Automating the assembly process of passenger car gearboxes

ABSTRACT

Aims: The study aims to identify ways and potential solutions to automate the assembly and production process for passenger car gearboxes.
Object of research: assembly and production process for car gearboxes.
Subject of research: modern and evolutionary automation tools that have the potential to be implemented in the assembly processes of automotive transmission controls.
Methodology: To achieve this goal, as part of this study, it is planned to apply methods of bibliometric analysis of leading scientometric databases to obtain correlation relationships and analytical conclusions regarding the vector of development of automation means of passenger car gearbox assembly process.
Results: As a result of the research by means of scientometric analysis and correlation the vector of probabilistic technical solutions of integration and development of automation means of the sequence of production operations during the assembly of the transmission, as well as adaptive framework-design solutions for the implementation of tools of the fourth iteration of industrial-industrial progress in the production processes of assembly of the studied technical control means and logical-technological connection of the elements of the transmission system, which affect the overall process of automotive manufacturization.
Conclusion: The passenger car gearbox is a multi-component, complex system whose assembly is a complex multi-operational process, and given the high responsibility of this machine element, there is an urgent need to introduce modern automation tools into the assembly and production processes, which will significantly optimize global automatofactoring. The practical results of the present study consist in the formation of a focus scientometric database of profile data, identification of a potential vector of development of means and systems of automation of assembly-production operations, identification and formation of solutions for the implementation of modern means of automated production in the actual global automotive manufacturing, which allows to get the optimum ratio of production costs/quality of products by improving the manufacturability, productivity and flexibility of processes of assembly of multi-element and multi-component automotive systems and structures.

Keywords: Autoproduction, Automanufacturing, Autoline, Robotics, Machine Vision, Machine Learning.

1. INTRODUCTION

The relevance of this study lies at the intersection of the vectors of economic development and technological progress caused by the fourth wave of the industrial-industrial revolution: the leading auto-industrial manufacturers are in a constant search for the optimal balance between the quality, reliability, and manufacturability of mobile means of transportation produced, and the costs of the production process (from design and production to testing and sales).

Nowadays, it is impossible to imagine modern civilization without such a commonplace thing as an automobile means of transportation (both group and personal, including At the same time, profile organizations like MarkLines [1], ACEA [2, 3], Trading Economics [4], OICA [5], Statista [6], U.S. Department of Transportation [7], SMMT [8] (etc.), in the twenty-year horizon, statistical analysis indicates a 42, 9% growth in global production of automotive equipment (2001 - 56, 0 million units / 2021 - 80 million units) / 2021 - 80 million units), however, the global automotive industry is currently in recession after a production peak in 2017-2018 (up to 97 million units annually), indicating the transformation of the studied industry caused by the integration of modern factors into the automotive production process: tightening requirements for the cost/quality balance (S. E. Gayiya [9]), tightening of environmental requirements and standards (M. Hirz [10]), tightening of requirements to increase the qualification background of the involved specialists and exclusion of "human" defect factors of car production (J. Reimer [11]), reprofiling of production focus on production with modern technological equipment (E. Shafiei [12]), toughening of safety qualities of produced automotive products, which requires integration into the production process of additional testing activities and inspections (S. König [13]), as well as other aspects caused by the global changes in the general concept of world manufactoring (H. A. Khan [14]) as an adequate response to the technological progress caused by the fourth wave of industrialization (L. Athanasopoulou [15], T. Papadopoulos [16], T. C. Ng [17] (et al.)).

The main strategy of modern autoproduction is to obtain an optimal cost/quality balance by implementing modern tools of the fourth iteration of industrial and technological progress, at that one of the fundamental industrial tools is automation (J. Soldatos [18], H. Parmar [19], M. Ammar [20] (etc.)). The introduction of automation in the production of motor vehicles is a promising direction for obtaining a cost/quality balance, so according to the research Z. Papulová [21] established the growth of the implementation of automation of Industry 4.0 in the production and technological processes of the leading car manufacturing companies, according to the research C. Guo [22] noted the high potential of the integration of robotics as the main process of automated automotive production, the research M. Hofmann [23] showed that the automotive manufacturing processes are currently transforming by integrating modern automation tools, which leads to a complete change in the paradigm of automotive production, etc. One of the responsible technological multi-component elements is the vehicle gearbox (which exceptional importance is confirmed by the relevant research reflected in the publications of Y. X. Li [27], J. A. Dhanraj [28], X. Liu [29], E. Abboud [30]), for the production of which, as well as for all machine production, the development, and implementation of adaptive solutions that allow to achieve an optimal cost/quality ratio, including through the integration of the developing tools of Industry 4.0 automation. As part of this study, it is planned to use scientometric tools to determine the vector of development of gearbox assembly process automation tools and identify potential solutions that will improve the manufacturability, productivity, flexibility of automated production lines with the appropriate provision of an optimal cost/quality ratio.

2. MATERIAL AND METHODS

In this study methods of scientometric search and analysis are used. This includes identifying and predicting the most likely, optimal, and potential direction of development in addressing the integration of Industry 4.0 automation tools in automotive industry processes, in particular in the sequence of assembly-production operations of passenger car gearboxes. In order to achieve the goal, it is proposed to use the following plan (sequence of stages) of research shown in Table 1.

