Technologia i Automatyzacja Montażu

Volume 127, Issue 1/2025, Pages 3-12
https://doi.org/10.7862/tiam.2025.1.1

Original Research

ROBOTIC ASSEMBLY AND TESTING LINE FOR DAMPERS AND GAS SPRINGS AS A UNIVERSAL SOLUTION FOR TIER 1 MANUFACTURERS

ZROBOTYZOWANA LINIA MONTAŻU I TESTOWANIA AMORTYZATORÓW ORAZ SPRĘŻYN GAZOWYCH JAKO UNIWERSALNE ROZWIĄZANIE DLA PRODUCENTÓW TIER1

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Abstract

The production of automotive dampers and gas springs involves many identical processes and is often carried out by the same manufacturers. These manufacturers, in turn, seek lines and machinery that offer efficiency and versatility, while also raising their expectations regarding the quality and accuracy of inline testing processes. This paper presents, in diagram form, the key operations in the production processes of dampers and gas springs and also revisits one of the definitions of Technology Readiness Level (TRL). It describes the primary types of automated line and machine solutions in practice by Tier 1 manufacturers. The compilation concludes with a description of the outcomes of the R&D project POIR.01.02.00-00-0056/18-00 – 'Development of a Product Innovation in the Form of an Advanced Production Line for the Assembly and Testing of Dampers and Gas Springs for Use by International Tier 1 Component Manufacturers in the Automotive Sector.' The outcome is a production line consisting of compatible elements integrated via robotics: a damping force characteristic tester for dampers and gas springs, a gas filling and damper sealing device integrated with the damping force tester, and a gas filling and gas spring sealing device, also integrated with the damping force tester. The article includes the main project goals, an review of competing solutions, and an available patent review.

Keywords: gas springs, dampers, production lines, robotization

Streszczenie

Wytwarzanie amortyzatorów samochodowych i sprężyn gazowych zawiera wiele tożsamych procesów i często jest prowadzone przez tych samych producentów. Ci z kolei poszukują linii i maszyn cechujących się wydajnością i uniwersalnością, a także podwyższają swoje oczekiwania jeśli chodzi o jakość i dokładność procesów testowania inline. Niniejsze opracowanie opisuje w postaci diagramów najważniejsze operacje w procesach produkcji amortyzatorów i sprężyn gazowych a także przypomina jedną z definicji poziomu dojrzałości technologicznej (TRL). Opisano najważniejsze typy rozwiązań zautomatyzowanych linii i maszyn w praktyce producentów Tier1. Prezentowane zestawienie zamyka opis efektów prac nad projektem badawczo-rozwojowym POIR.01.02.00-00-0056/18-00 – „Opracowanie innowacji produktowej w postaci nowatorskiego ciągu technologicznego do montażu i testowania amortyzatorów oraz sprężyn gazowych, do zastosowania u międzynarodowych producentów komponentów na poziomie Tier1 w branży automotive". Efektem tym jest ciąg technologiczny składający się z kompatybilnych elementów zintegrowanych za pomocą robotyzacji: testera charakterystyki siły tłumienia dla amortyzatorów oraz sprężyn gazowych, urządzenia do napełniania gazem i zamykania amortyzatorów zintegrowanego z testerem charakterystyki siły tłumienia oraz urządzenia do napełniania gazem i zamykania sprężyn gazowych zintegrowanego z testerem charakterystyki siły tłumienia. W artykule uwzględniono główne cele projektu, analizę rozwiązań konkurencyjnych i dostępną analizę patentową.

Słowa kluczowe: sprężyny gazowe, amortyzatory, linie produkcyjne, robotyzacja

1. Introduction

The practice of the manufacturer of machines and devices shows that the needs of most customers are generally met by defining the production process as a sequence of operations (Fig. 1). The purpose of this sequence is to manufacture a product in proper way using various types of resources. The beginning of the production process can be defined as the moment of delivering materials (raw materials, semi-assembled products) to the first production station. Then a cycle of processing and machining operations takes place, following which the subassemblies are merged into the final product. The last phase of the production process is to perform quality control of the received product (Helmann 2013, Liwowski, Kozłowski 2011). Partial quality control also occurs on earlier steps in the form of supervisory vision system for assembly correctness checks.

