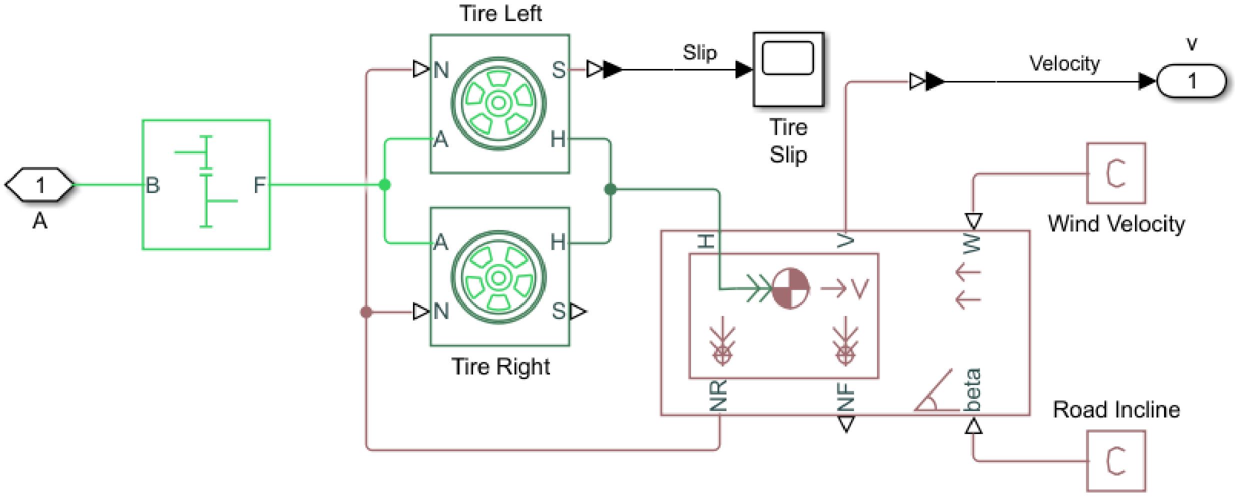

Figure 4. Simulink vehicle model propelled by DC motor

3.1 BEV runs horizontally

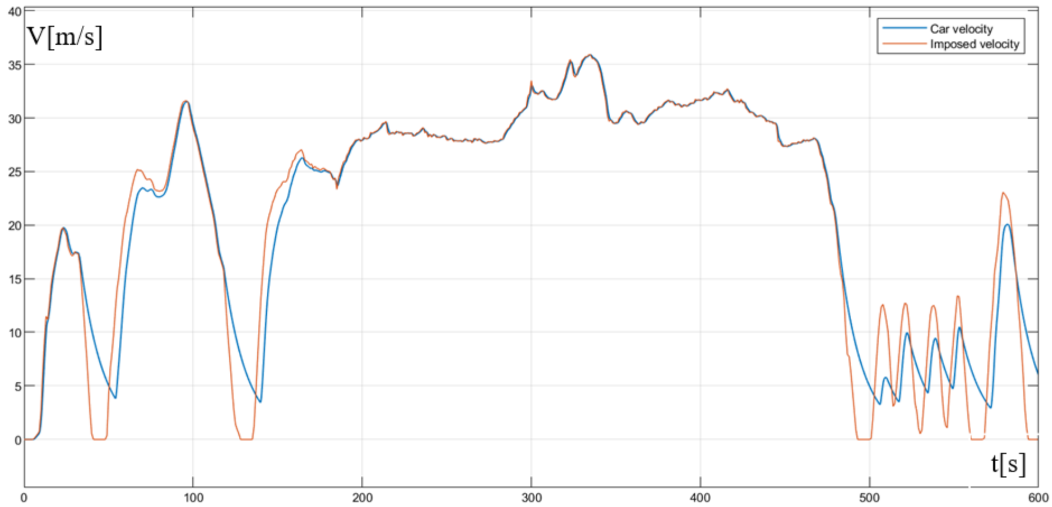

Figure 5. Keeping the drive cycle, without mechanical brake, by BEV with G.R.=5

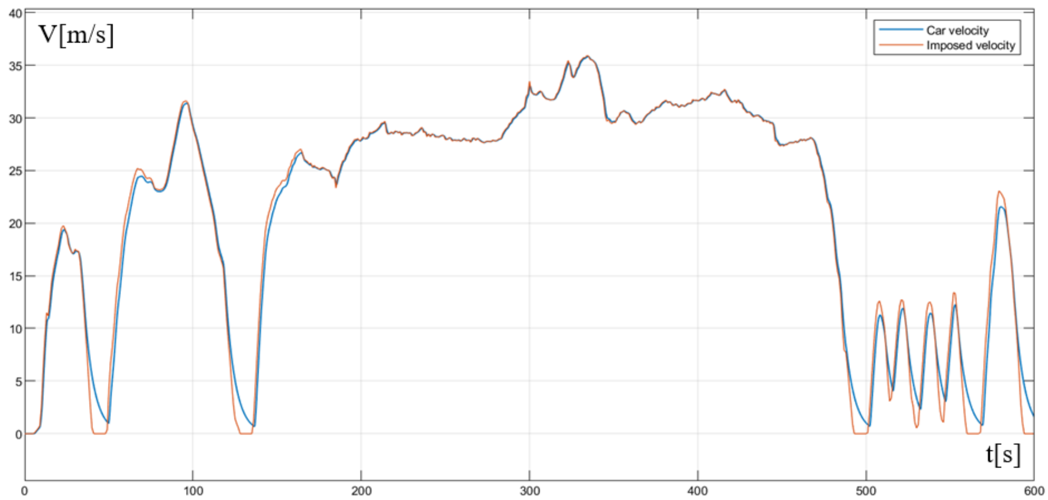

Figure 6. Keeping the drive cycle, without mechanical brake, by BEV with G.R.=8

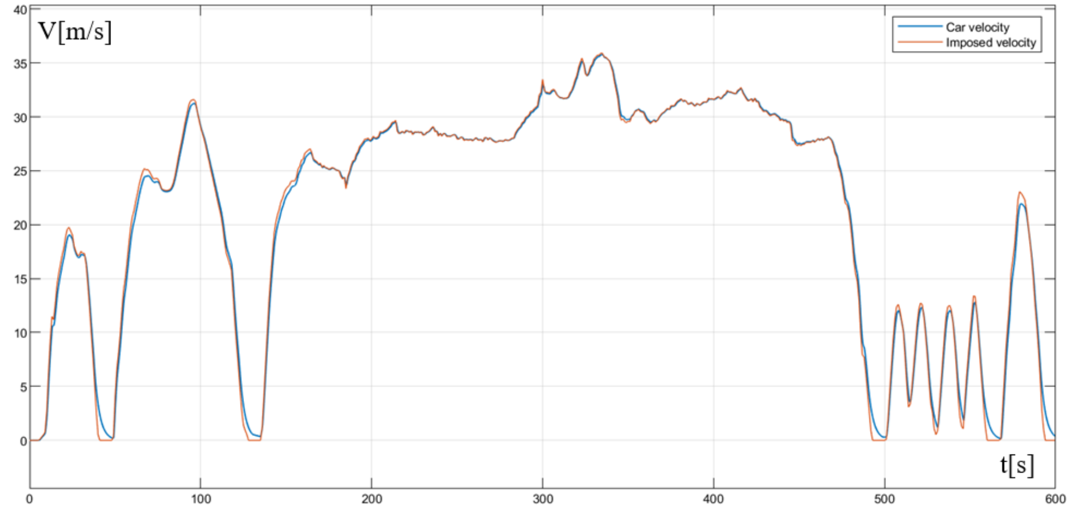

Figure 7. Keeping the drive cycle, without mechanical brake, by BEV with G.R.=11

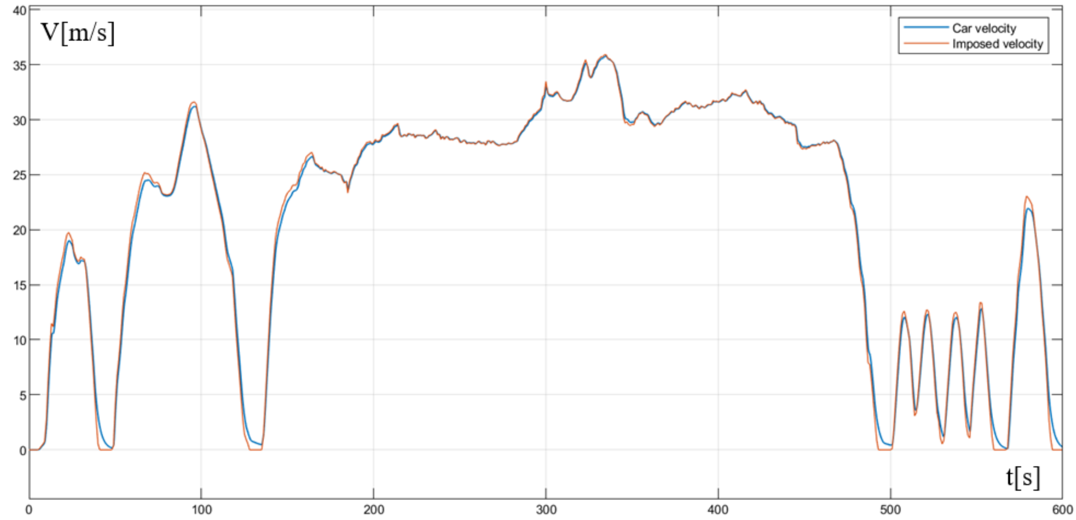

Figure 8. Keeping the drive cycle, without mechanical brake, by BEV with G.R.=11.6

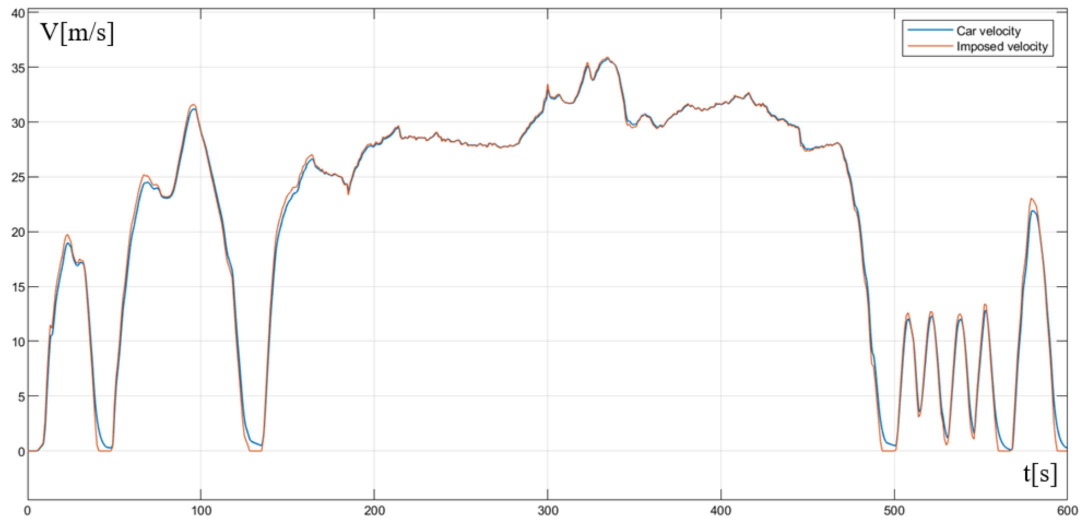

Figure 9. Keeping the drive cycle, without mechanical brake, by BEV with G.R.=12

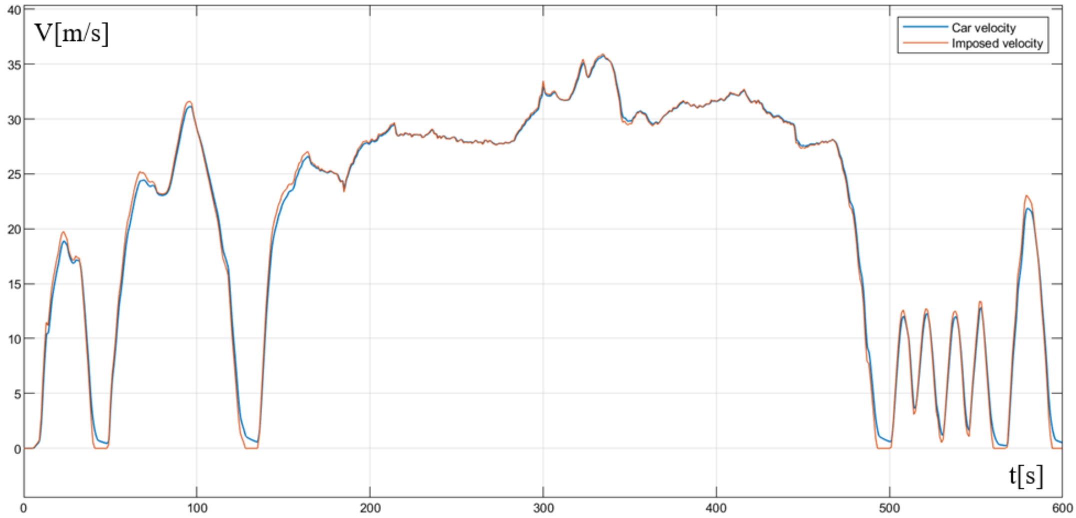

Figure 10. Keeping the drive cycle, without mechanical brake, by BEV with G.R.=13

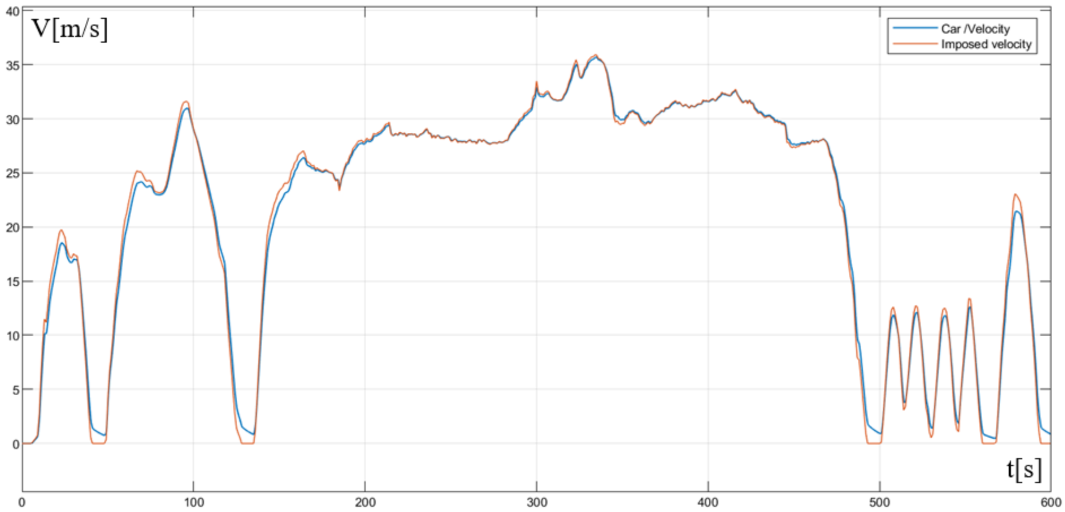

Figure 11. Keeping the drive cycle, without mechanical brake, by BEV with G.R.=17