Table 1. Research plan

Number of stage	**Name of the stage**	**Research operations**
1	Research object analysis	analysis of functional and technological purpose, median-generalized technological and design solutions on the device and the principles of direct operation, the nature of modern assembly and manufacturing process
2	Research subject analysis	assessment of the level of technological development of automation tools that have the potential to be implemented in the sequence of assembly gearbox technology
3	Bibliometric analysis	analysis of leading scientometric databases regarding the problems of development and implementation of automation systems and tools in automobile manufacturing and gearbox production
4	Correlative analysis using taxonometric tools	identification of vectors and horizons of potential technological solutions in the implementation of systems and means of automated assembly production of motor vehicles and the studied means of controlling the automobile transmission functioning
5	Analytical conclusions	drawing conclusions about the extracted information and scientometric correlative data horizon followed by the formation of framework-design solutions for the integration of potential automation technologies in the assembly process of passenger car gearboxes
6	Generalized conclusions and results	Formation of generalized conclusions and results with the identification of further expedient ways in the development of the specified research vector

The presented sequence of research operations is aimed at forming a database focusing on research object and subject with the identification of vectors and horizons of technological solutions development in increasing the level of automation of automotive production through the integration into the technological production operations of the modern tools of the fourth iteration of industrial-industrial progress. It potentially determines the overall paradigm of production processes not only the automotive industry (in particular with respect to the production of the automotive industry), but the entire field of automated and robotic global manufacturing. Collection, analysis, systematization of disparate data presented in the leading scientometric databases will allow to form an appropriate factorial background, based on which it is already possible to obtain analytical-correlative conclusions regarding the goals and objectives of the study with the potential possibility to determine probabilistic vectors of development of diffusion interaction between the automotive industry and the branch of automation, auto-mechanization, and robotization systems. The methodology includes elements of scientometric analysis. It will reveal the level of scientific coverage of the problems systems integration and means of automation of technological processes of automotive production, as well as determine the subsequent evolutionary milestones of a given research vector, which has practical results and interest for all manufacturing industries in the process of transformation with the transition to automated manufacturing technological operations.

3. RESULTS

Transmission is a responsible technological element of propulsion systems of the car, carrying out the logical-structural connection between the engine and transmission system. It allows to expand the functionality of the motor unit car by multidirectional reduction of power coming from the engine to the transmission system, gear ratio control, increasing the operating range of speed and torque, providing idling and reversing the motion of the vehicle (Fig. 1) [31-35].

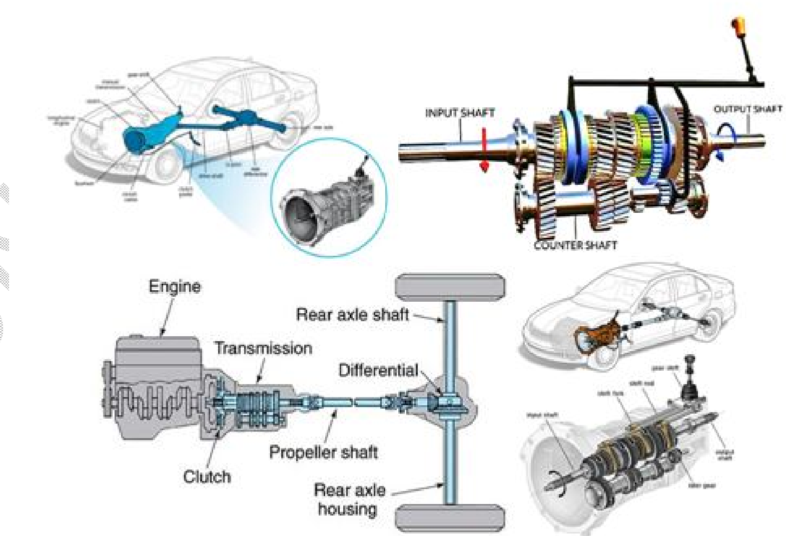

Fig. 1. Conceptual representation of the structural arrangement of the control gear in the transmission system of a car

In accordance with the data presented in Fig. 1, it is possible to establish that the unitary-medium performance of the gearbox of a motor vehicle is performed in the form of a separate box (crankcase), in which the gears and shafts of the mechanical gears are in working engagement, the principle of reduction of engine power which is shown in Fig. 2.