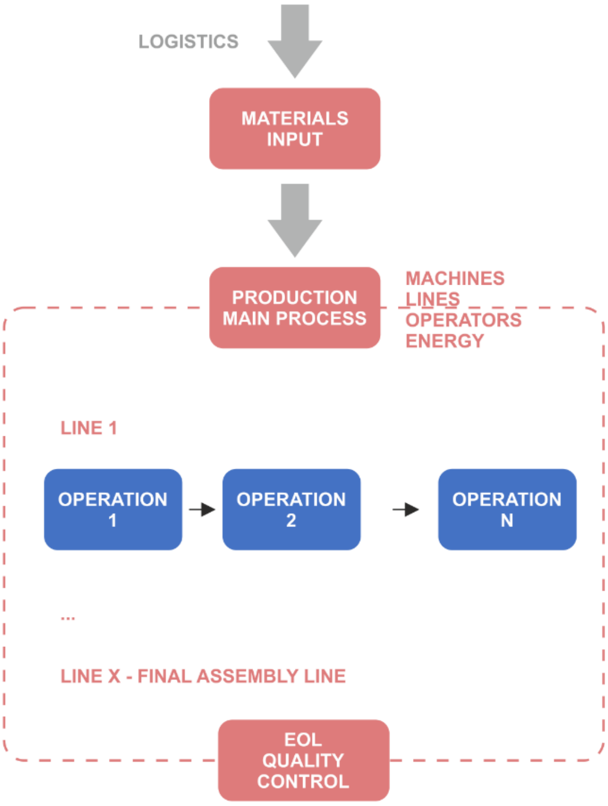

Fig. 1. Production process description example

Processing operations are a set of various production activities: screwing, crimping, welding, soldering, fitting, applying, etc. Many criteria for divisions and resources used can be entered here. Most often, they create a certain logical sequence resulting from previous research and development work on a specific product or group of products for which a given line is intended. At the stage of designing such a line or individual machines – at least a digital model of the target product already exists. This results in the parameters that the future line must handle. It is also necessary to take into account auxiliary processes that will run in parallel with the main production process, e.g. maintenance of traffic, i.e. meeting specific HMI and service standards (Nag, 2023). An important issue is ensuring a specific process stability described by the cycle time, number of pieces in time, etc. (Mazurczak, Gania 2008). Here, customers are increasingly reaching for smart factory-type IT tools that ensure traceability and predictive maintenance (Bortolini, Ferrari, Gamberi, Pilati, Faccio, 2017).

1.1. Production processes of a damper and gas spring

The production process of a damper or gas spring (Fig. 2) can also be described in this way, starting from cutting and forming the tubes, up to functional tests, assembling elements and packaging. In both cases, the process is similar, but there several differences, which are shown in Fig. 3 and Fig. 4.

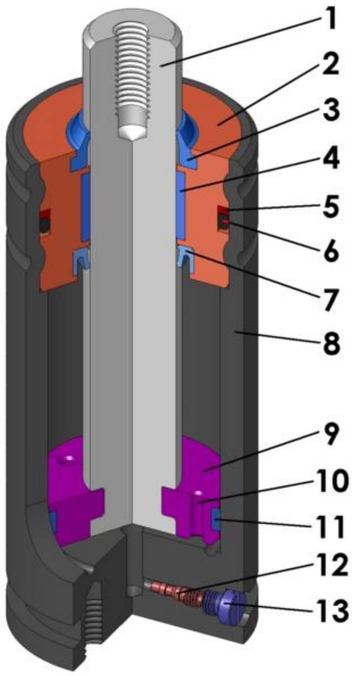

Fig. 2. 3D-view of a gas spring with sectional view (Silberwolf, 2007). 1) Piston rod; 2) Head cap; 3) Piston rod wiper; 4) Piston rod guide bushing; 5) Retaining ring; 6) O-ring; 7) Piston rod seal; 8) Cylinder; 9) Piston; 10) Flow-restriction orifice; 11) Piston guide bushing; 12) Valve; 13) Valve-sealing screw