3.2 BEV runs on ramp

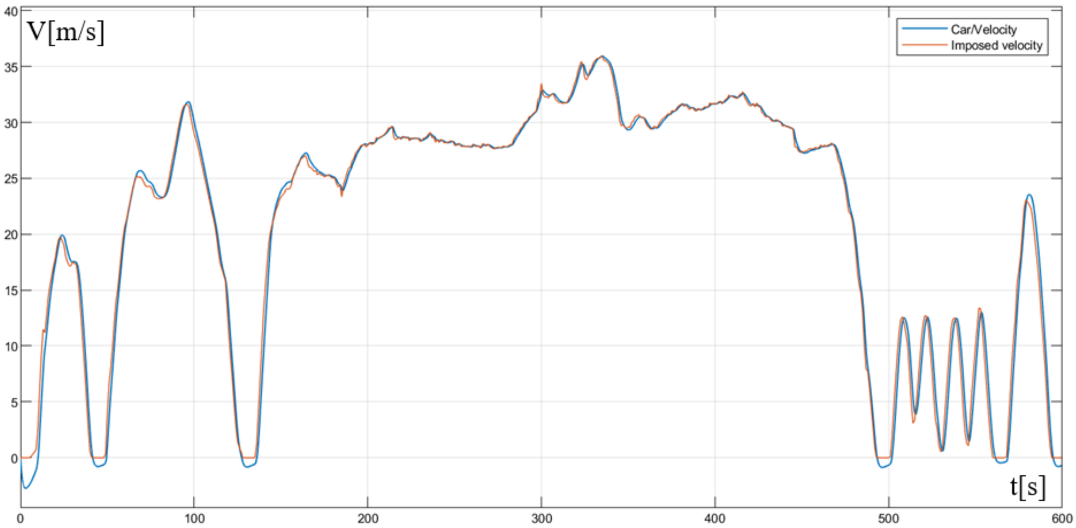

Figure 12. Keeping the drive cycle, without mechanical brake, by BEV with G.R.=3

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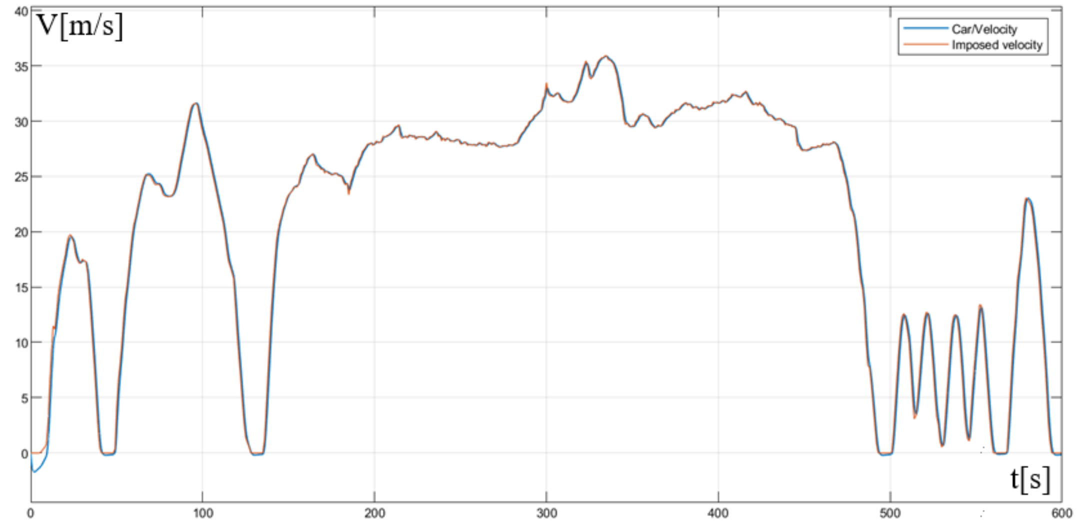

Figure 13. Keeping the drive cycle, without mechanical brake, by BEV with G.R.=5

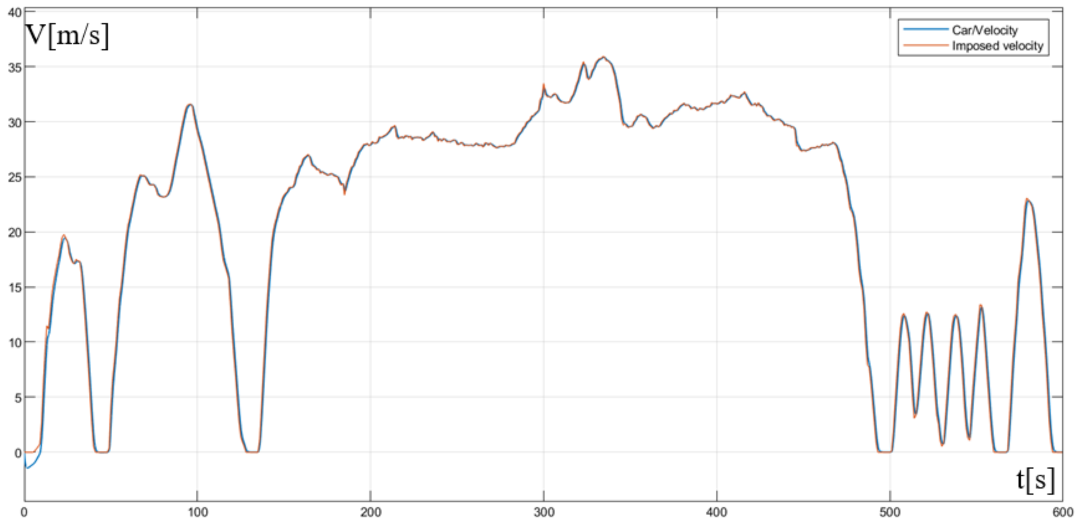

Figure 14. Keeping the drive cycle, without mechanical brake, by BEV with G.R.=6

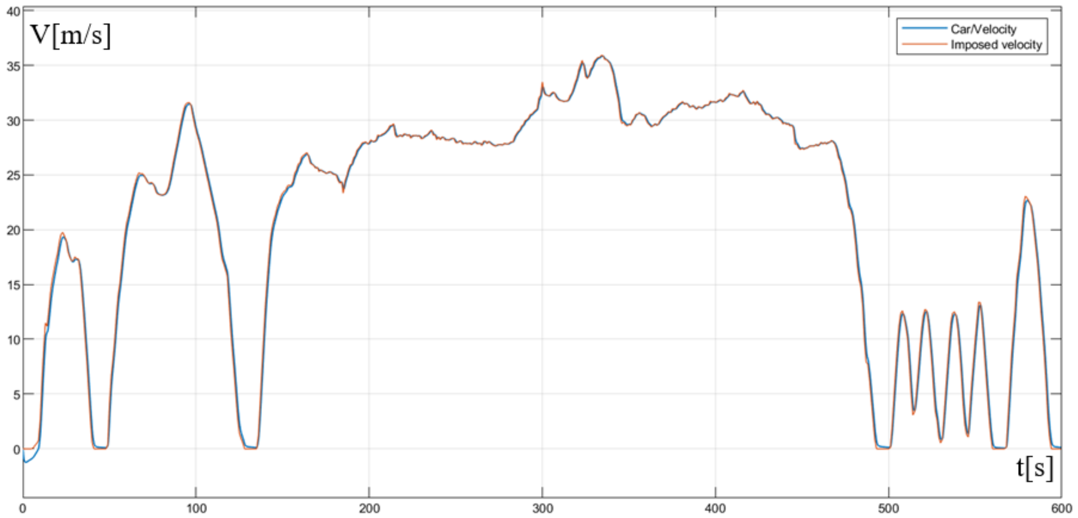

Figure 15. Keeping the drive cycle, without mechanical brake, by BEV with G.R.=7

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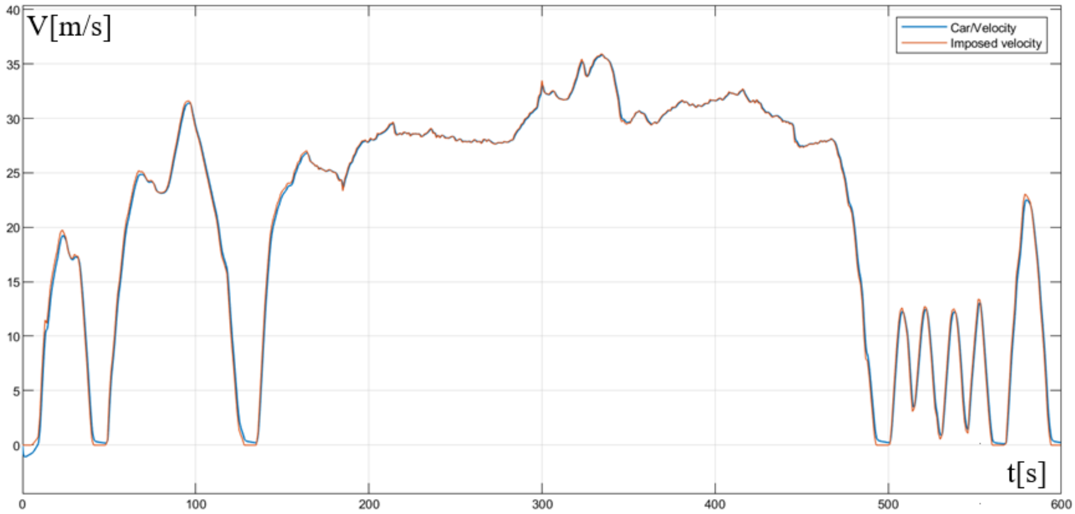

Figure 16. Keeping the drive cycle, without mechanical brake, by BEV with G.R.=8

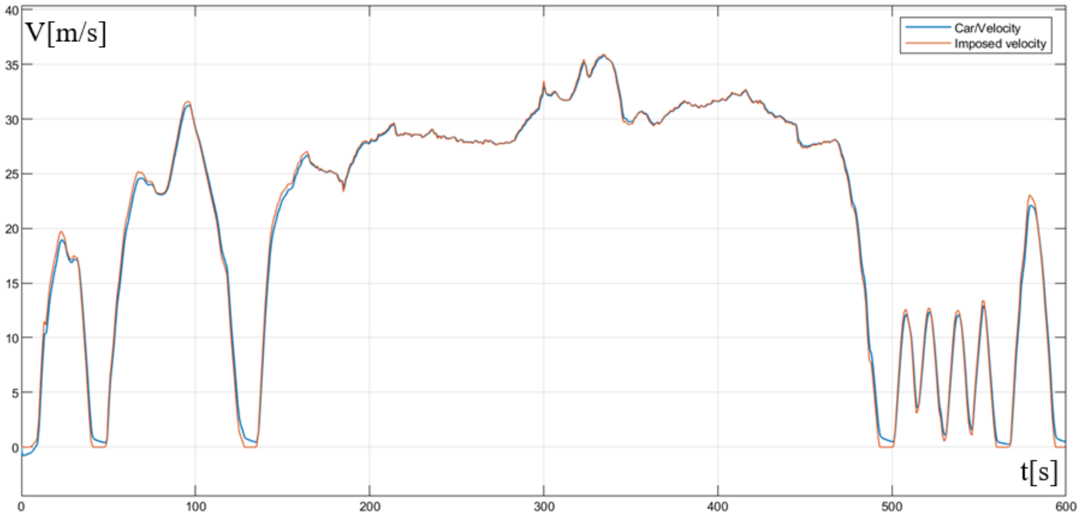

Figure 17 Keeping the drive cycle, without mechanical brake, by BEV with G.R.=11

In this case, a G.R. of 6 seems to be more appropriate than 11. Of course, it does not make sense to consider a higher G.R., as we move even further away from respecting the imposed cycle.

3.3 BEV runs on slope

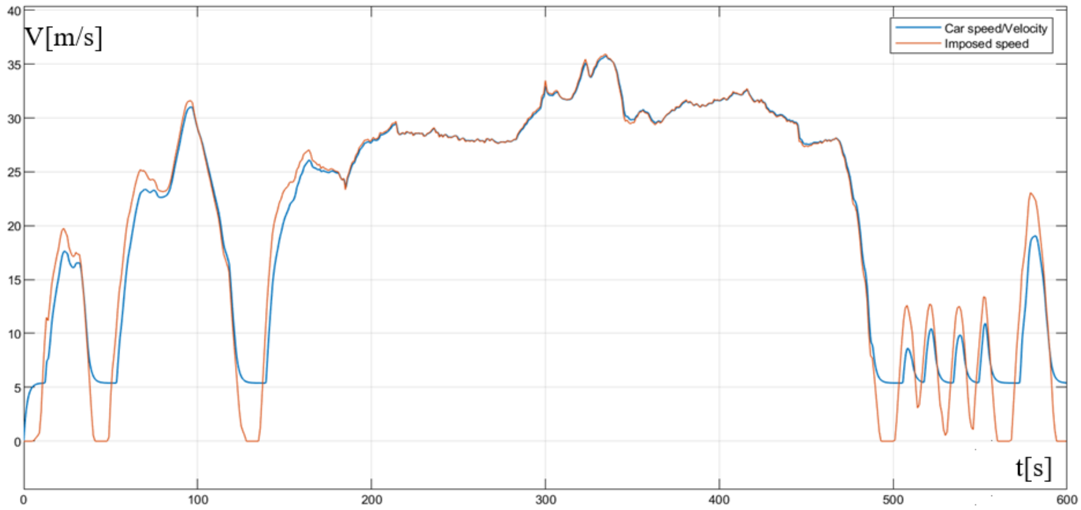

Figure 18. Keeping the drive cycle, without mechanical brake, by BEV with G.R.=14

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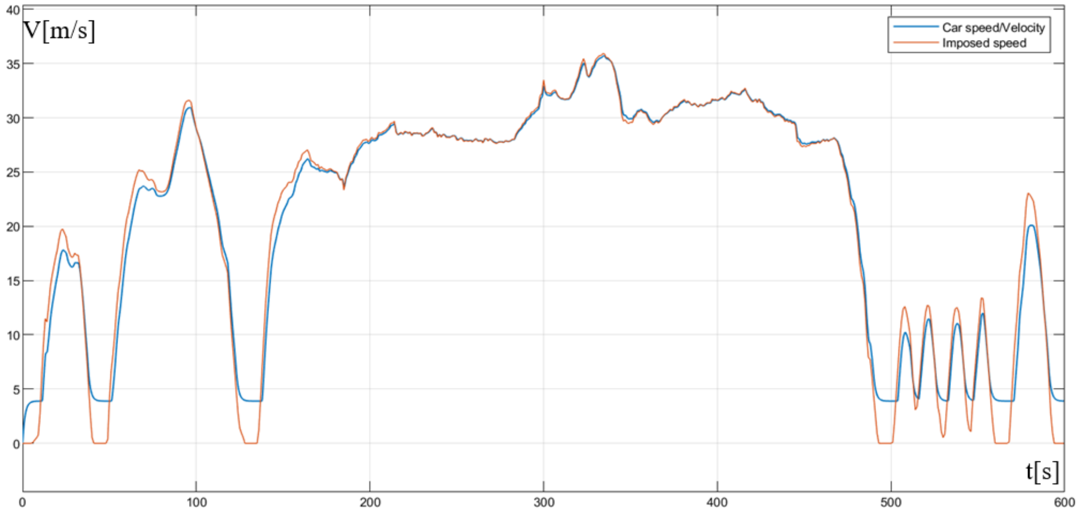

Figure 19. Keeping the drive cycle, without mechanical brake, by BEV with G.R.=16.5