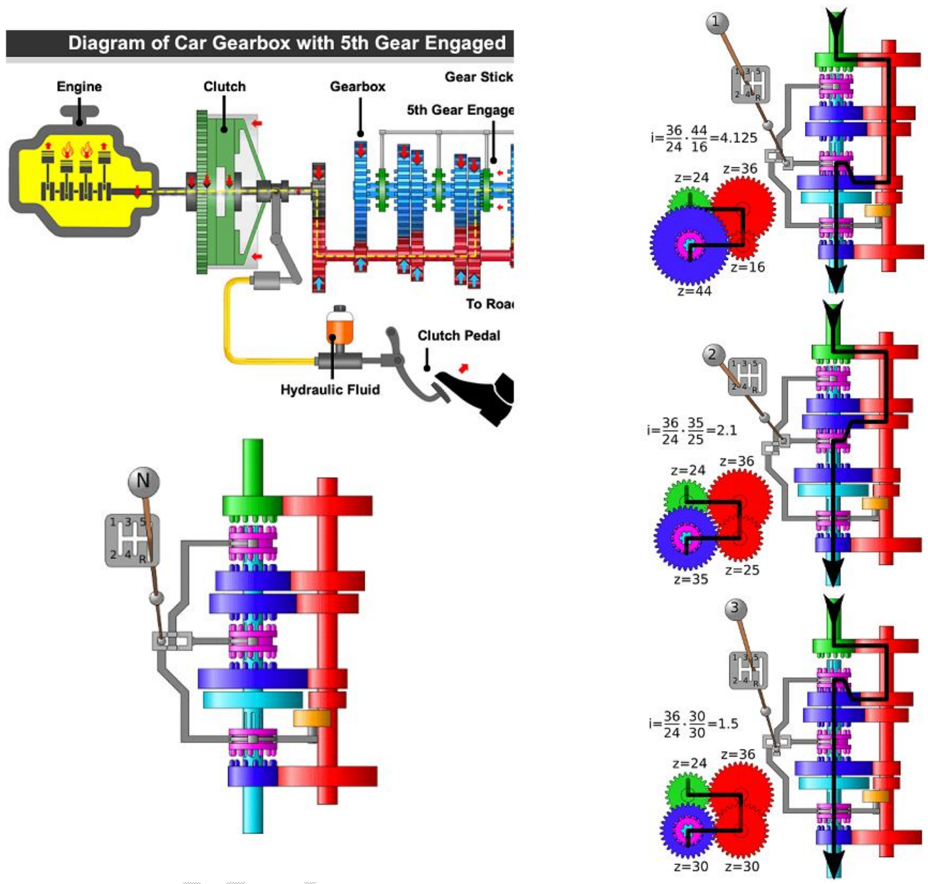

Fig. 2. Visualization of the engine power reduction process by establishing the characteristic working gears on the example of a 5-speed gearbox of a passenger car transport vehicle [31-35]

According to the research of Y. Chen [31], currently the global automotive industry produces three technological and structural versions of manual transmission (MT), automatic transmission (AT) and neighborhood electric vehicle (NEV). (Fig. 3), and currently prevailing are gearboxes series AT6/7/8, and by 2030 planned to increase production of AT9/10 series (Fig. 4), which is due to increasing demands on economic (the introduction of optimal energy-balanced modes of “engine + transmission” system functioning) and environmental (implementation of solutions and activities aimed at decarbonization of the system “engine + transmission” functioning) requirements. Thus, it is established that the gearbox is a multi-component responsible transmission unit, which potentially leads to emergency failure of vehicle subsystems (with the corresponding destructive consequences). As a result, there is an urgent need to find, develop and create effective solutions to improve the quality of the production process, in particular by automating the assembly and production operations (Fig. 5).

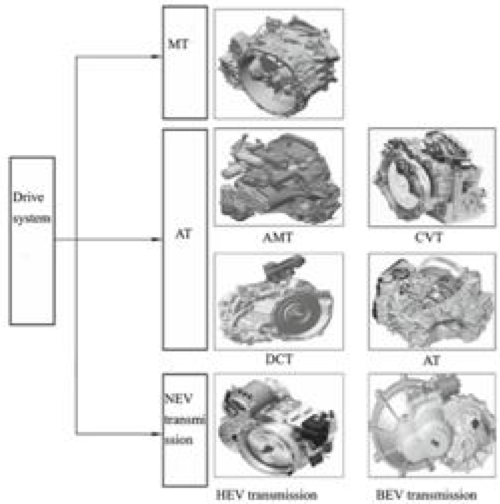

Fig. 3. The main directions of techno-constructional implementation of the gearbox of passenger cars highlighted in the study of Y. Chen [31]

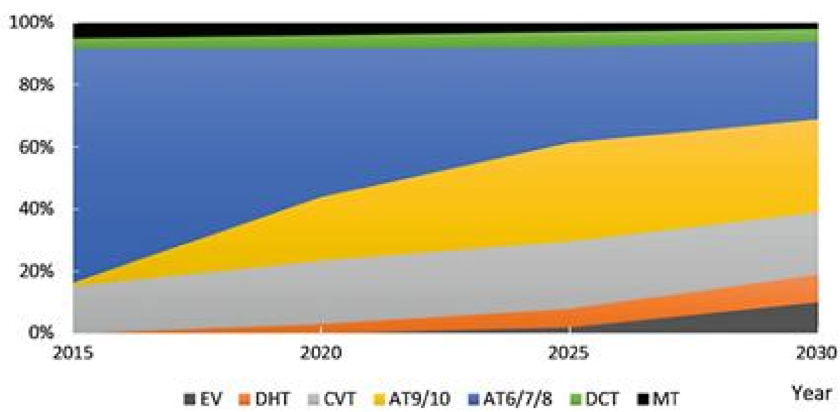

Fig. 4. Production structure of the main product range of gearbox in the global automobile manufacturing according to the assessment of Y. Chen [31]

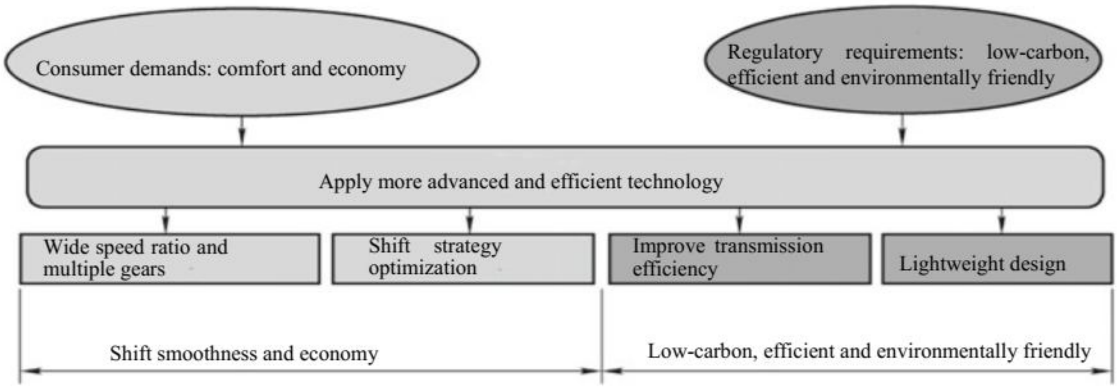

Fig. 5. The goals and requirements for the techno-constructive gearbox performance highlighted by Y. Chen [31]