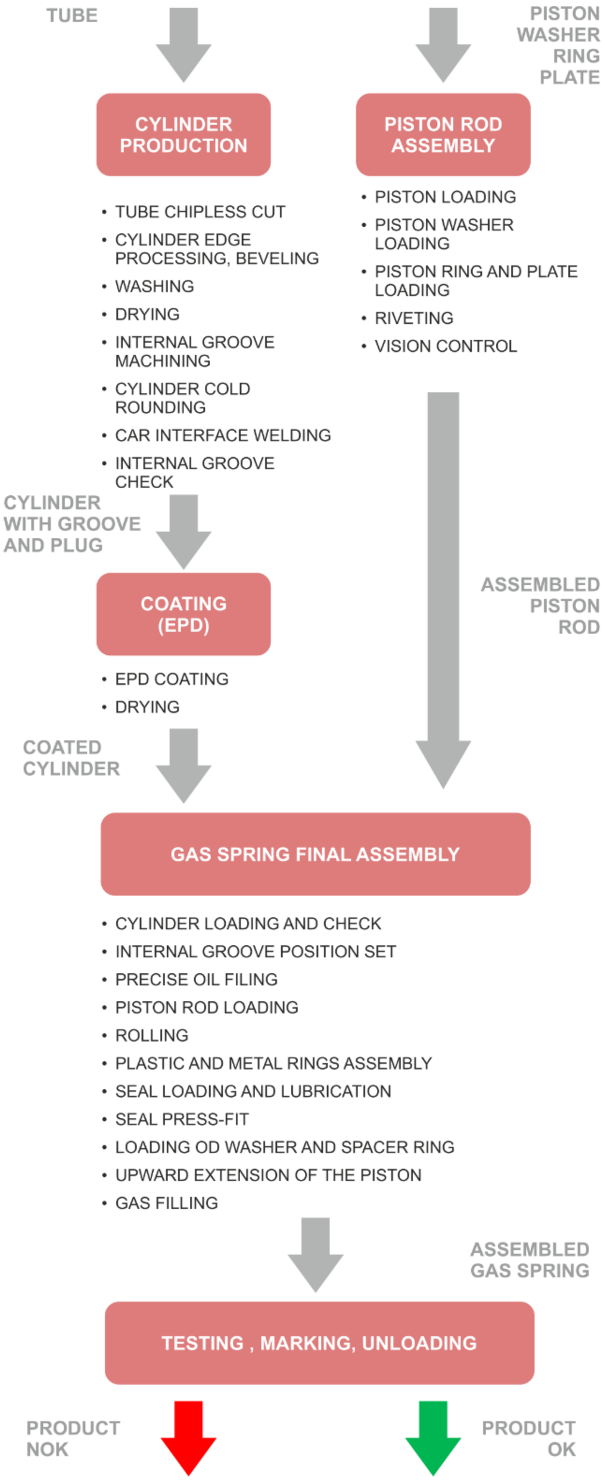

Fig. 3. Example of gas spring production process

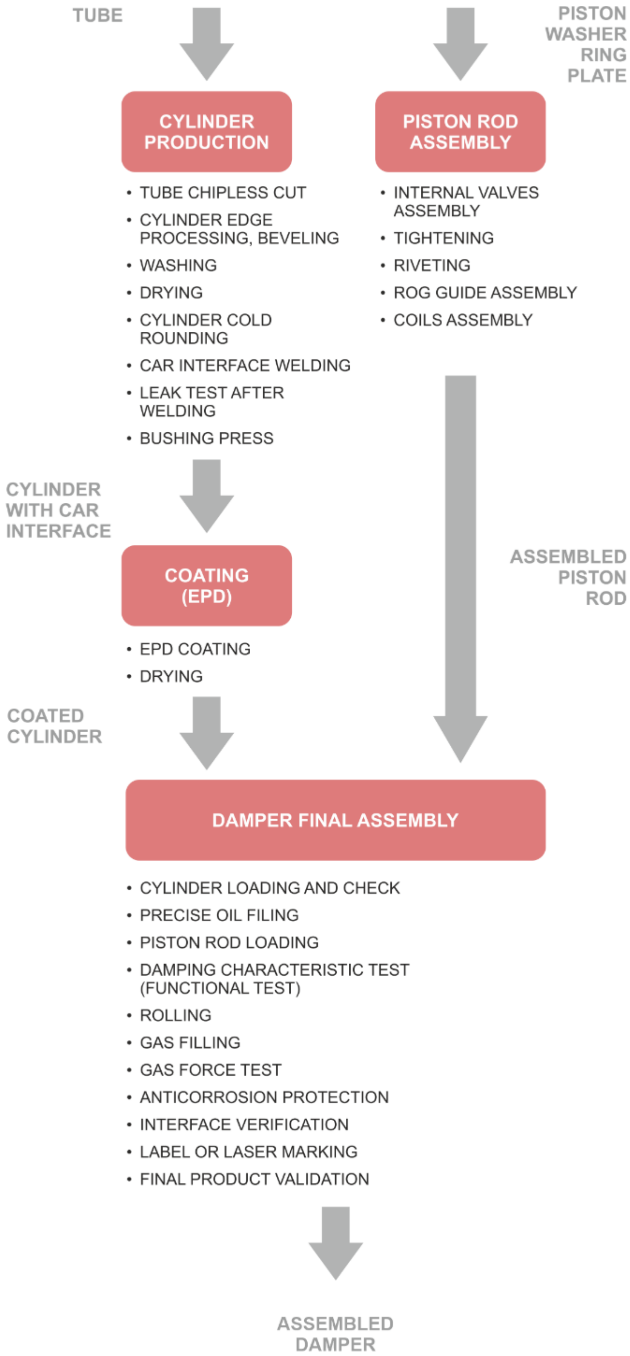

Fig. 4. Example of dampers production process

1.2. Technology readiness level

Technology readiness levels (TRLs) are a method for estimating the maturity of technologies during the acquisition phase of a program. TRLs enable consistent and uniform discussions of technical maturity across different types of technology. [1] TRL is determined during a technology readiness assessment (TRA) that examines program concepts, technology requirements, and demonstrated technology capabilities. TRLs are based on a scale from 1 to 9 with 9 being the most mature technology as seen in Table 1 (Wikipedia 2024; Mihaly, Heder 2017; Deutsch, Meneghini, Mermut, Lefort 2012) TRL was developed at NASA during the 1970s. In 2013, the TRL scale was further canonized by the International Organization for Standardization (ISO) with the publication of the ISO 16290:2013 standard (Wikipedia 2024; Mihaly, Heder 2017). This scale is also used to describe research and development projects co-financed by the European Union (Table 1).

Table 1. TRL definitions (European Commision, 2019)

TRL Lvl	Description
1	Basic principles observed
2	Technology concept formulated
3	Experimental proof of concept
4	Technology validated in lab
5	Tech. valid. in relevant industrial environment
6	Tech. demo in relevant industrial environment
7	System prototype demo in operational environment
8	System complete and qualified
9	Actual system proven in operational environment

2. Overview of most common automated solutions for Tier 1 manufacturers

2.1. Gas spring cylinder production line

The input resources for this line (Fig. 5) are a steel pipe of the appropriate diameter and a selected assembly tip. The output of the line is a cylinder prepared for electrophoretic deposition (EPD) painting and later used in the assembly of a gas spring.

The cylinder line is divided into several functional modules (Fig. 5):

Module 1 – automatic tube feeder synchro-nized with the cutting machine (Fig. 6).