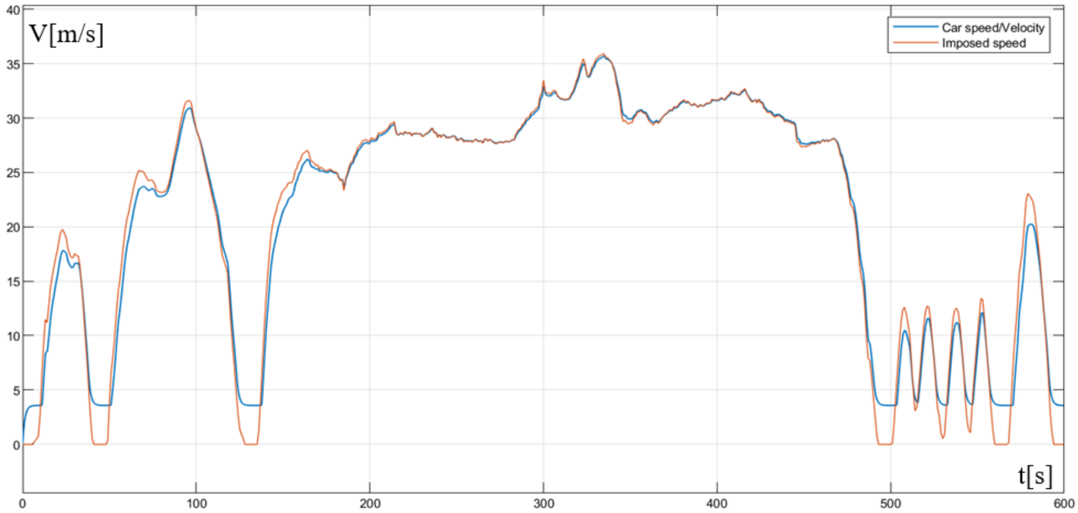

Figure 20. Keeping the drive cycle, without mechanical brake, by BEV with G.R.=17.2

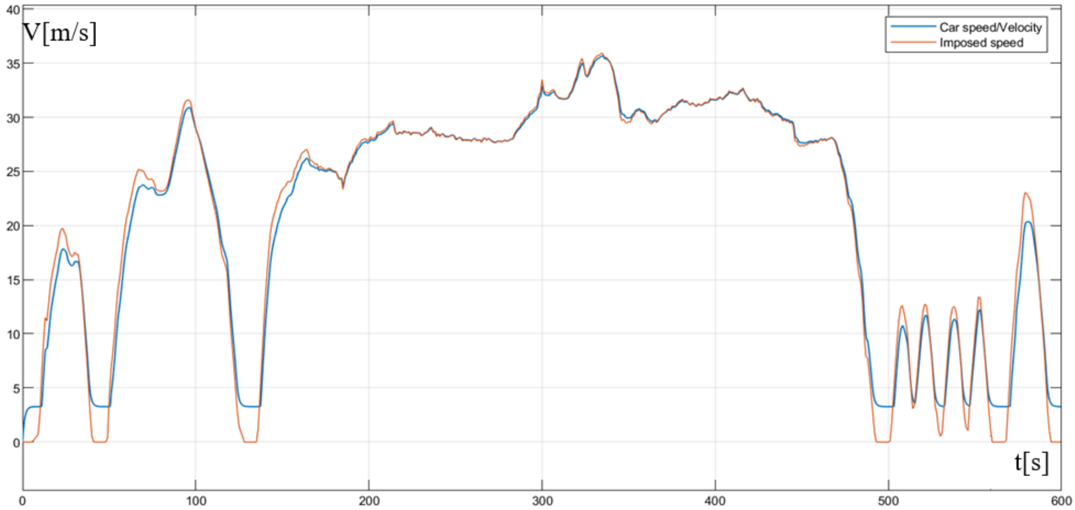

Figure 21. Keeping the drive cycle, without mechanical brake, by BEV with G.R.=18

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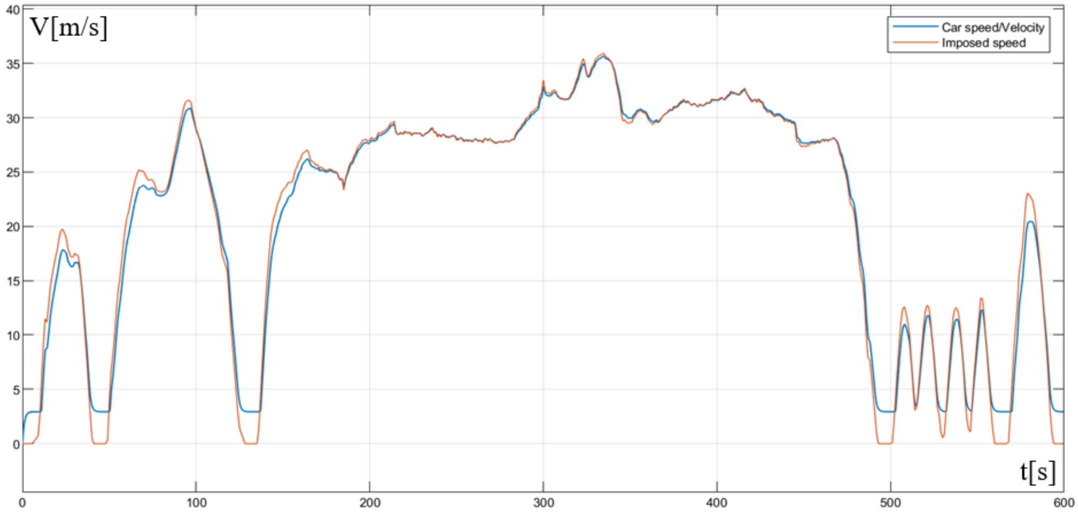

Figure 22. Keeping the drive cycle, without mechanical brake, by BEV with G.R.=19

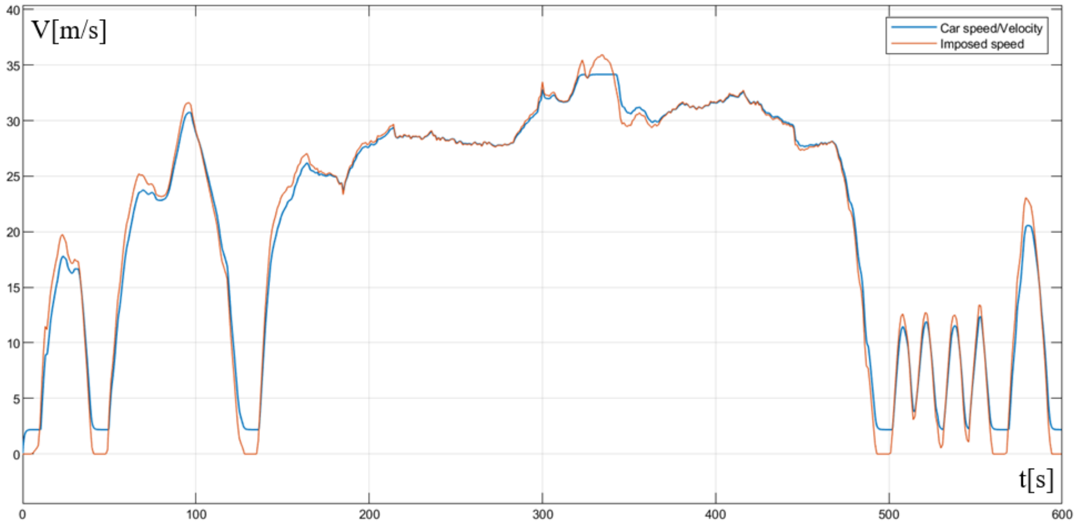

Figure 23. Keeping the drive cycle, without mechanical brake, by BEV with G.R.=22

We must keep in mind that it is theoretically impossible to stop the vehicle or run at very low speed, on a slope, using only a regenerative brake. For this reason, it is practically impossible to respect the imposed cycle. But the authors' desire was to see "how much" the cycle can be followed without using mechanical braking.

3.4 Running ICE vehicle using mechanical brake

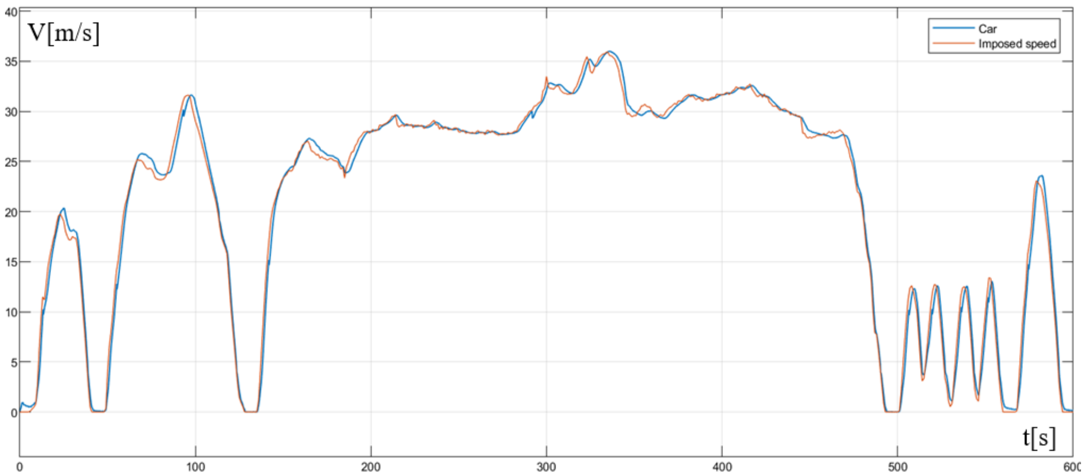

Figure 24. ICE vehicle runs horizontally

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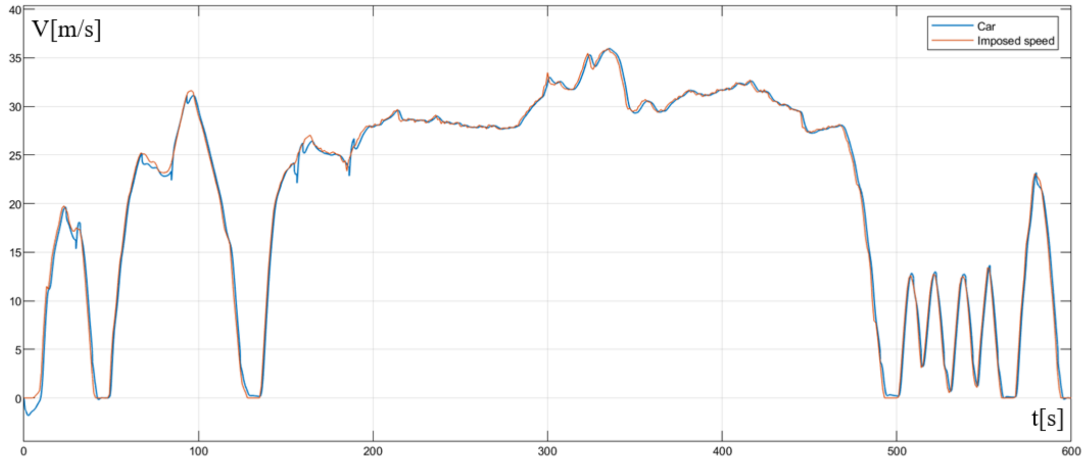

Figure 25. ICE vehicle runs on ramp

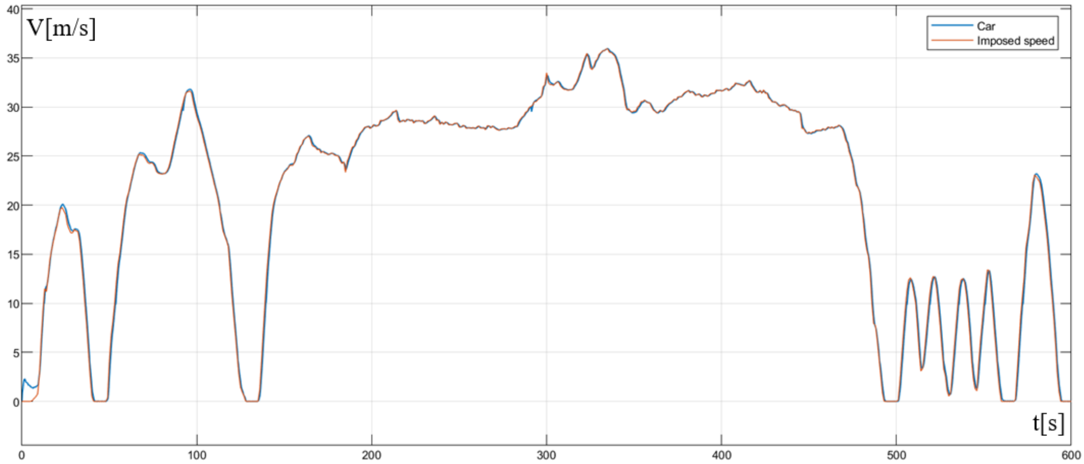

Figure 26. ICE vehicle runs on slope

For different G.R.s, we analyse the manner how the car respects the imposed speed, these being presented before.

4. CONCLUSION

As has been shown, for the studied case, the optimum G.R. in case of BEV running horizontally is in range 11 to 12. This ratio is around 6 in case of running on ramp while in case of running on slope is around 17-18. But what is important is the fact that when BEV rolling horizontally, for studied case, a G.R. of 17 is not bad.

The major difference is in case of BEV rolling on ramp, when the optimum G.R. is around 6-7. Regarding the consumed energy, of course it is maximum when BEV runs on ramp. For considered conditions (vehicle. mass 1200 kg, incline -25 and US06 driving cycle, etc.) this energy was about 6 kWh, while running horizontally (incline 0) requires 0.25 kWh and when the vehicle is rolling on slope (incline -25) there is no consumed energy only recovered energy. In case of ICE vehicle in the same conditions as BEV, the consumed gasoline has been 0.456 kg (horizontal rolling), 1.3 kg (rolling on ramp) and 0.4 kg (rolling on slope) or the equivalent of about 5.3 kWh, 15 kWh and 4.8 kWh respectively.

We notice there is a very small difference between horizontal rolling and rolling on slope in case of ICE vehicle. We also will mention that ICE vehicle respects well the imposed cycle because of the mechanical braking.

Regarding the comparison between BEV and ICE vehicle, things are generally known. While the rated efficiency of an electric motor used at BEV is at least 0.9, the efficiency of an ICE is at best 0.4. But the great advantage of an electric drive is highlighted in the case of regenerative braking and therefore in the case of cycles that require frequent braking or downhill.

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But what we want to emphasize is the fact that a single transmission ratio in case of BEV, cannot satisfy an optimal operation from the point of view of electric propulsion and energy consumption in all situations. We consider that for maximum efficiency of a BEV (in this case with DC motor), a transmission with a minimum of two gears will be more suitable. In the future study, we want to make a comparison between two BEVs, one with a single G.R., the other with two G.R.s.

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ISSN 2457 – 5275 (Online, English)
ISSN 1842 – 4074 (Print, Online, Romanian)

SELF-ADAPTIVE MECHANICAL REDUCER WITH VARIABLE GEAR RATIO

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(Received 04 February 2021; Revised 10 March 2021; Accepted 27 March 2021)

Abstract: *The invention presented in this paper consists of a mechanical reducer which can be integrated in the transmission of a full electric car or a hybrid one, in order to reduce the electricity consumption required by the motors, during running under real road conditions and to improve dynamics. The reducer allows the continuous, self-adaptive variation of the total gear ratio, between two limit values, depending on the load torque, ensuring the operation of the motors on a restricted range of speeds and with minimum electricity consumption. The proposed solution is the subject of patent application No. A 2019 00889.*

Keywords: *mechanical reducer, gear transmission, electric vehicle transmission, electric motor, electric vehicle*

1. INTRODUCTION

The information regarding low emissions and independence to the fossil fuel energy sources ultimately decreasing global warming and pollution in the world has attracted increasingly attention in recent years. Therefore, the development of commercially viable hybrid electric vehicles (HEVs) and electric vehicles (EVs) is one of the major contributions from the automotive industry. This is because those types of vehicles are considered as more environmentally friendly, cost competitive maintain and run than that of comparable gasoline fueled vehicles over perspective lifetimes [25]. Although interest in HEVs is now overwhelming [1][12], most experts predict that they are only a temporary intermediate development that will finally be replaced by EVs [23], because EVs produce zero emissions on the road.
Unlike conventionally powered vehicles, with internal combustion engines, in which the transmission includes a multi-speed gearbox, in most current construction solutions of electrically powered car transmissions, the transmission of torque from the electric motor to the drive axle is provided by a single-stage mechanical gearbox and a differential, which makes the electric motor operate in a wide range of speeds, with increased energy consumption. In this case, the value of the single transmission ratio is chosen in such a way as to ensure the best balance between the acceleration performance and the maximum speed reached by the electric car. Choosing a transmission ratio that is too low favors acceleration, but the maximum speed reached has a lower value. On the other hand, a transmission ratio that is too high leads to a maximum value of the speed reached towards the extreme limit, but there are penalties for acceleration [22].
For example, Formula E uses single-seater cars with three-speed gearboxes [5].
Various constructive solutions similar to the one presented here are known in the literature. For example: “Differential reducer with two reduction stages” (Patent RO 122685 B1/Szabo Adam et al.), “Magnetic reducer with gear ratio” (Patent RO 130450 B1/Fodorean Daniel) and “Reducer power multiplier” (Patent RO 126331 A0/Dănilă Iftimie). The disadvantage of these constructive solutions is that they do not allow the continuous variation of the transmission ratio depending on the moment of resistance.
This paper aims to highlight how the present invention eliminates the disadvantages presented above by continuously varying the gear ratio of the gearbox between two extreme limits, depending on the value of the moment of resistance (M_c) of the consumer. The variation of the transmission ratio is made between two fixed values, chosen constructively, so that the electric motor operates on a limited range of speeds, with low energy consumption.