Global auto-factoring and auto-production in the production of light motor vehicles since 1903 came to the use of a flow method of production on assembly lines [36-42]. The formation of typical operating cycles in the mass automobile production process led the leading automobile concerns to the use of production and assembly lines, which initially functioned with the participation of workers. In the process of industrialization and development of the technological effectiveness of the indicated automotive lines, which was an adequate response to the increase in technical complexity and quality of produced automotive vehicles, conditions for the implementation of automation and robotization means and systems in the assembly and production process were formed [36-42] (Fig. 6):

- condition of typing of techno-industrial operation: when applying techno-industrial processes typical operations that require repetition, it is advisable to use robotization/automation means, which allows significantly reduce the impact of the attention reduction factor when performing the specified functions by employees in working order, which directly affects the quality of the ongoing technological process and safety of workers, whose ability to monotonous work is lower than that of robotic-mechanized systems and tools, resulting (for the two reasons described) and leads to the impact on the economic performance of automotive production;

- condition of increased accuracy of technological and industrial operations: robotic complexes, systems, and tools have a clear coordinate positioning system, therefore (in the case of the correct task of the production algorithm by creating an appropriate service software-operational sequence) significantly reduces the possibility of errors and errors in the execution of the industrial process, which also affects the economic efficiency of the latter;

- condition of increased productivity: if it is necessary to organize a typical industrial process, the basis of which are typical monotonous operations with high intensity of performance, it is advisable to use robotic means, which at lower probability of errors and uncertainties, capable of effectively performing the specified techno-industrial operations with high intensity for a long time;

- safety condition of implementation of technological and industrial process: in case of necessity to perform technological and industrial operations in the environment hazardous for the working personnel, it is reasonable to apply the advantages of robotic systems and complexes that do not require strict compliance with industrial hygiene and normative conditions of organization of working process, and also can be specially designed for the relevant conditions hazardous for the workers. In this case, the goal is achieved not only in the continuation of production processes in adverse conditions but also in compliance with industrial safety by preserving the personnel involved in the production processes.

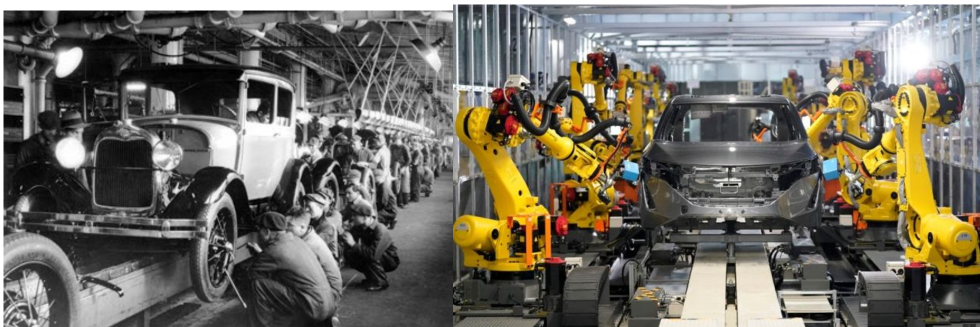

Fig. 6. Conceptual scheme of auto-production line functioning with the allocation of logical-technological flows of assembly-production processes [43-48]

For the studied element of the automobile transmission the gearbox currently uses methods of semi-automatic machine-human assembly [31-35, 50] (Fig. 7).

Fig. 7. Visualization of the modern sequence of assembly-technological operations for the control of a passenger car, presented on the electronic resource [50]

The lack of widespread use of automation and robotization in the process of assembly production of passenger car gearboxes is caused primarily by a significant number of components of the studied transmission unit, which is illustrated by the example of a 5-speed gearbox model of a passenger car transport vehicle [51-56] (Fig. 8, Table 2).

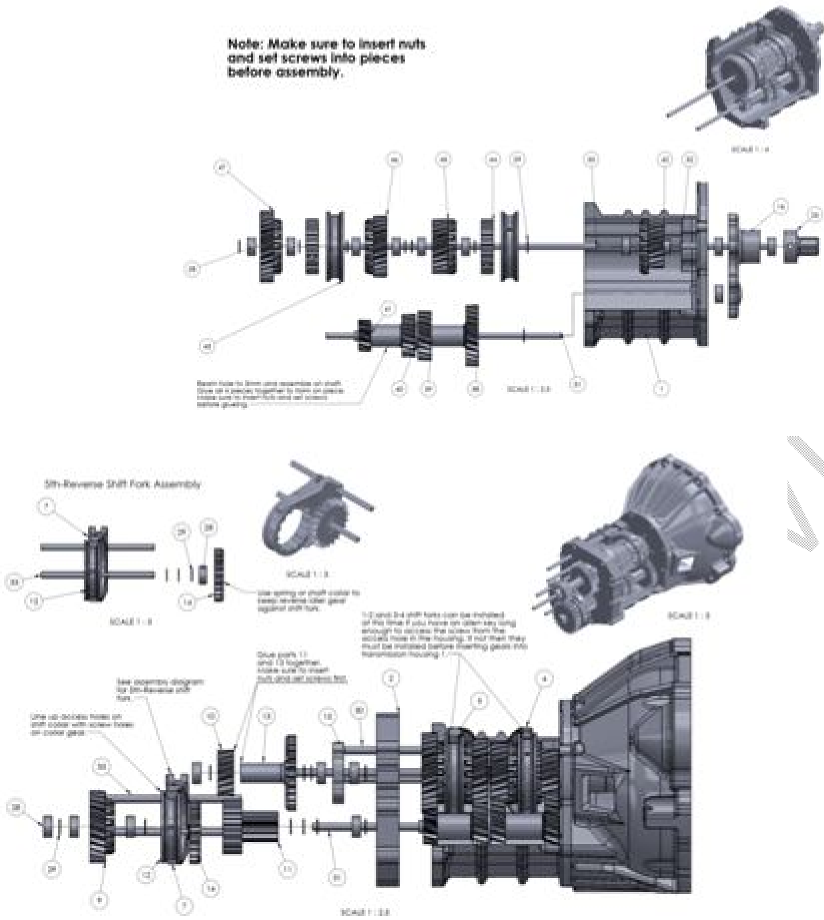

Fig. 8. Nomenclature and specification analysis of the component composition of the 5-speed transmission of passenger cars [51-56]