Module 2 – automatic, chipless cutting of the tube to a size depending on the manufactured reference, preparation of the cylinder edge (chamfering), edge cleaning, forming the inlet cone with blow-off.

Module 3 – automatic cleaning of the cylinder by spraying using a dedicated cleaning emulsion at an elevated temperature, internal and external drying of the cylinder, excess liquid tank.

Module 4 – multi-position rotary table:

- cylinder loading from module 3 – dedicated manipulator,
- profiling of internal grooves – CNC drive with a vision system,
- cylinder positioning – changing the grip height with a dedicated manipulator,
- cold rolling of the cylinder end – CNC drive with a vision system,
- resistance welding of the end with the cylinder (Fig. 7),
- checking the correctness of the groove profile using the flow method – measurement with a flow meter at controlled movement of the measuring piston inside the cylinder.

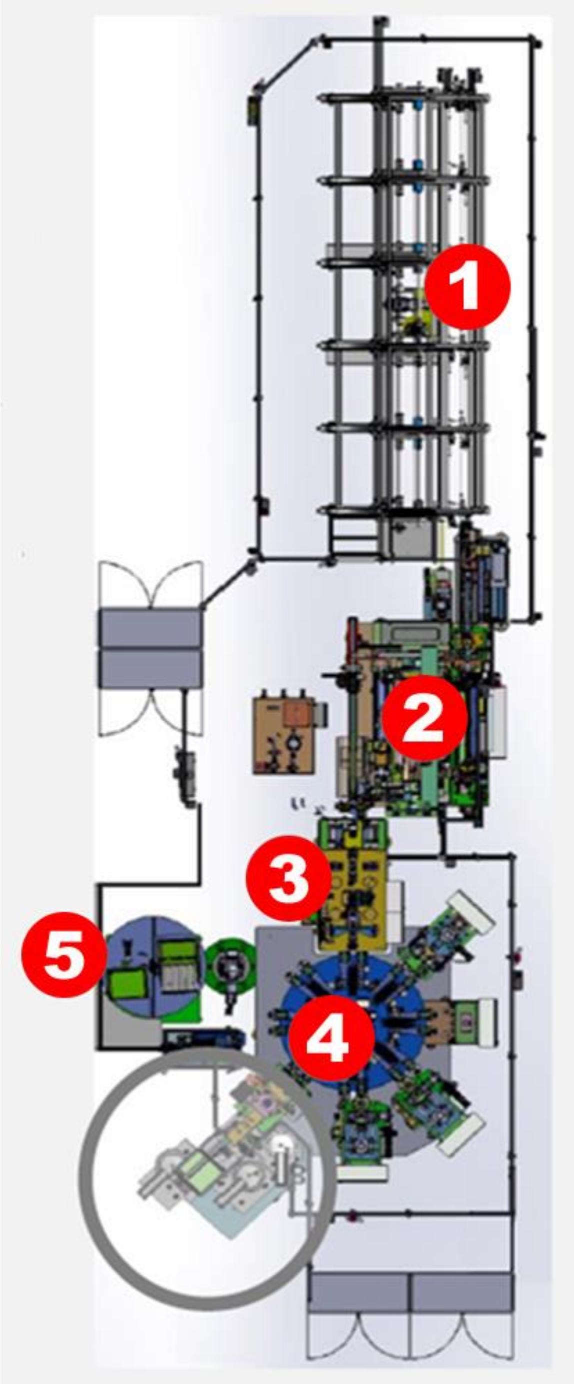

Fig. 5. Cylinder production line layout

Module 5 – unloading to the receiving basket – a universal 6-axis robot equipped with a vacuum gripper loading the semi-finished product into dedicated baskets of the washing machine (Fig. 8).

The range of cylinders manufactured includes external diameters of Ø15÷Ø28 mm, material thickness of 1÷2 mm and height of 100÷1100 mm.