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2. LITERATURE REVIEW

Current state-of-the-art on gearbox or alternative transmissions use on electric vehicles (EVs) is found in [20][10][23][13][18] including a vast number of simulation based comparisons using 2-speed versus single speed gearbox or CVT's use [8][4][20][3][16][19][7][17]. In [15] different electric drivetrain configurations were discussed along with the implications of installing a multiple speed transmission in a fully electric drivetrain. In [14] the authors went on to analyze two-speed, three-speed and four-speed drivetrains with gear ratios selected based on the results of the CVT gear ratio optimization. The results show a marked improvement over the single-speed drivetrain by using a multiple-speed transmission with energy consumption gains ranging from 4.5 % to 11 % over different driving cycles [21]. It is evident that further gains can be made by adopting a CVT, however, the marginal gains over the four-speed transmission would in fact be lost in the additional transmission losses between the two systems. Finally, some concept gearbox prototypes targeting mostly EVs use are already presented in the market, such as those by Vocis/Oerlikon Graziano, Antonov and Kreisler Electric [2][11][6].

3. CONCEPT

3.1 Construction

Figure 1 shows the constructive solution of the self-adaptive mechanical reducer with variable gear ratio. The following notations were made:

i_T – the total transmission ratio of the gearbox,
ω_m – angular speed of rotation of the motor,
ω_c – angular speed of rotation of the output shaft,
ω_1 – angular speed of rotation of the straight-toothed cylindrical gear (1),
ω_2 – angular speed of rotation of the straight-toothed cylindrical gear (2),
$\omega_{1'}$ – angular speed of rotation of the straight-toothed cylindrical gear (1'),
$\omega_{2'}$ – angular speed of rotation of the straight-toothed cylindrical gear (2'),
M_m – motor torque,
M_c – the moment of resistance of the consumer.

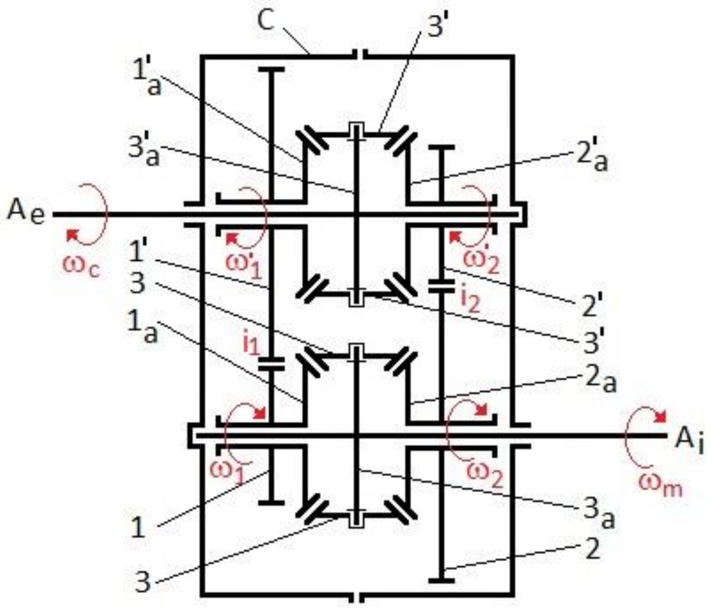

Figure 1. Schematic of the self-adaptive mechanical reducer with variable gear ratio

The reducer is composed of a cast housing (**C**), with a separation plane, consisting of two bodies, in which an input shaft (**A**$_i$) is mounted (see Figure 1). The straight-toothed cylindrical gears (**1**) and (**2**) are mounted on it, integral with the straight-toothed conical gears (**1**$_a$) and (**2**$_a$). The stiffening of the two pairs of gears: (**1**) with (**1**$_a$) and (**2**) with (**2**$_a$) respectively is done by joining them with the help of wedges.

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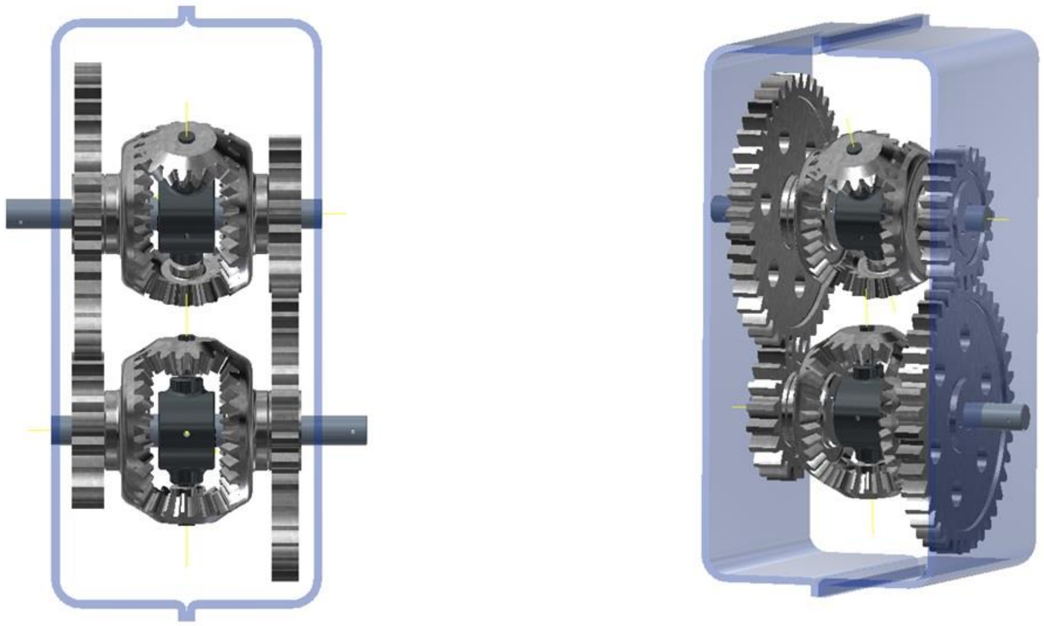
The straight-toothed conical gears (**1_a**) and (**2_a**) are permanently engaged with two satellite pinions (**3**), pinions which are freely mounted on a satellite port (**3_a**), fixed in turn by means of grooves, on the input shaft (**A_i**). Also inside the housing is mounted the output shaft (**A_e**), directly connected to the consumer. The straight-toothed cylindrical gears (**1'**) and (**2'**) are freely mounted on it, integral with the straight-toothed conical gears (**$1'_a$**) and (**$2'_a$**). The stiffening of the two pairs of gears: (**1'**) with (**$1'_a$**) and (**2'**) with (**$2'_a$**) respectively is done by joining them with the help of wedges. The straight-toothed conical gears (**$1'_a$**) and (**$2'_a$**) are permanently engaged with two satellite pinions (**3'**), pinions which are freely mounted on a satellite port (**$3'_a$**), fixed in turn by means of grooves, on the output shaft (**A_e**).
The straight-toothed cylindrical gear (**1**) is in permanent gear with the straight-toothed cylindrical gear (**1'**) with transmission ratio (**i_1**).The straight-toothed cylindrical gear (**2**) is in permanent gear with the straight-toothed cylindrical gear (**2'**) with the transmission ratio (**i_2**). Constructively, **i_1**> **i_2** is chosen.
In addition to the main elements and parts described and listed above, parts that constructively define the self-adaptive mechanical reducer with variable gear ratio, its structure also includes a series of assembly, fixing and locking mechanisms. Figure 2 a) and b) illustrate a three-dimensional model of the self-adaptive mechanical reducer with variable gear ratio.



a) b)

Figure 2. Three-dimensional virtual model of the self-adaptive mechanical reducer with variable gear ratio

3.2 Functionality

The input shaft **A_i** is driven by the electric motor with angular speed **ω_m** and an motor torque **M_m**, the main desideratum being to keep both quantities quasi-constant during operation. The output shaft **A_e** is connected directly to the consumer, it rotates during operation with angular speed **ω_c** – variable.
The rotational motion at angular velocity **ω_m** received by the input shaft **A_i** from the vehicle's electric motor is transmitted, via the satellite port (**3_a**) and the two satellite pinions (**3**), to the conical gears (**1_a**) and (**2_a**) and implicitly to the cylindrical gears (**1**) and (**2**), which will rotate with angular velocities **ω_1** and **ω_2** respectively respecting the relation:

$$2\omega_m = \omega_1 + \omega_2$$

ω_1, **ω_2** and **ω_m** with the same direction of rotation.
Next, the rotational movement from the gear (**1**) is transmitted to the gear (**1'**), which will rotate with **ω'_1**, the transmission ratio being **i_1**, and the rotational movement from the gear (**2**) is transmitted to the wheel (**2'**), which will rotate with **ω'_2**, the transmission ratio being **i_2**. Constructively, **i_1**> **i_2** is chosen.

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By means of the cylindrical gears (**1'**) and (**2'**) and of the conical ones (**1'$_a$**) and (**2'$_a$**) the rotational movement is transmitted to the two satellite pinions (**3'**) which, through the satellite port (**3'a**) transmit the rotational movement to the output shaft **A$_e$**, shaft that will rotate with angular velocity ω_c, so that the following relation will be respected:

$$2\omega_c = \omega_{1'} + \omega_{2'}$$

3.3 Kinematic calculation

$$i_T = \frac{\omega_m}{\omega_c} = \frac{M_c}{M_m} \quad (1)$$

$$2\omega_m = \omega_1 + \omega_2 \quad (2)$$

$$2\omega_c = \omega_{1'} + \omega_{2'} \quad (3)$$

$$i_1 = \frac{\omega_1}{\omega_{1'}} \quad (4)$$

$$i_2 = \frac{\omega_2}{\omega_{2'}} \quad (5)$$

$$i_1 > i_2 \quad (6)$$

ω_m and **M$_m$** are considered constant during operation.
From relations (1), (2), (3), (4) and (5) results the formula of the total transmission ratio

$$i_T = \frac{2 i_1 i_2 \omega_m}{i_2 \omega_1 + i_1 \omega_2} \quad (7)$$

The aim is to continuously vary the total transmission ratio **i_T**, so that the electric motor can overcome the continuous increase of the moment of resistance **M$_c$**, keeping the angular velocity ω_m and the motor torque **M$_m$** constant.
From relation (7) it is observed that the numerator is a constant, **i_1** and **i_2** being constructively constant, and ω_m is deliberately imposed as constant. So the only variable in formula (7) is the denominator. It follows that the maximum value of **i_T** is given by the minimum value of the denominator of the fraction in (7). At the limit, when the denominator becomes zero, **i_T** tends to infinity.
So, assuming that:

$$i_2 \omega_1 + i_1 \omega_2 = 0 \quad (8)$$

It results:

$i_T \to \infty$, that is, the total transmission ratio is not limited to the upper limit, which translates to:
$\omega_c = 0$, according to relation (1).

From (8) it results:

$$\omega_2 = -\frac{i_2}{i_1}\omega_1 \quad (9)$$

$$\omega_1 = -\frac{i_1}{i_2}\omega_2 \quad (10)$$

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From (2) and (9) it results:

$$\omega_1 = \frac{2i_1}{i_1 - i_2}\omega_m \tag{11}$$

From (2) and (10) it results:

$$\omega_2 = -\frac{2i_2}{i_1 - i_2}\omega_m \tag{12}$$

From (12) we conclude that, in this case, the straight-toothed cylindrical gear (**2**) changes its direction of rotation. In order to upper limit the total transmission ratio, a straight-toothed cylindrical gear (**4**) is mounted inside the housing, with one-way movement, which is permanently engaged with the straight-toothed cylindrical gear (**2'**), which causes it to be prevented from changing its direction of rotation, the minimum value of its angular velocity being zero (Figure 3).

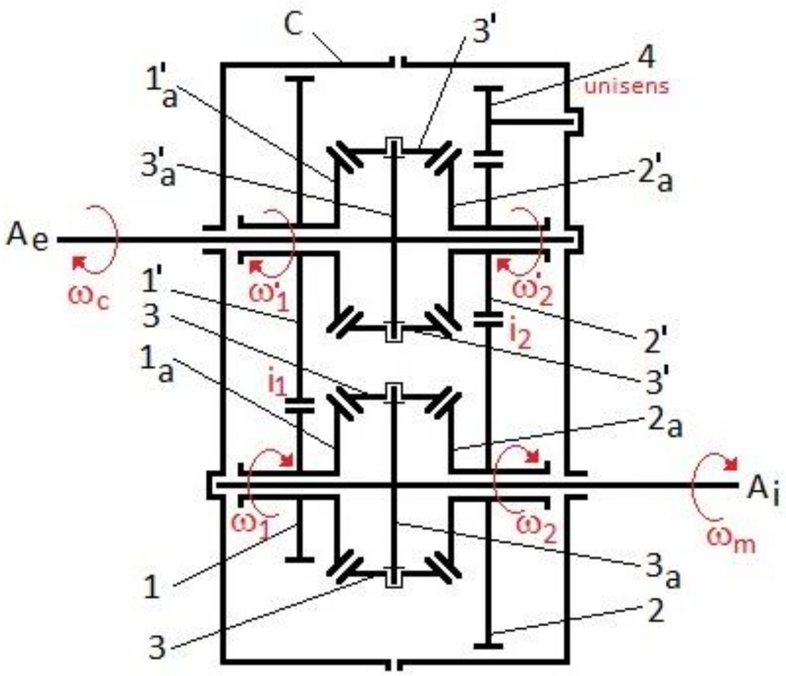

Figure 3. Schematic of the self-adaptive mechanical reducer with variable gear ratio – variant

Thus, the value of ω_2 becomes zero, and the maximum value of the total transmission ratio $\mathbf{i_T}$ will be $\mathbf{i_1}$.
As: $\mathbf{M_m}$ and $\mathbf{\omega_m}$ are considered constant, and $\mathbf{M_c}$ and $\mathbf{\omega_c}$ are variable values, a continuous variation of the transmission ratio $\mathbf{i_T}$ in the interval $(\mathbf{i_2,i_1}]$ results so that:

$$M_c = i_T \cdot M_m \tag{13}$$

The limits between which $\mathbf{i_T}$ can vary can be changed by changing the transmission ratios $\mathbf{i_1}$ and $\mathbf{i_2}$.

4. CONCLUSION

The self-adaptive mechanical reducer with variable gear ratio, characterized in that it allows continuous, self-adaptive variation of the transmission ratio $\mathbf{i_T}$, depending on the value of the moment of resistance $\mathbf{M_c}$, between values $\mathbf{i_1}$ and $\mathbf{i_2}$, ensures the operation of the electric motor on a narrow range of speeds and minimum electricity consumption.