The specification of the component composition of the transmission is presented in Table 2.

Table 2. Specification of component composition of a 5-speed gearbox of a passenger car transport vehicle [51-56]

ITEM NO.	PART NUMBER	QTY.
1	Transmission housing 1	1
2	Transmission housing 2	1
3	Transmission housing 3	1
4	3-4 shift collar fork	1
5	1-2 shift collar fork	1
6	1-2 shift fork	1
7	5-R shift fork	1
8	3-4 shift fork2	1
9	Gear 5 Counter shaft	1
10	Gear 5 Top	1
11	Shift collar gear - 5th	1

12	5th gear Shift collar	1
13	Reverse Gear	1
14	Reverse idler	1
15	Transmission housing 2 bearing retainer	1
16	Front bearing retainer	1
17	Bell housing	1
18	Output shaft	1
19	Shift linkage	1
20	Shifter base	1
21	Shifter base 1	1
22	Shifter base 2	1
23	Shifter ball top	1
24	Shifter ball bottom	1
25	Transmission housing 3 - Shell - cover	1
26	input shaft	1
27	Transmission housing 1 Cover	1
28	623zz bearing	18
29	3mm washer	20
30	1-2 and 3-4 shift rail	2
31	Counter Shaft	1
32	Input Shaft-	1
33	Reverse idler - 5th gear shift rail	2
34	Shifter	1
35	Top Shaft	1
36	Shift Linkage 2	1
37	Shift Linkage 3	1
38	Gear 1 Counter shaft	1
39	Gear 2 Counter shaft	1
40	Gear 3 Counter shaft	1
41	Gear 4 Counter shaft	1
42	Gear 1 Top	1
43	Shift collar	2
44	Shift collar gear	2
45	Gear 2 Top	1
46	Gear 3 Top	1
47	Gear 4 Top	1

Completion of passenger car gearbox assemblies is illustrated in Fig. 9, which shows a model representation of the transmission unit under study and was made in a simulation software environment [51-56].

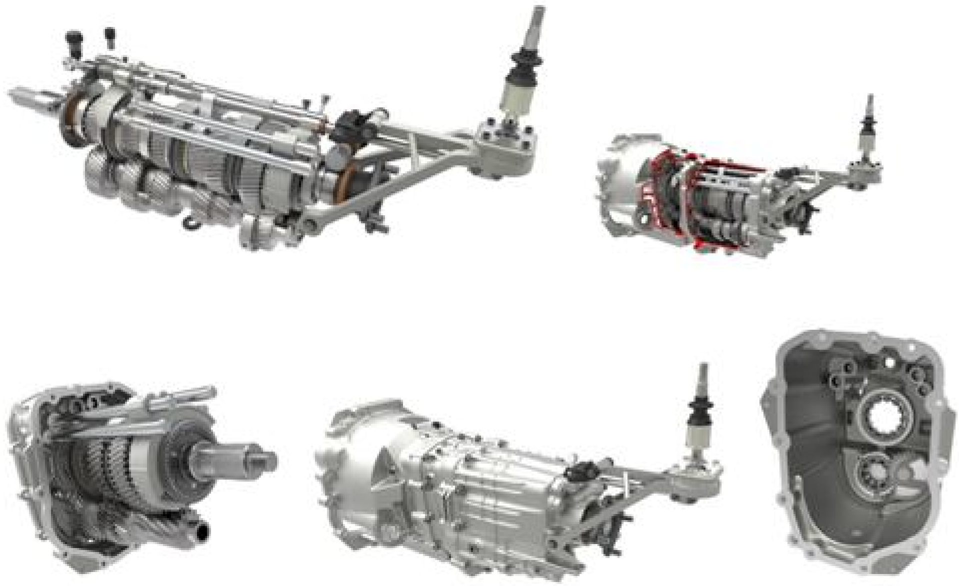

Fig. 9. Illustration of the enlarged assemblies of the control unit of a passenger car transport vehicle [51-56]

On the basis of the nomenclature and specification analysis of the component design of the studied transmission unit of a passenger car vehicle, we come to the conclusion about the significant number of technological components, for the assembly and adjustment of which it is necessary to involve highly specialized specialists. In this case, according to the median data on the organization of the modern assembly process for the passenger car gearbox, presented on an electronic resource [50] in the form of an appropriate video clip, we state that at the present stage of technological development, it is impossible to organize a fully automated sequence of assembly-technological operations on the device of the studied transmission unit. Moreover, it is necessary to involve human resources, and from the means of automation, it is possible to use semi-automatic devices and systems of controlled unit assembly. Thus, there is a scientific problem in finding the possibility of full-featured automation of assembly and technological processes for the device controlling the transmission of a passenger car.