Fig. 6. Tube feeder synchronized with cutting station

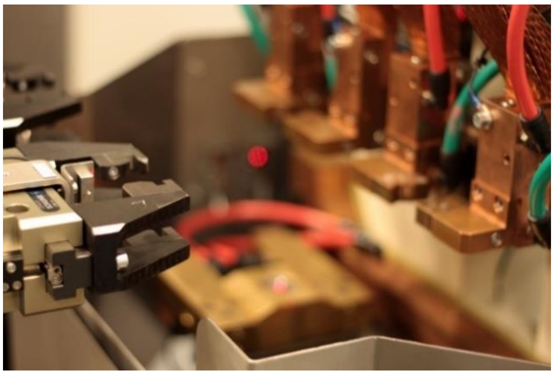

Fig. 7. Resistance welding station (module 4)

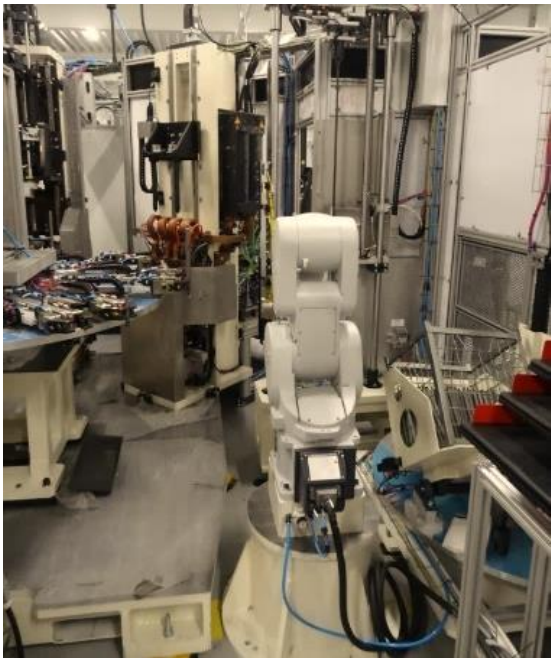

Fig. 8. Unloading robot

2.2. Gas springs final assembly line

A line for the final assembly of a gas springs (Fig. 9). The input includes: cylinders ready for further assembly after EPD painting and drying, additional elements in the form of rings and seals, and filling gas and oil dosed with an accuracy of 1 g. The piston rod elements are also fed, which are merged into a whole piston rod assembly. The piston rod assembly is then mounted to the cylinder together with additional elements, and the whole is filled with gas under pressure reaching several tens MPa and tested.

The line was designed to meet customer expectations related to reducing the space occupied by the lines, the number of operators necessary for service and ensuring the outflow of finished pieces every 7-8 s (depending on the dimensions of a given production reference). All these assumptions were achieved thanks to the use of a compact design with universal robots (Fig. 11) and rotary tables inside and redundant stations, e.g. the test station (Fig. 10).

The line control system supports 34 servo axes, 20 distributed compact I/O and safety modules, 2 coupled universal robots, 4 SCARA robots for fast Pick&place operations and the CC Link IE Field (1Gbps) industrial communication network.

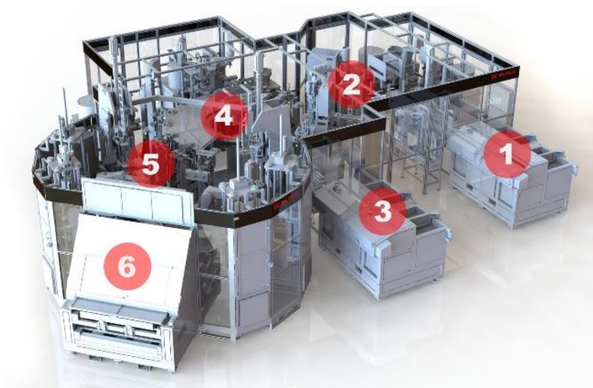

Fig. 9. Gas springs assembly line 3D model; 1) piston rod loading; 2) piston rod assembly; 3) coated cylinders loading; 4) gas spring assembly; 5) gas filling and functional testing; 6) unloading station