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The main feature is the possibility of continuous variation of the angular speeds of the straight-toothed cylindrical gears (1) and (1') - gearbox 1, respectively (2) and (2') - gearbox 2, depending on the value of the moment of resistance $\mathbf{M_c}$ (figure 1). Thus, the operation of the electric motor with a quasi-constant motor torque $\mathbf{M_m}$ is allowed, while the moment of resistance $\mathbf{M_c}$ can change over a relatively wide range of values.
The reducer upper limits the total transmission ratio $\mathbf{i_T}$ to $\mathbf{i_1}$ by the additional mounting of the straight-toothed cylindrical gear (4), with one-way movement, which is in permanent gear with the straight-toothed cylindrical gear (2'), preventing the reversal of the direction of its rotation (figure 3).

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RESEARCH ABOUT THE IMPLEMENTATION OF THE STATISTICAL PROCESS CONTROL WITH APPLICATION TO THE AUTOMOTIVE STEERING KNUCKLE

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(Received 24 January 2021; Revised 10 February 2021; Accepted 03 March 2021)

Abstract: *Statistical Process Control (SPC) represents one of the most useful methods in Quality Engineering and Lean Six-Sigma methodology, being a technique of quality process improving, which permits the identification of errors before their apparition, making it possible to carry out an intervention of process correction, before nonconformities occurrence. By SPC implementation, the product with "zero defects" is reached, which is the target of any industrial company. This study presents the implementation of Statistical Control Process, in a supplying company of auto components for an international automobiles company aiming to improve the quality of the technological process for steering knuckle manufacturing. Thus, sampling observations ~~it~~ was done by applying statistical methods, so a number of 25 samples pieces have been preserved, each specimen containing a number of 5 pieces. After measuring and controlling the parts, a series of techniques and statistical data were used, respectively control diagrams and sheets, that enabled the certainty of the process capability by using MiniTab software. The last stage consisted of reasonable assumption for the capability of the steering knuckle technological process and its defective fractions, obtaining 2,23 the indicated value of process capability. This represents an excellent value of the capability of the steering knuckle technological process, far beyond the 1,67, the need for consideration, as representing a high-performance process, for the automotive field. According to the complex analysis of Sixpack Report presented in the paper, it can be considered that the processing process is precise and well regulated, with a performance level of 6σ.*

Keywords: *Statistical Process Control (SPC), Quality, steering knuckle, automotive components, capability*

1. INTRODUCTION

In the last decade, quality control has become a priority in the development strategy of companies in all fields: industry, distribution, transport companies, health, government agencies, financial organizations, etc. Achieving and maintaining a high level of quality of products or services offers competitive advantages that allows a company to dominate their competitors in the field of work. Thus, a company, by applying continuous improvement and quality control, can dominate its competitors [14].
In the automotive field, the application of quality control in all stages of an automobile achievement is considered a zero-priority [12][15].
One of the most used methods in the field of quality engineering is the Statistical Process Control (SPC) with applicability especially in the phase of the manufacturing process of a product [3].
The applicability of this methodology in the automotive field expanded in the 1980s, especially in Europe and the USA [4], a period in which many Western companies discovered that competing Japanese firms have been applying mathematical statistics procedures since the 1960s to improve manufacturing processes and discovering new types of processes, evaluating product performance, improving product reliability and performance, and many other aspects of product design, including component selection and tolerance system [7]. This know-how was generated by the decline of the automotive industry (the engine of the global economy), an industry heavily affected by foreign competition in the '70s. For example, a Western profile company estimated losses of nearly $ 1 million per hour in 1980 [14]. The adoption and use of statistical methods have played a central role in relaunching American industry, especially in the automotive industry [6]. The basic principle of the method is not the identification of errors, but their avoidance being catalogued among the preventive methods of quality management.
The application of SPC contributes to cost reduction due to the rejection of subsequent processing and inspection costs, thus enabling the achievement of a "zero defect" production and continuous product [8].

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ISSN 2457 – 5275 (Online, English)
ISSN 1842 – 4074 (Print, Online, Romanian)

SPC can only apply for stable static and dynamic processes, whose distribution comply with certain statistical distribution [5]. In the case of attributive characteristics, the binomial distribution and the Poisson distribution will often be used [11]. The variable (measurable) characteristics have a normal distribution in most cases. The application of SPC determines the capability and performance of the manufacturing process, with the possibility of applying solutions to improve its quality [1]. SPC involves following the operations during the manufacturing process, identifying in real time the areas that can lead to errors, applying methods to reduce dispersion and verify that they work, to optimize the process and determine the reliability of parts [2, 10]. The first stage in the application of SPC presumes sampling according to the rules of mathematical statistics, making the sample pieces, according to ISO / TS 11462: 2016, measuring and controlling the components in the sample pieces [7]. The next step consists of control charts plotting, verification that the average range and standard deviation of the confidence interval is represented by the chart control limits called a control diagram of the monitoring and evaluation of process capability variability [16]. Thus, the primary techniques of SPC is the control chart [9]. In the last stage of the SPC, the capability of the production process or equipment is actuated, whose minimum value is 1,67, in the automotive field [6].
This paper presents a study on the application of SPC to a supplier company of knuckles for middle class automobiles, in order to establish the capability and performance of the manufacturing process, through a modern and high-performance approach, using the MiniTab software.

2. EXPERIMENTAL DATA

This study of the SPC was considered of interest for the element's components of the knuckle, by using a dedicated software MiniTab for statistical processing and quality, due to its particularly important role in the operation of an automobile [12]. The steering knuckle is the main connecting element between the suspension system, the braking system and the steering system, all of which are assembled directly on the spindle [17]. This research has been accomplished on an industrial producer of steering knuckle for middle class automotive, presented in Figure 1.a. To carry out the statistical control of the knuckle manufacturing process, it was considered of interest, according to the data delivered by the supplier, to calculate the capability of the spindle port clamping bore with the damper having a nominal diameter of Φ $26_{-0,2}^{\ 0}$m, Figure 1.b.

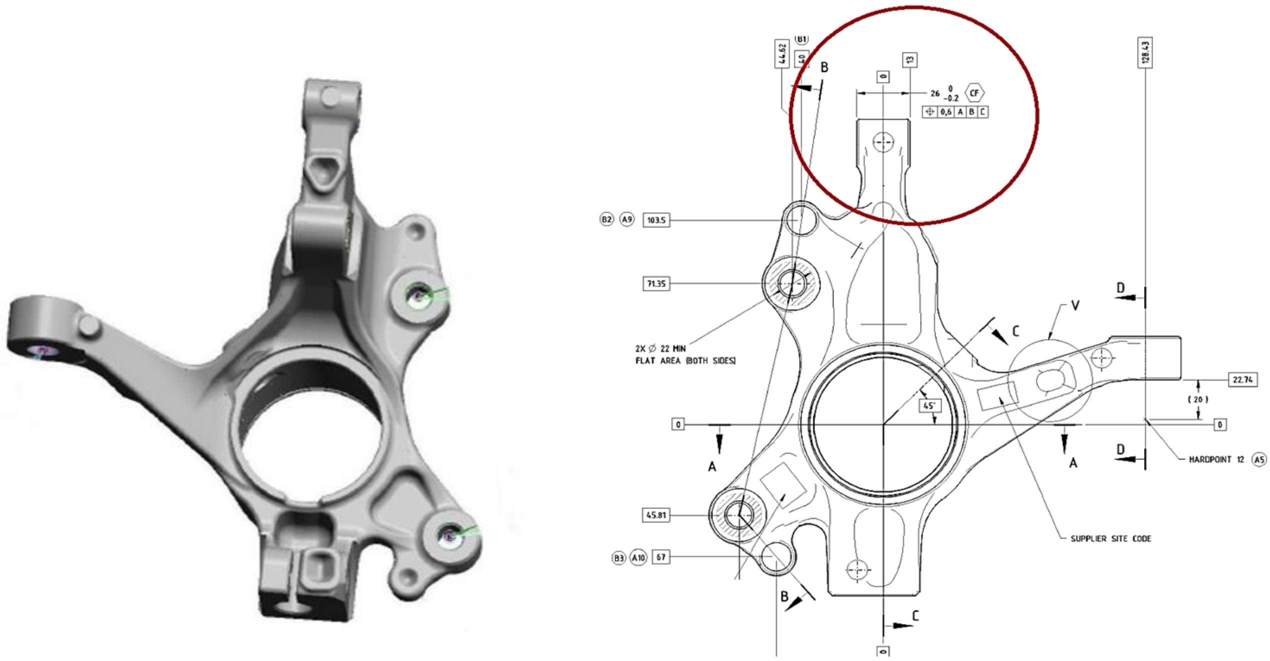

Figure 1. Steering knuckle: a. main view; b. drawing execution

Dimensional and geometric deviations arise especially due to errors that may intervene during the stages in which the mechanical processing by cutting of the forged / cast semi-finished product is performed.

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ISSN 1842 – 4074 (Print, Online, Romanian)

To carry out the study regarding the statistical control of the technological process for steering knuckle, in the phase of the final inspection of the product, a number n = 25 samples were strobed, each sample having a number of n = 5 pieces.

For each of the sampled parts, in accordance with SR ISO 3951-5: 2009, the actual diameter dimension was measured, the spindle having by design the diameter $\Phi 26_{-0,2}^{\ 0}$ mm, according to Figure 1.b.

In Table 1 the values obtained from the measurements are presented.

Table 1.
Actual size of the diameter of the spindle bore for the sampled parts

Sample No.	**Part of the sample**				
	X_1 [mm]	X_2 [mm]	X_3 [mm]	X_4 [mm]	X_5 [mm]
Sample 1	25,88	25,92	25,91	25,89	25,91
Sample 2	25,89	25,91	25,89	25,87	25,9
Sample 3	25,89	25,9	25,89	25,86	25,87
Sample 4	25,9	25,9	25,86	25,88	25,9
Sample 5	25,88	25,91	25,91	25,86	25,88
Sample 6	25,88	25,89	25,89	25,9	25,89
Sample 7	25,9	25,89	25,89	25,89	25,9
Sample 8	25,9	25,89	25,9	25,86	25,89
Sample 9	25,91	25,89	25,86	25,86	25,9
Sample 10	25,89	25,89	25,89	25,87	25,88
Sample 11	25,91	25,88	25,86	25,89	25,91
Sample 12	25,88	25,86	25,89	25,87	25,89
Sample 13	25,89	25,89	25,91	25,89	25,89
Sample 14	25,89	25,88	25,9	25,86	25,88
Sample 15	25,9	25,89	25,89	25,88	25,87
Sample 16	25,9	25,89	25,9	25,86	25,88
Sample 17	25,91	25,89	25,89	25,9	25,88
Sample 18	25,88	25,89	25,86	25,9	25,87
Sample 19	25,89	25,88	25,91	25,89	25,87
Sample 20	25,89	25,88	25,9	25,89	25,86
Sample 21	25,91	25,9	25,86	25,87	25,89
Sample 22	25,91	25,87	25,87	25,86	25,86
Sample 23	25,88	25,88	25,89	25,9	25,86
Sample 24	25,87	25,91	25,9	25,89	25,9
Sample 25	25,88	25,89	25,89	25,9	25,9

The SPC of the knuckle manufacturing process was performed by using the MiniTab software, specialized for efficiency and quality improving through smart data analysis, with features and statistical enhancements incorporated that allow of data analysis, subsuming binary response for Design of Experiments (DOE), capability performance enhancements and more [3][13]. In the first stage, the control diagrams for mean and amplitude were determined, as presented in Figure 2.

ISSN 2457 – 5275 (Online, English)
ISSN 1842 – 4074 (Print, Online, Romanian)

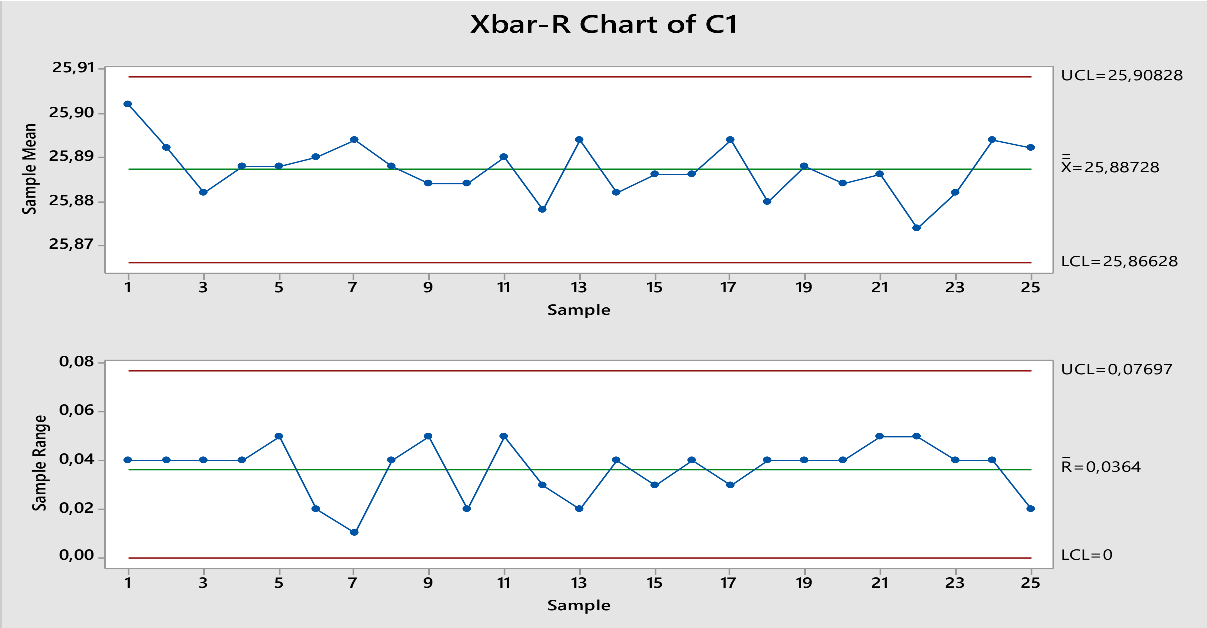

Figure 2. The control diagrams for mean and amplitude

After the control diagrams for the mean and amplitude, and the confirmation of the stability of the technological process of the steering knuckle, the distribution curve of the final characteristics obtained by measurement was performed, Figure 3. The last stage of SPC consisted in the capability of the steering knuckle technological process quantification and its defective fraction.
The *Cp* process capability index represents the ability to frame a process within the specified limits and is determined as the ratio between the size of the tolerance field and the capability, the latter being evaluated at 6σ, applying the following formula:

$$C_p = \frac{T}{6 \cdot \sigma} \tag{1}$$

where: *T* is the tolerance field imposed on the design and 6σ represents the boundary field (the basis of the Gaussian curve)
The value of the process capability index was obtained and is presented in equation 2:

$$Cp = 2,14 > 1,67 \tag{2}$$

where 1,67 represents the minimum accepted value of the capacity for a process to be efficient, for the automotive industry.
The obtained value of 2,288 means an excellent value of the capability of the steering knuckle technological process, so the manufacturing process is efficient. The process capability index Cp highlights the stability of the process, its value being higher than 2, representing a small variability of the process, respectively a high stability of it.
Next, the centering index of the process was determined with the formula:

$$C_{pk} = \min\left[\frac{LSL - \bar{\bar{x}}}{3 \cdot \sigma}; \frac{\bar{\bar{x}} - USL}{3 \cdot \sigma}\right] \tag{3}$$

where: *LSL* – high limit; *USL* – low limit; 3σ- half of the boundary field; $\bar{\bar{x}}$ - the values of the actual diameters measured from the 25 samples taken.
Following the calculations, it turned out that the centering index of the Cpk process has the value, according to relation (4):

$$C_{pk} = \min \{C_{pk\ sup}(CPU); C_{pk\ inf}(CPL)\} = 1{,}87 > 1{,}67 \quad (4)$$

where: $C_{pk\ sup}$ (CPU) is the upper centering index which is determined by the formula:

$$C_{pk\,\sup} = \frac{LSL - \bar{\bar{x}}}{3 \cdot \sigma} = 2{,}41 \quad (5)$$

and $C_{pk\ inf}$ (CPL) is the lower centering index that is calculated with the relation:

$$C_{pk\ \inf} = \frac{\bar{\bar{x}} - LSL}{3 \cdot \sigma} = 1{,}87 \quad (6)$$

The *Cpk* index highlights the extent to which the process is or is not centered at the target value of the set quality characteristic, its value being higher than 1,67 indicates a high adjustment and centering of the process, Figure 3. Most capability appraisals can be grouped into one of the two categories: Potential (within) and Overall capability [3] (Figure 3). Each of them represents a unique measure of the process's capability. Potential capability is often called the "entitlement" of the process: it ignores differences between subgroups and represents how the process could perform if the shift and drift between subgroups were eliminated. It is also called actual capability or long-term capability. Capability indices that assess potential capability include *Cp*, *CPU*, *CPL*, and *Cpk*. On the other hand, Overall capability represents the customer's experience; it accounts for the differences between subgroups. It is also called short-term capability Capability indices that assess overall capability include *Pp*, *PPU*, *PPL*, *Ppk*, and *Cpm* [13], they are process performance indices, highlighting the proportion of non-compliant products that occur due to exceeding the upper and / or lower control limit. *Ppk* is the performance index that assesses the focus of the process. It highlights the distance between the process average and the nearest specified limit at the center of the total process spread.