In order to identify the vector of scientific search in solving the problem of integration of fully automated assembly processes of a passenger car drivetrain, using the bibliometric tool VOSviewer [57], we perform a correlative scientometric analysis of profile publications on leading scientometric databases in the five-year (2017/2022) search horizon for several iterations of the correlation of taxonometric units of gearbox auto-linear assembly technology and methods brought by the fourth wave of industrial progress. Iteration 1 (Fig. 10) contains a correlative scientometric analysis with a focus on the passenger car transmission unit under study, the gearbox; subsequent iterations 2-5 (Figs. 11-14) provide a co-correlative taxonometric analysis regarding the integration of Industry 4.0 tools, which identifies potential vectors for the development of full-cycle, full-featured automation tools in automotive passenger car drivetrain manufacturing.

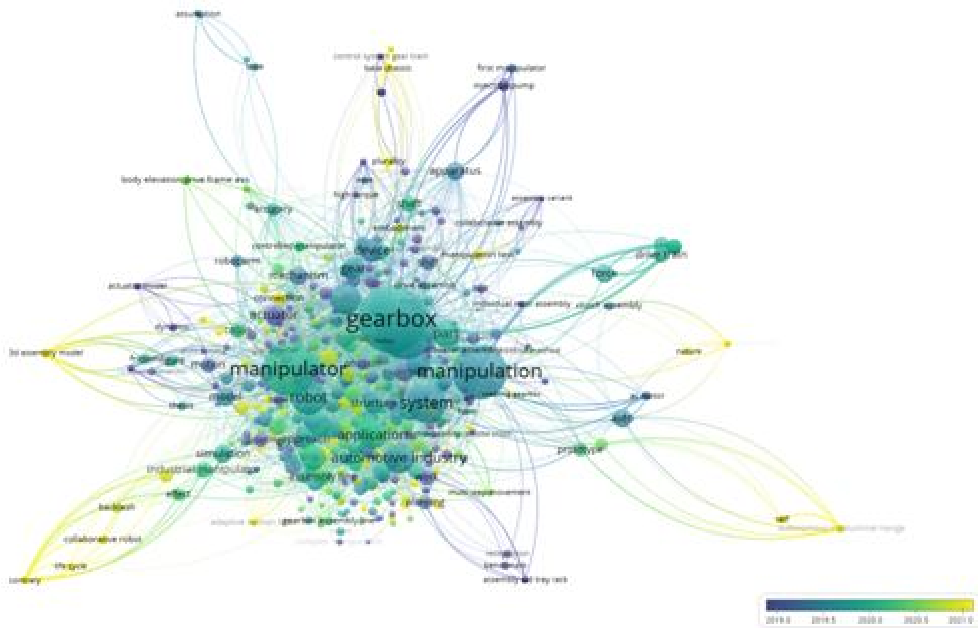

Fig. 10. Bibliometric analysis of the correlation of taxonometric units of gearbox autolinear assembly technology and methods brought by the fourth wave of industrial progress by leading scientometric databases in a five-year (2017/2022) search horizon using the VOSviewer toolkit [57] - 1 iteration

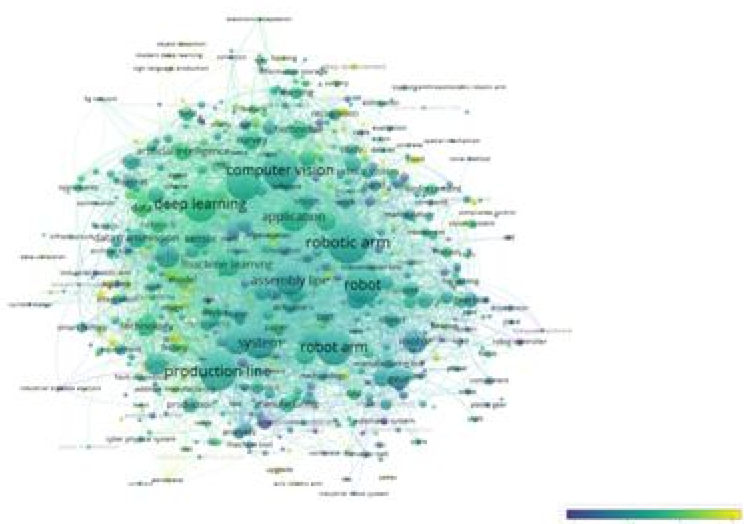

Fig. 1. Bibliometric analysis of the correlation of taxonometric units of gearbox autolinear assembly technology and methods brought by the fourth wave of industrial progress by leading scientometric databases in a five-year (2017/2022) search horizon using the VOSviewer toolkit [57] - 2 iteration

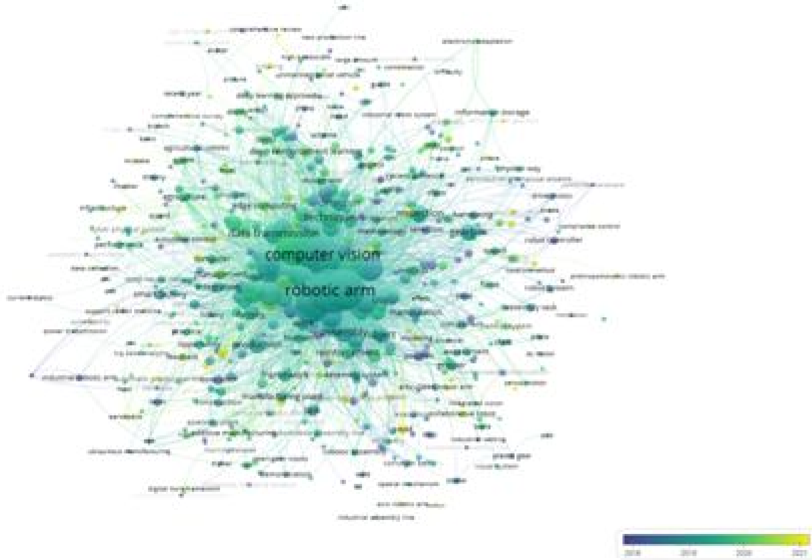

Fig. 12. Bibliometric analysis of the correlation of taxonometric units of gearbox autolinear assembly technology and methods brought by the fourth wave of industrial progress by leading scientometric databases in a five-year (2017/2022) search horizon using the VOSviewer toolkit [57] - 3 iteration