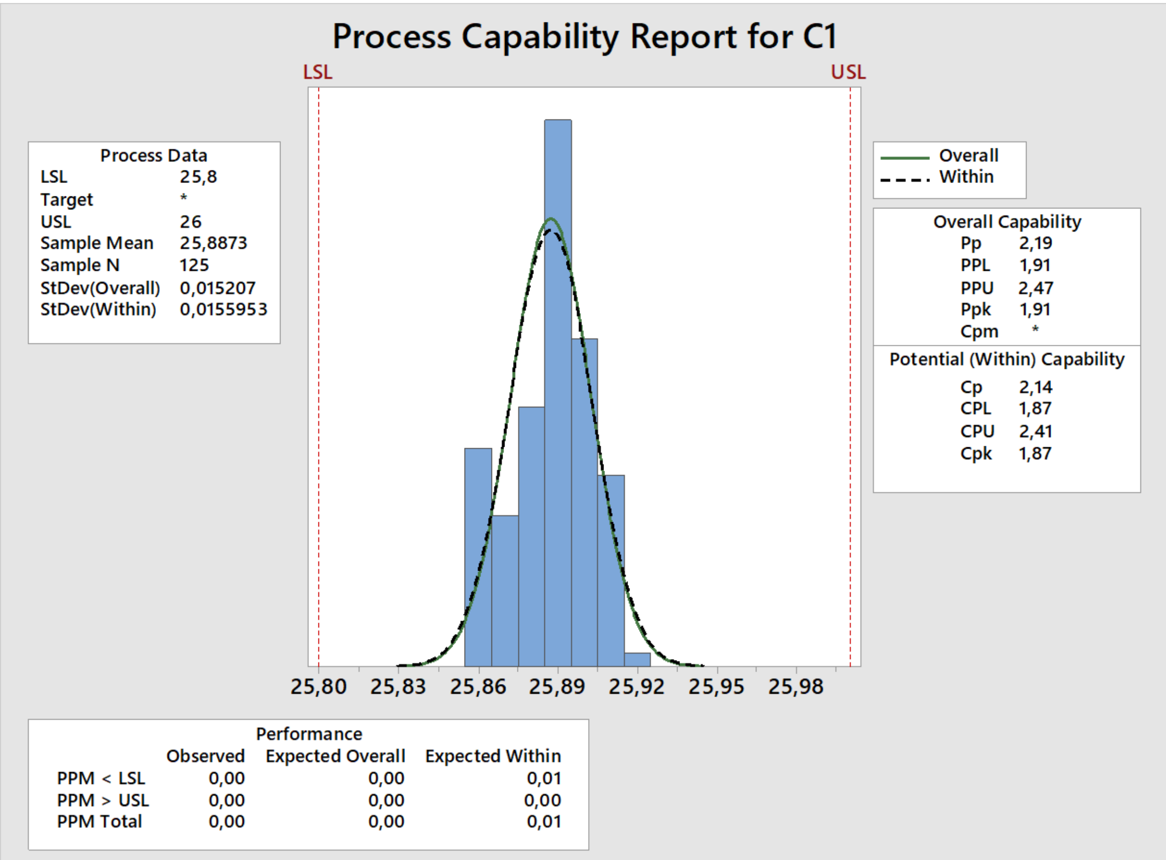

Figure 3. The process capability

ISSN 2457 – 5275 (Online, English)
ISSN 1842 – 4074 (Print, Online, Romanian)

By using the MiniTab software, the following values were obtained for the lower performance index ($P_{pk\ inf}$, *PPL*), upper ($P_{pk\ sup}$, *PPU*) and total ($P_{pk\ tot}$), they are determined by the relations:

$$P_{pk\ inf} = P\{X < LIS\} = P\{Z < Z_{inf}\} = \frac{1}{\sqrt{2\pi}} \int_{-x}^{Z_{inf}} e^{\frac{z^2}{2}}\, dz = 1{,}91 \qquad (7)$$

$$P_{pk\ sup} = 1 - P\{Z \leq Z_{sup}\} = 1 - \frac{1}{\sqrt{2\pi}} \int_{-x}^{Z_{sup}} e^{-\frac{z^2}{2}}\, dz = 2{,}47 \qquad (8)$$

$$P_{pk\ tot} = P_{pk\ inf} + P_{pk\ sup} \qquad (9)$$

The values of the Laplace function are tabulated, depending on the value of the normalized normal variable:

$$Z = \frac{x_i - \overline{x}}{\sigma} \qquad (10)$$

Process capability index *Pp* relative to process performance indices:

$$P_p = \frac{P_{tot}}{2} = 2{,}19 \qquad (11)$$

The *Pp* performance index is only used to compare with *Cp* and *Cpk* and to measure performance improvement over time. Estimation of the standard deviation by the mean square deviation *s* (σ_s) is performed when the process is affected by both common causes and special causes of variation.
The overall capability of the process, respectively the general standard deviation of the process, *Ppk*:

$$Ppk = \min \{Pinf\ (PPL);\ P\ sup\ (PPU)\} = 1{,}91 \qquad (12)$$

Parts per million (PPM) represents the number of nonconforming parts out of a million parts. Minitab expresses the expected and observed performance of the process in terms of PPM. The observed performance is the actual number of nonconforming parts with respect to the upper, lower, and both specifications out of million parts in the process. From Figure 3 it can be observed that for the process of steering knuckle manufacturing the PPM= 0, that means “zero nonconforming parts out of a million pieces”, a perfect value that means a production with “zero defects”.
Because the values of all determined capability indices are higher than 1,67, it was also considered necessary to perform the 6Sigma test, Figure 4. The Minitab software uses several types of standard deviation to capture different patterns of variation in a process, obtaining an estimate of the variation of the process output, presented in Table 2 and Figure 4. The approximate values obtained show that there are no major variations in the sampled values both in the processing of the steering knuckle by different operators and, subsequently, during the process of measuring the dimensions.

Table 2
The values of the standard deviations of the manufacturing process precision of the steering knuckle, determined with the MiniTab software

Standard deviation	**Defining**	**Simbols σ**	**Value [mm²]**
Overall	represents the variation of the entire process output, ignoring samples	$\sigma_{overall}$	0,01521
Within-subgroup	represents the variation within the samples	σ_{within}	0,0156
Between-subgroup	represents the variation between samples	$\sigma_{between}$	0
Between/within	a single value that accounts for the variation between samples and within them	$\sigma_{B/W}$	0,01521

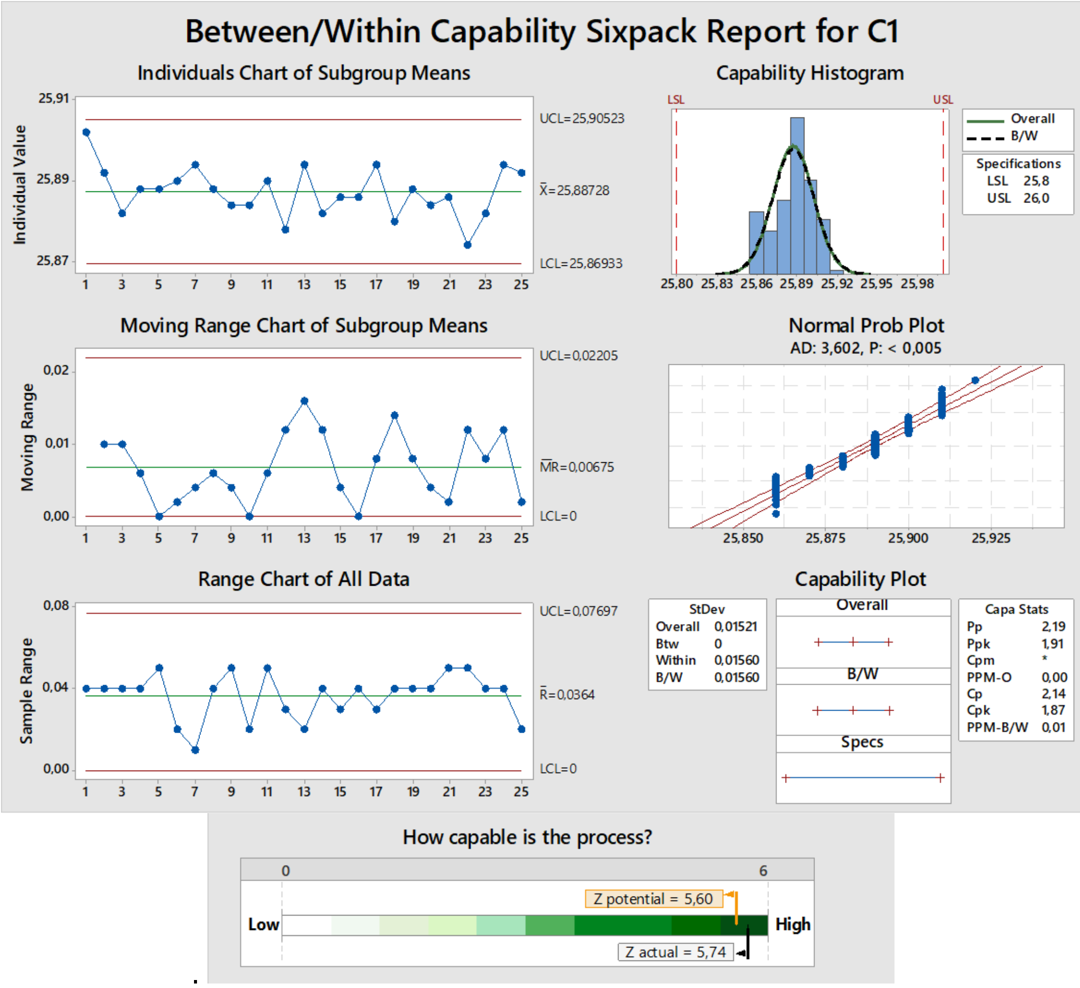

Figure 4. Process capability Sixpack report

Z bench values provided by the MiniTab software, Figure 4, are used to describe the sigma capability of the process. A value of Z bench of 6 represents 0,000987 defective parts per million products, from Figure 4 it is observed that, for the manufacturing process of the spindle, the value of Z actual is 5,74. *Short-term Z bench* represents the number of standard short-term deviations, being a measure of the current process performance if this short-term variation could be maintained, respectively defects outside the combined upper and lower specifications, being the best scenario to characterize the process at the present time. *Long-term Z bench* represents the number of standard long-term deviations, being a better measure of reality, because, usually, the short-term variation in time cannot be maintained, being able to be characterized as the discomfort felt by the client. *Z shift* is the difference between the two values of Z bench (Short-term and Long-term). The higher the *Z shift*, the more opportunities there are to improve and control the process by eliminating or reducing the special causes that determine the variation between samples. In the case of the steering knuckle manufacturing process, it results that *Zshift = 0,16*. For the manufacturing process of the steering knuckle, it is found that the Z bench values are appropriate, and both are close to a high precision of the process quality and, implicitly, of the product. According to the complex Sixpack Report analysis in Figure 4, it can be considered that the manufacturing process of the cylindrical bore of the steering knuckle connecting to spindle port clamping bore with the shock absorber is precise and well regulated, with a performance level of 6 σ.

3. CONCLUSION

The analysis of the technological manufacturing processes of the vehicles, as a complex phenomenon, must emphasize the constructive particularities and the role of the parts, because each part in the construction of the vehicle has a precise destination and possesses a determined number of characteristics and particularities. The constructive and functional peculiarities required for the execution of the steering knuckle high dimensional and geometric precision.

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The piece is intensely and variably requested. The most demanding tolerances are for the surfaces that connect with the fundamental and constructive elements of the automobile. These are performed in accuracy class 6 or 7 ISO. This is the reason why the precision of processing the cylindrical bore of steering knuckle connecting with the shock absorber was chosen as a study element. It was found that the process has a high centering and variability, which shows the stability of the process and in terms of adjustment. The effective capacity is *Cpk* = 1,87, and *Cp* = 2,14, a potential capacity which can be reached by adjusting the process (without increasing the accuracy). The use of the dedicated Minitab quality software allowed to identify trends, extract and discover valuable information from data, highlighting process performance, through a comprehensive suite of statistical analysis and process improvement tools: determining new concepts of overall capability, potential/within capability, the four types of standard deviations ($\sigma_{overall}$, σ_{within}, $\sigma_{between}$, $\sigma_{B/W}$) and the value of the sigma capability of the process from the perspective felt by the beneficiary, by determining *Z* bench, provides a more comprehensive analysis and with a special relevance on the acuity and the manufacturing precision of the steering knuckle, finding that it is appropriate.

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ISSN 2457 – 5275 (Online, English)
ISSN 1842 – 4074 (Print, Online, Romanian)

ASPECTS REGARDING THE OPERATION AND ELECTRONIC CONTROL OF DIESEL ENGINES

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(Received 10 February 2021; Revised 28 April 2021; Accepted 05 May 2021)

Abstract: *The paper studies one of the most used internal combustion engines to equip motor vehicles, namely diesel engines, which have incited a lot of controversy lately, especially after the issue with some abnormal values regarding pollutant emissions and the mechanism used to report parameters specific to fuel consumption and resulting exhaust gases.*

Keywords: *Diesel engine, common-rail, electronic control, engine load and speed*

NOMENCLATURE

EGR – Exhaust Gas Recirculation
ERFC – Emphasis on Reducing Fuel Consumption

1. INTRODUCTION

The approach to the operation and electronic control of motor vehicles is one of the main concerns of specialists in the field, who have constantly sought to improve the dynamic and economical performance of road transport. The developments of different disciplines in various fields, the emergence of increasingly advanced experimental equipment and the equipment of engines with electronic control systems were the most important factors influencing the algorithms to study their operation.
Diesel engines currently manufactured meet the requirements of anti-pollution regulations [5][14][16][17], even if they have become more complex and more expensive. The motors manufactured today have an electronic management of the operation by equipping with sensors, actuators, and microcontrollers, all these ensuring the control of the operation in real time [1][2][3][6][7][8][9]. In this way, the current diesel engine has become more efficient, more powerful, quieter, more economical and cleaner. A current diesel engine has different electronic control systems, the main ones being fuel injection control system, supercharged air pressure control system, recirculated gas quantity control system, pollutant control system, fuel control system, air-fuel mixture quality control system, speed control system, engine torque control system etc.

2. EXPERIMENTAL RESEARCH

The experimental research was conducted with a Ford Focus car (denoted FF) and a Volkswagen Touareg II 3.0 V6 TDI (denoted VW), both equipped with a supercharged diesel engine and a common rail fueling system. For data acquisition from the on-board computer, the Ford interface and software were used, respectively the VCDS application developed by Ross-Tech, which is the specialized diagnostic software for the Volkswagen group. To highlight electronic control elements, 100 tests were retained while driving the Ford Focus car in urban and extra-urban areas. To highlight separately, comparatively, the particularities of the engine operation when driving the vehicle in urban and extra-urban areas, 40 tests from each were retained, for both cars, FF, and VW.

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ISSN 2457 – 5275 (Online, English)
ISSN 1842 – 4074 (Print, Online, Romanian)

Thus, figure 1 shows the values of the intake air pressure p_a (considered in many cases as engine load), and figure 2 of the fuel pressure in the common ramp p_c, when driving the Ford Focus car in urban areas (40 tests) and in extra-urban environment (40 tests). As can be seen from these graphs, in the extra-urban environment the values of the two variables are higher than in the urban environment. Thus, from figure 1 it results that in the urban environment the intake air pressure varied in the range 101.3-140.9 kPa, and in the extra-urban environment in the range 107.3-216.3 kPa. In addition, figure 2 shows that in the urban environment the fuel pressure varied in the range of 24.5-136.7 MPa, and in the extra-urban environment in the range of 52.0-145.6 MPa. Also, from figure 1 and figure 2 it results that the average value on the entire tests, air intake pressure is 31.8% higher in the extra-urban environment, and of the fuel pressure in the common rail is 4.8 times higher. The graphs in figure 1 show that all values of the intake air pressure are higher than 100 kPa, which confirms that the engine is supercharged.

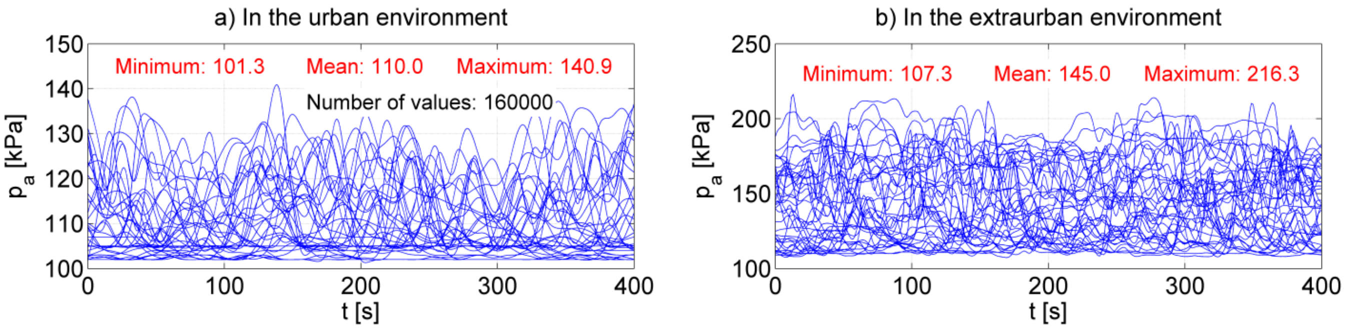

Figure 1. Intake air pressure, FF car

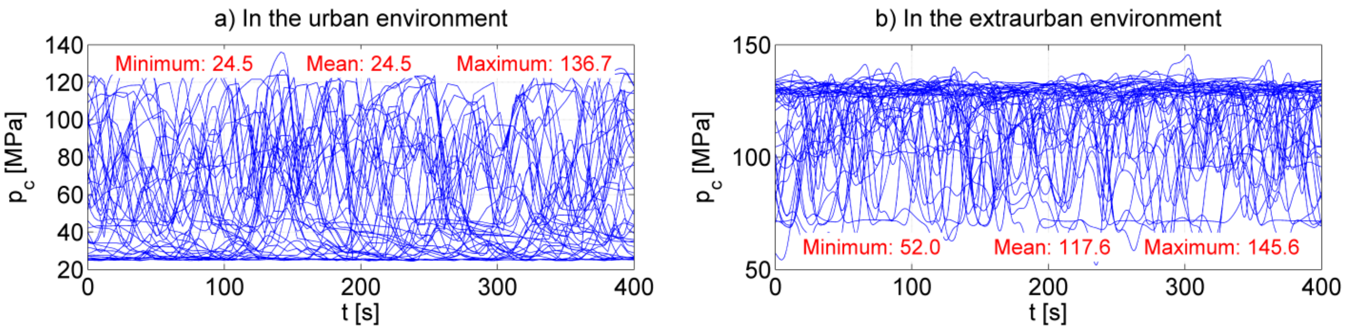

Figure 2. Fuel pressure in the common-rail, FF car

Figure 3 shows the values of the position of the accelerator pedal *p* (considered in many cases as the engine load), and figure 4 of engine speed *n*, when driving the Volkswagen Touareg II 3.0 V6 TDI in urban areas (40 tests) and in extra-urban areas (40 tests). As can be seen from these graphs, in the extra-urban environment the values of the two variables are higher than in the urban environment.
Thus, from figure 3 it results that in the urban environment the position of the accelerator pedal varied in the range of 5.0-86.6%, and in the extra-urban environment in the range of 6.6-98.4%. In addition, figure 4 shows that in urban areas the engine speed varied in the range of 917.4-2910.1 rev/min, and in the extra-urban environment in the range of 1172.6-3885.6 rev/min. Also, from figure 3 and figure 4 it results that the average value on all the tests of the position of the accelerator pedal is by 33.2% higher in the extra-urban environment, and of the engine speed by 55.9% compared to the urban environment.
From figure 1 and figure 3, where the variables that constitute the engine load are shown, it is also found that the operation of the engine during the operation of the vehicle is mainly at partial loads and practically very little at full load.

3. FUNCTIONAL DEPENDENCIES AND MATHEMATICAL MODELS

Experimental research has established functional dependencies between variables, including by deducing related analytical expressions. For example, figure 5 shows graphs illustrating functional dependencies such as M_e=f(*n*, *p*) and P_e=f(*n*, *p*) for the VW car, with M_e torque and P_e engine power.

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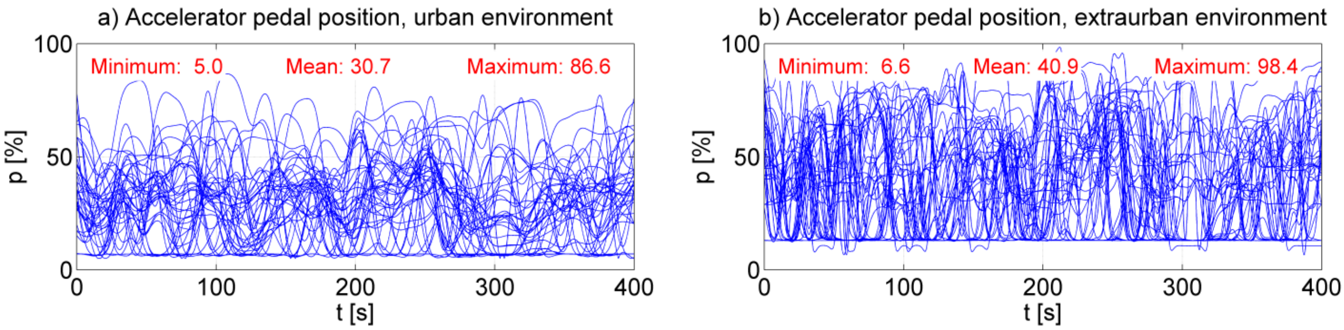

Figure 3. Accelerator pedal position, VW car

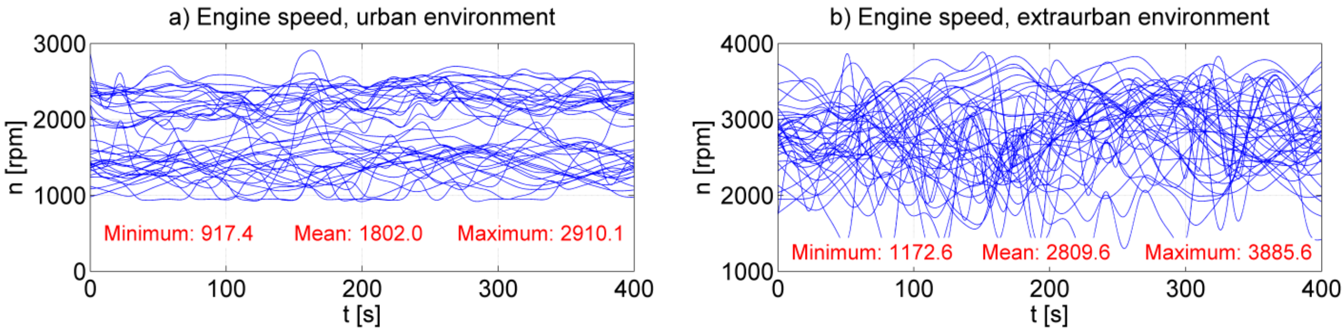

Figure 4. Engine speed, VW car

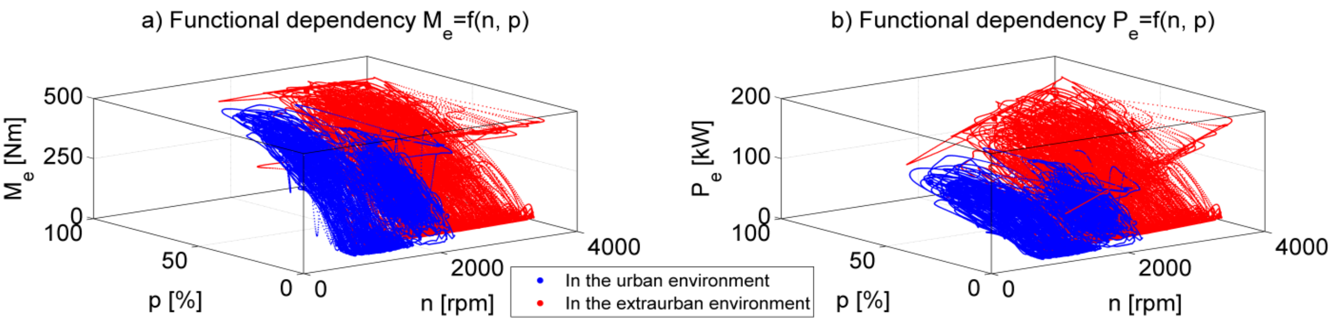

Figure 5. Functional dependencies M_e=f(n, p) and P_e=f(n, p), VW car

The graphs in figure 5, with discrete representation of the experimental data, confirm that when traveling in the extra-urban environment the values of engine torque and engine power are arranged at higher speeds and loads, compared to those in urban areas. Figure 6 shows graphs illustrating functional dependencies such as M_e=f(p_c, p_a) and M_e=f(n, p) in the case of the 100 tests of the Ford Focus car.
These graphs contain the switching surface of the static characteristic, as well as the experimental data in discrete representation.

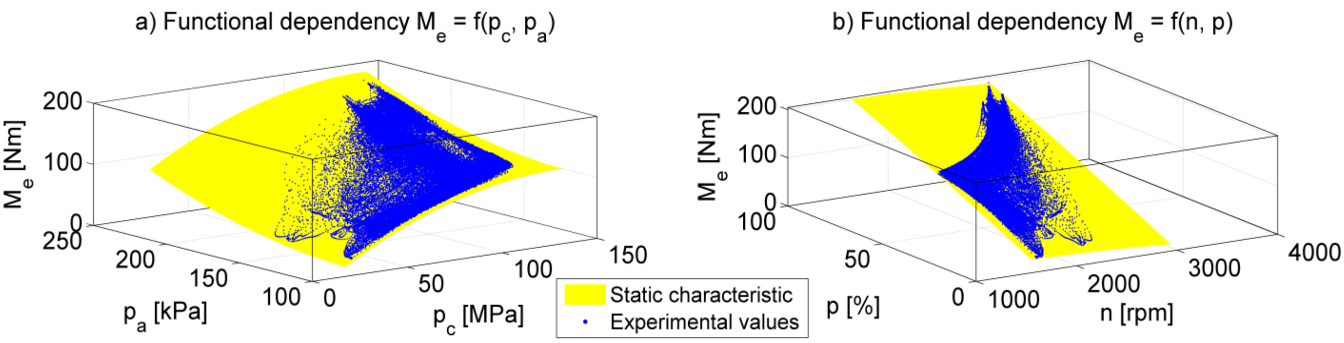

Figure 6. Functional dependencies M_e=f(p_c, p_a) and M_e=f(n, p), FF car

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The switching surface of the static characteristic in figure 6a is described mathematically by the analytical expression:

$$M_e = 2.234p_c - 0.685p_a - 0.008315p_c^2 + 0.003683p_a^2 \quad (1)$$

and the one in figure 6b of the relationship:

$$M_e = 0.0127n + 2.069p - 0.0000047n^2 + 0.0013284p^2 \quad (2)$$

These mathematical models allow the study of engine operation even at partial loads, and relation (2) also takes into account the action of the driver through the position of the accelerator pedal *p*.
Similarly, other functional dependencies can be established, with the instantaneous values of the variables or with the average values on their tests. An example in the latter case is shown in figure 7, which illustrates the functional dependence between the hourly air consumption and the air pressure allowed for the 100 experimental samples of the Ford Focus car: in figure 7a for the instantaneous values C_a and p_a, and in figure 7b for average values on C_{am} and p_{am} tests.

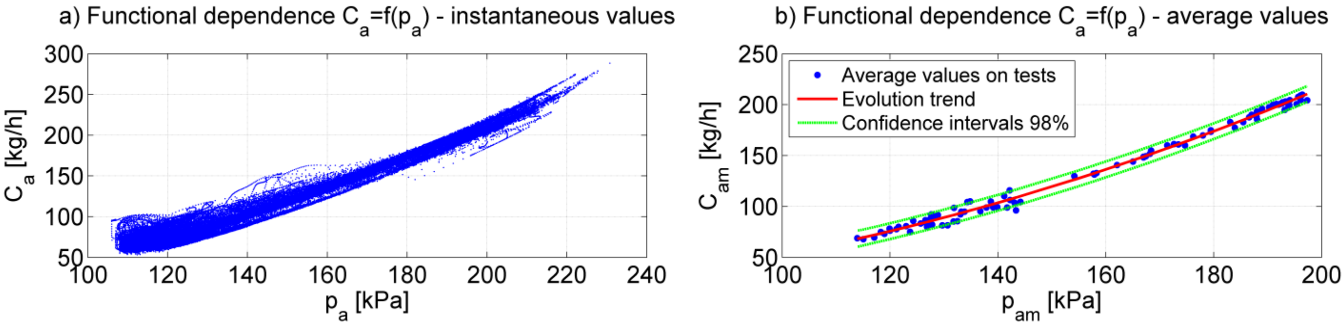

Figure 7. Functional dependencies C_a=f(p_a) and C_{am}=f(p_{am}), FF car

The functional dependence in figure 7b (trend curve) is mathematically described by the analytical expression:

$$C_{am} = 0.00604\,p_{am}^2 - 0.17666\,p_{am} + 9.929 \quad (3)$$

the graph also shows the 98% confidence intervals (upper and lower).