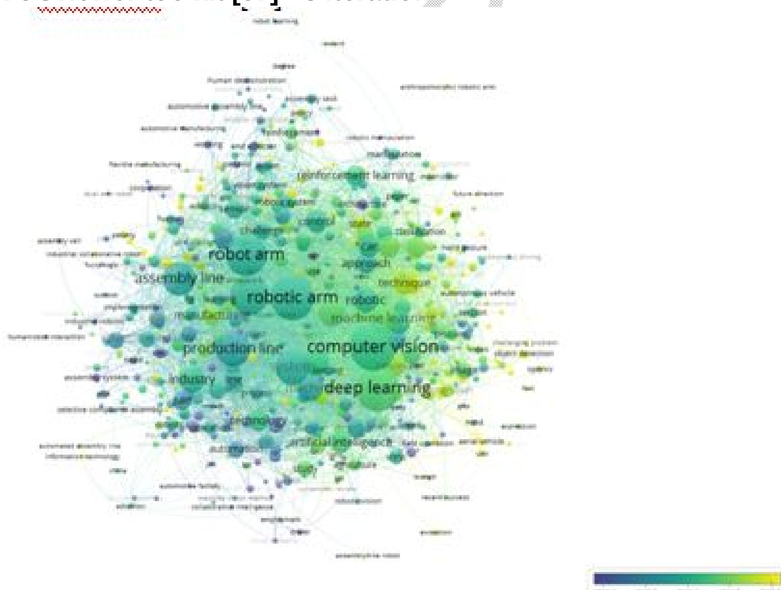

Fig. 13. A bibliometric analysis of the correlation of taxonometric units of gearbox autolinear assembly technology and methods brought by the fourth wave of industrial progress by leading scientometric databases in a five-year (2017/2022) search horizon using the VOSviewer toolkit [57] - 4 iteration

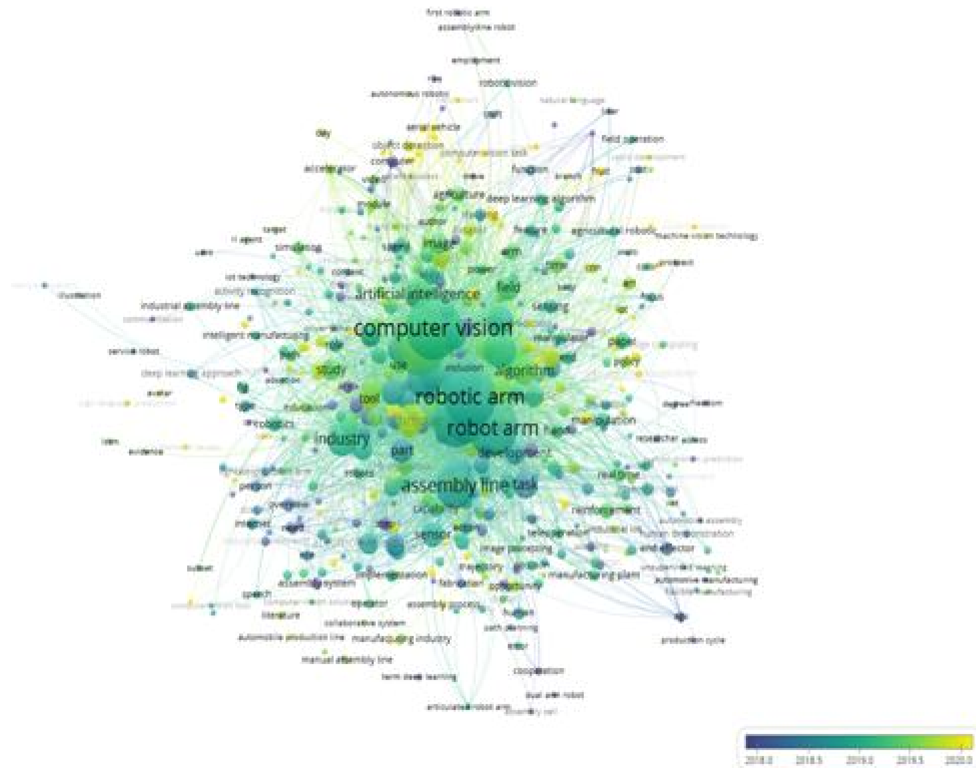

Fig. 14. A bibliometric analysis of the correlation of taxonometric units of gearbox autolinear assembly technology and methods brought by the fourth wave of industrial progress by leading scientometric databases in a five-year (2017/2022) search horizon using the VOSviewer toolkit [57] - 5 iteration

On the basis of the bibliometric analysis of leading scientometric databases regarding the adopted research direction it was established:

- vector of scientific search concerning the implementation of full-cycle and full-featured automation of the assembly and technological process on the passenger car control unit (iteration 1, Fig. 10) is aimed at using robotic means, in particular, robotic complexes equipped with manipulators, while, as indicated earlier, there is a problem of complexity of organization and implementation of the positioning of robotic means of automatic assembly, due to the complexity and multi-componentness of the studied transmission;
- a co-correlated taxonometric analysis regarding the integration of Industry 4.0 tools in automotive passenger car manufacturing (iterations 2-5, Figs. 11-14) indicate possible ways of solving the problem identified in iteration 1 regarding the implementation of full-cycle and full-function automation of the assembly and manufacturing process for passenger car gearbox device, among which the potential ones are, implementation and development of such tools of the fourth wave of industrial progress as machine vision, machine learning, artificial intelligence.

Based on the conducted scientific search, the scientific problem regarding the implementation of full-cycle and full-featured automation of the assembly and technological process on the control device of a passenger car, which is based on the limitations of the existing robotic manipulators of the assembly lines of automotive products, was identified.

Also, subsequent iterations of the scientometric search and analysis, allowed to identify potential solutions to the identified scientific problem through the integration into the assembly-production processes of automation means of the fourth wave of industrial progress.

4. DISCUSSION

As a result of the research on a given research vector, the expected results in terms of the implementation of full-cycle and full-featured automation of the assembly and technological process of the passenger car control unit have been established:

- formed a scientific problem in the search for the possibility of automating the assembly and production operations on the control device of a passenger vehicle by robotic means (iteration 1, Fig. 10), which correlates with the results of scientific research of the authors M. Bilal [58], J. A. P. Pereira [59], J. Jiang [60] and others;
- a co-correlated taxonometric analysis regarding the integration of Industry 4.0 tools into the autolinear manufacturing of passenger cars (iterations 2-5, Fig.s 11-14) established potential ways of solving the identified technical and research problems - implementation, adaptation to the conditions of autolinear production and development of systems and tools of the fourth wave of industrial and technological development: machine vision (which correlates with the results of scientific research of authors M. Javaid [61], A. Charan [62], P. Kumar [63], etc.), machine learning (which correlates with the results of research by authors B. Nemec [64], N. S. Solke [65], P. Dobra [66], etc.) and artificial intelligence (which correlates with the results of research by the authors A. Manimuthu [67], S. S. Kamran [68], R. Bogue [69] and others).

Thus, by means of scientometric search and analysis, the problems and solutions in the organization and implementation of full-cycle and full-function automation of the sequence of assembly and production operations for the passenger car gearbox assembly are established, the focus of which is to develop solutions for potential integration of robotic automation tools equipped with systems and tools that are Industry 4.0 products into the studied industrial processes for the assembly of the transmission unit.

A search of open sources confirmed the scientific findings of this study, which were implemented by IBG [70] as an industrial prototype of a full-cycle and full-function automation process for passenger car transmission assembly. According to the limited description of IBG [70] (due to trade secrets), the developed automated system for the implementation of the assembly-production process for the passenger car gearbox device has the following aspects of operation (Fig. 15):

- solution: A total of six cameras capture the position of the drive disc and transmission shaft for precise positioning of the transmission according to two- and three-dimensional measured values. With the robot, for the first time in the automotive industry, the engine and transmission are connected to each other in a torque-dependent manner;
- system advantages: in addition to the high degree of automation, the system also offers a more humane and safer workplace. The precision of the automatic assembly offers quality advantages for the service life and noise reduction of the following vehicle.

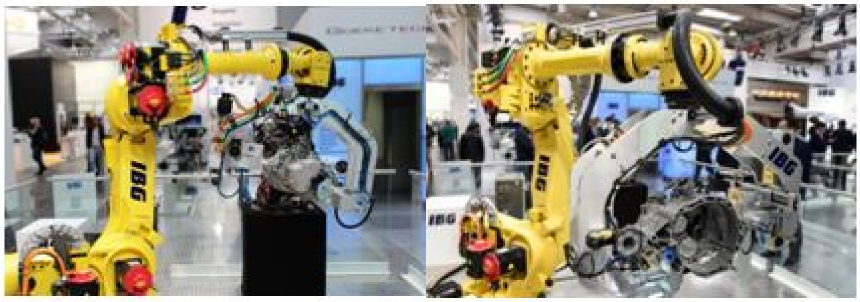

Fig. 15. Prototype of a robotized full-cycle and full-function automated passenger car transmission assembly system developed by IBG [70]

Based on the limited open access data provided by IBG [70], we conclude that the prototype assembly robotic arm has an advanced precision positioning system, the functioning of which is impossible without ensuring the integration of Industry 4.0 tools: the prototype robotic arm is equipped with an effective machine vision system with AI control elements in the general development of learning by machine learning technology. The obtained search results complement the results of the scientometric analysis and confirm the identified scientific problem and potential ways to solve it.

5. CONCLUSION

Based on the conducted research, the results that meet the initially set objectives in terms of identifying potential solutions for the implementation of full-cycle and full-featured automation of the assembly and technological process for the device control of a passenger car, which are expressed in the following analytical conclusions:

- multicomponent composition of the studied transmission unit of passenger car vehicles creates technical difficulties in the organization and implementation of full-cycle automation of the assembly process, which is the root of the identified scientific problem;

- the results of the scientometric analysis of the correlation of taxonometric units of gearbox auto-linear assembly technology and methods, which brings the fourth wave of industrial progress on the leading scientometric databases in the five-year (2017/2022) search horizon using the VOSviewer tool [57] allows us to identify potential ways of solving the identified scientific and technological problem, which involve the introduction of improved tools and systems of automated robotization equipped with samples of tools of the current level of technological development Industry 4.0: machine vision, machine learning and general control of robot manipulator positioning in the production of assembly and production operations by elements of AI.

The next stage of research in the given vector of research is the formation of detailed mechanisms of implementation and adequate adaptation of potential Industry 4.0 tools in the mechanical assembly process of the passenger car control unit.

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