4. ENGINE ELECTRONIC CONTROL

Previously, the electronic control systems that equip the current diesel engines in order to meet the required performance were presented [10][11][12][13][15][17]. The experimental research focused on four control systems of a diesel engine, which ensure the regulation of cyclic fuel flow, boost air pressure, the number of recirculated gases and exhaust emissions. For example, figure 8 shows the dependence of the cyclic fuel flow c_c on the engine speed *n* and the position of the accelerator pedal *p*, respectively, by the average values on samples c_{cm}, n_m and p_m, in the case of the 100 tests of the Ford Focus car. The graphs in figure 8 confirm that the cyclic fuel flow increases with increasing engine speed and load. The trend curve in figure 8a is described by the analytical expression:

$$c_{cm} = 0.000002n_m^2 + 0.00138n_m + 4.244 \quad (4)$$

and the one in figure 8b of the relationship:

$$c_{cm} = 0.00001p_m^2 - 0.01975\,p_m + 21.563 \quad (5)$$

both graphs also show the confidence intervals 98%.

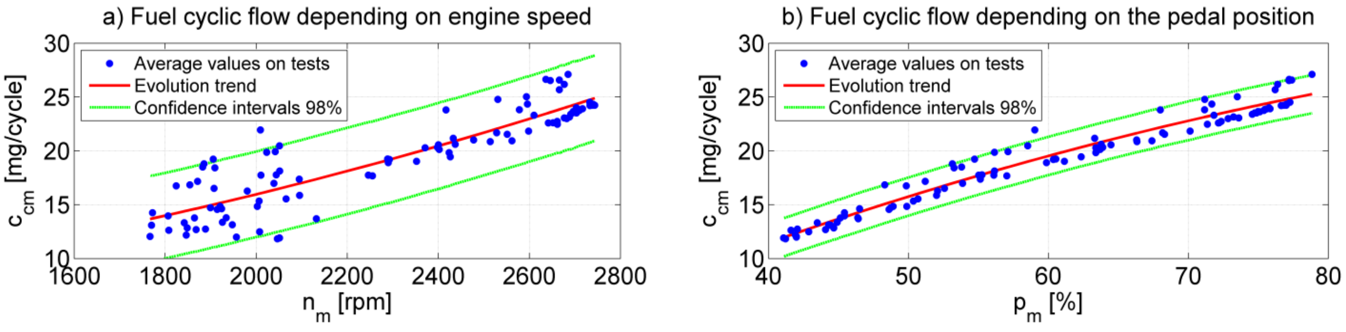

Figure 8. Functional dependencies $c_{cm}=f(n_m)$ and $c_{cm}=f(p_m)$, FF car

Figure 9 and figure 10 show the dependence of the percentage of recirculated gas γ (EGR - Exhaust Gas Recirculation) on the engine speed *n* and the position of the accelerator pedal *p* respectively.
Figure 9a and figure 10a show the instantaneous values, and figure 9b and figure 10b are the average values on the 100 tests of the Ford Focus car.
The graphs in figure 9 and figure 10 confirm that the amount of recirculated gas decreases with increasing engine speed and load.
The trend curve in figure 9b is described by the analytical expression:

$$\gamma_m = -0.000006 n_m^2 + 0.01693 n_m + 8.8735 \qquad (6)$$

and the one in figure 10b of the relationship:

$$\gamma_m = -0.0022271 p_m^2 - 0.03154 p_m + 26.1027 \qquad (7)$$

the graphs also show the confidence intervals 98%.

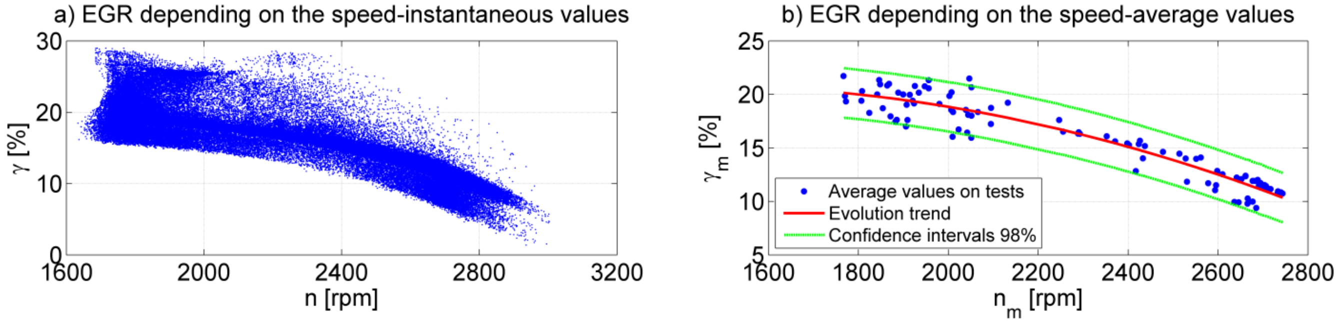

Figure 9. EGR depending on the engine speed, FF car

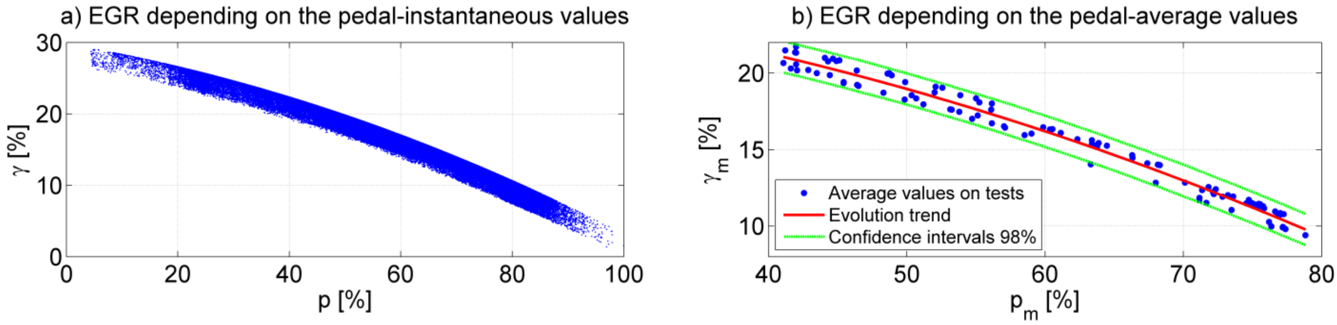

Figure 10. EGR depending on the position of the accelerator pedal, FF car

ISSN 2457 – 5275 (Online, English)
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5. ENERGY EFFICIENCY OF THE ENGINE

The study of energy efficiency simultaneously aims at the dynamism and fuel saving of the engine. Efforts today and in the future are aimed at improving the fuel saving at the expense of dynamism, the forecast for 2035 being the one according to the ERFC concept (Emphasis on Reducing Fuel Consumption). It is therefore interesting the efficiency of fuel use, knowing that usually a high dynamism is accompanied by a low fuel saving.
The specialized literature presents various criteria for assessing the dynamism and fuel saving of vehicles [4]. Similarly, some criteria for assessing energy efficiency can be adopted to assess the use of fuel, and two of them are presented below.
Thus, a first criterion for assessing energy efficiency is the consumption of C_L fuel [milliliters] to obtain a power of 1 kW:

$$k_1 = \frac{C_L}{P_e} \tag{8}$$

whose values are shown in figure 11 for the Volkswagen Touareg II3.0 V6 TDI when traveling in urban and extra-urban areas.
As can be seen from figure 11, on the whole of the tests in the extra-urban environment, 50.3% less fuel is consumed than in the urban environment (12.7 milliliters/kW compared to 19.1 milliliters/kW).

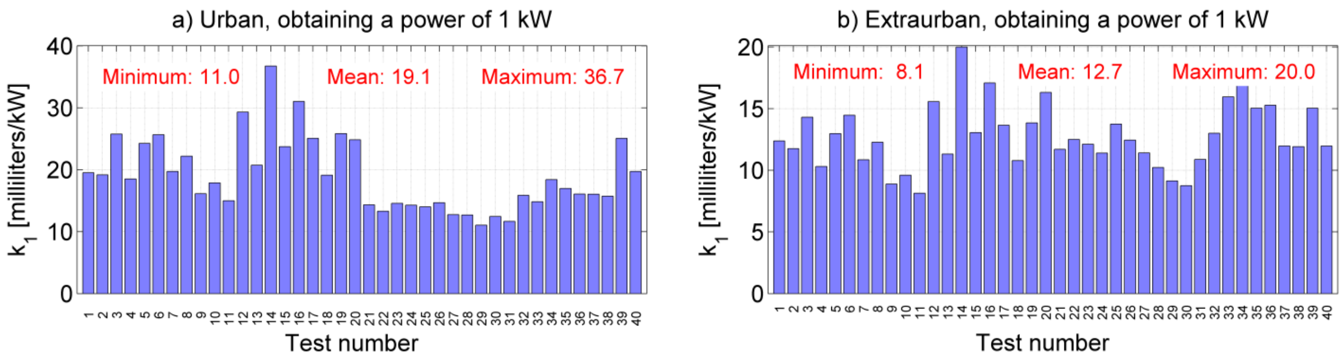

Figure 11. Fuel consumption per engine power unit, Volkswagen Touareg II car

A second criterion for assessing energy efficiency is the consumption of C_L fuel [milliliters] to obtain a torque of 1 Nm:

$$k_2 = \frac{C_L}{M_e} \tag{9}$$

whose values are shown in figure 12 for the Volkswagen Touareg II 3.0 V6 TDI when driving in urban and extra-urban areas.
As can be seen from figure 12, on the whole of the tests in the extra-urban environment, 47.3% less fuel is consumed than in the urban environment (3.8 milliliters/Nm compared to 5.6 milliliters/Nm).
Figure 11 and figure 12 show that when driving in an extra-urban environment, energy efficiency is higher compared to urban areas.
Figure 11 and figure 12 also show that more fuel is consumed per unit of engine power than per unit of engine torque.
Thus, in the urban environment is consumed 3.41 times more, and in the extra-urban environment 3.34 times more fuel.
Similarly, other criteria for assessing energy efficiency can be adopted, which can also be used to optimize it according to the ERFC concept.

ISSN 2457 – 5275 (Online, English)
ISSN 1842 – 4074 (Print, Online, Romanian)

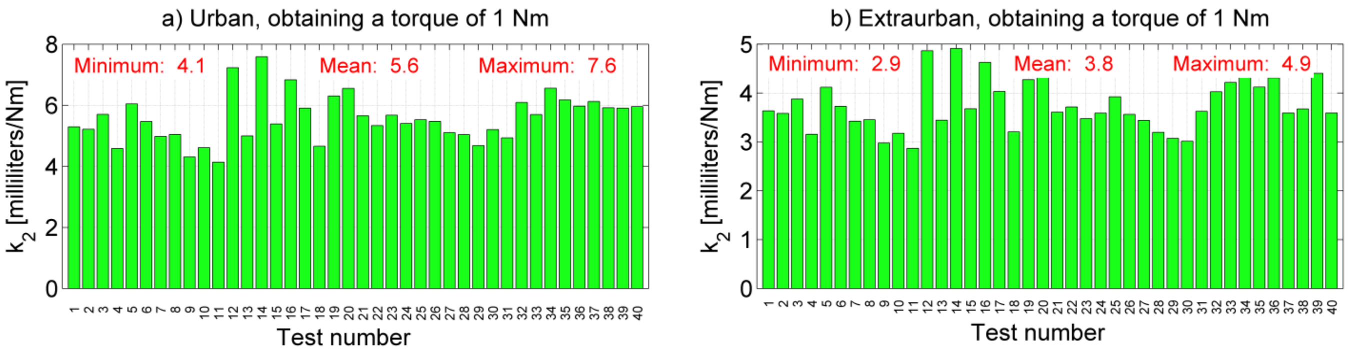

Figure 12. Fuel consumption per engine torque unit, Volkswagen Touareg II car

5. CONCLUSION

Experimental research has shown that in almost all functional regimes the engine operates at partial loads and very rarely at full load.

When driving in extra-urban areas, the values of engine load, engine speed, opening angle of the variable geometry turbine blades, intake air pressure, accelerator pedal position and fuel pressure in the common ramp are higher than in urban areas.

The cyclic fuel flow, the charge of the supercharged air and the opening angle of the turbine blades with variable geometry increase with increasing engine load and speed, and the number of recirculated gases decreases.

In comparison to urban environment, the extra-urban driving is more energy efficient.

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RoJAE
Romanian Journal of Automotive Engineering

AIMS AND SCOPE

The Romanian Journal of Automotive Engineering has as its main objective the publication and dissemination of original research in all fields of „Automotive Technology, Science and Engineering". It fosters thus the exchange of ideas among researchers in different parts of the world and also among researchers who emphasize different aspects regarding the basis and applications of the field.

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The emphasis is placed on contribution that appears to be of permanent interest to research workers and engineers in the field. If furthering knowledge in the area of principal concern of the Journal, papers of primary interest to the innovative disciplines of „Automotive Technology, Science and Engineering" may be published.
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www.ro-jae.ro www.siar.ro
ISSN 2457 – 5275 (Online, English)
ISSN 1842 – 4074 (Print, Online, Romanian)

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Romanian
Journal of Automotive Engineering

ISSN 2457 – 5275 (Online, English)
ISSN 1842 – 4074 (Print, Online, Romanian)

The Scientific Journal of SIAR
A Short History

The engineering of vehicles represents the engine of the global development of the economy.
SIAR tracks the progress of the automotive engineering in Romania by: the development of automotive engineering, the development of technologies, and road transport services; supporting the work of the haulers, supporting the technical inspection and of the garage; encouraging young people to have a career in the automotive engineering and road haulage; stimulation and coordination of activities that promote an environment that is suitable for continuous education and improving of knowledge of the engineers; active exchange of ideas and experience, in particular for students, master students, PhD students, and young engineers, and dissemination of knowledge in the field of automotive engineering; cooperation with other technical and scientific organizations, employers' and socio-professional associations through organization of joint actions, of mutual interest.
By the accession to FISITA (International Federation of Automotive Engineering Societies) since its establishment, SIAR has been involved in achieving an overall professional community that is homogeneous in competence and performance, interactive, dynamic, and competitive at the same time, oriented towards a balanced and friendly relationship between people and the environment; this action will be constituted as a challenge worthy of effort and recognition.
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In order to succeed, ever since its founding, SIAR has considered that the stress should be put on the production and distribution, at national and international level, of a publication of scientific quality.

Under these circumstances, the development of the scientific magazine of SIAR had the following evolution:
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ISSN 1222 – 5142
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Frequency: Quarterly — Electronic publication on: www.ro-jae.ro
Total number of issues: 30 — Type: Open Access
The above constitutes series nr. 1 of SIAR scientific magazine.

2. Ingineria automobilului (in English: ***Automotive Engineering***)
ISSN 1842 – 4074
Period of publication: as of 2006 — Format: print and online, Romanian
Frequency: Quarterly — Electronic publication on: www.ingineria-automobilului.ro
Total number of issues: 59 — Type: Open Access
(including the June 2021 issue)
The above constitutes series nr. 2 of SIAR scientific magazine (Romanian version).

3. Ingineria automobilului (in English: ***Automotive Engineering***)
ISSN 2284 – 5690
Period of publication: 2011 – 2014 — Format: online, English
Frequency: Quarterly — Electronic publication on: www.ingineria-automobilului.ro
Total number of issues: 16 — Type: Open Access
(including the December 2014 issue)
The above constitutes series nr. 3 of SIAR scientific magazine (English version).

4. *Romanian Journal of Automotive Engineering*
ISSN 2457 – 5275
Period of publication: from 2015 — Format: online, English
Frequency: Quarterly — Electronic publication on: www.ro-jae.ro
Total number of issues: 26 (June 2021) — Type: Open Access
The above constitutes series nr. 4 of SIAR scientific magazine (English version).

Summary

Total of series:	*4*
Total years of publication:	*27 (11: 1990 – 2000; 16: 2006 – 2021)*
Publication frequency:	*Quarterly*
Total issues published:	*89 (Romanian), out of which, the last 42 were also published in English*