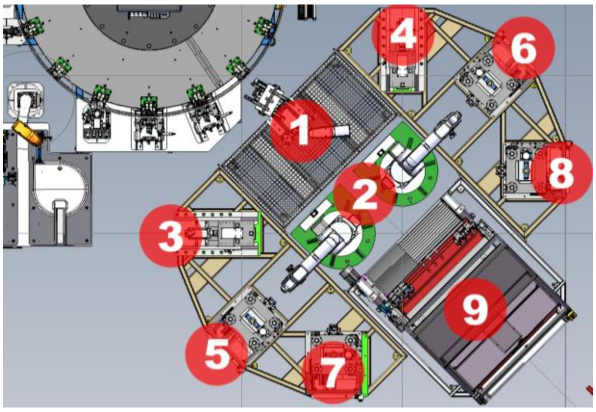

Fig. 10. Redundant stations at line output; 1) transfer from gas spring assembly module; 2) synchronized universal robots handling gas filling stations, functional testers and unloading; 3) gas filling station 1; 4) gas filling station 2; 5) functional tester 1; 6) functional tester 2; 7) functional tester 3; 8) functional tester 4; 9) unloading station

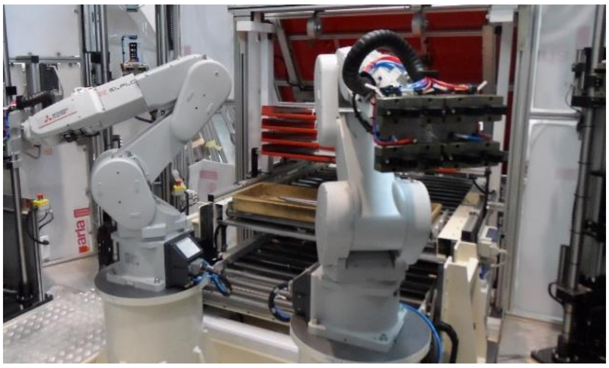

Fig. 11. Universal robots tandem, unloading station at background

2.3. Modular line for dampers assembly and testing

The line (Fig. 12, Fig. 13) assembles a ready-made twin-tube cylinder with a piston rod assembly, a floating piston. The input components are: a tube closed on one side, an internal tube with a valve, a ready-made piston rod assembly with a guide, an overlay, oil, nitrogen, labels. At the output of the line, an assembled damper is expected, ready for final assembly. Modularity was assumed for flexible adjustment of the pallet flow and exchange of stations, as well as the easiest possible changeover to different references.

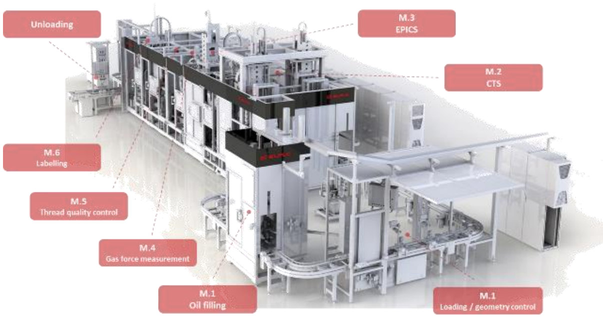

Fig. 12. Dampers modular line 3D model

Fig. 13. Assembly line panoramic photo

Description of individual line modules:

- **module 1** – initial module consisting of a loading station and filling the damper with oil;
- **module 2** – module for pressing the damper piston rod guide integrated with the module for controlling the damper damping characteristics (CTS for the inline process);
- **module 3** – module for filling with nitrogen and closing the damper by rolling (EPICS for the inline process);
- **module 4** – module for measuring the force generated by nitrogen in the damper and for length control;
- **module 5** – module for pressing the sliding pad and thread quality control;
- **module 6** – module for printing and sticking the label;
- **module 7** – station for checking selected damper dimensions.

The ranges of the CTS inline tester (Fig. 14) main parameters are described in Table 2.

Table 2. Main parameters ranges

Parameter	Value, range
Tube diameter range	30 ÷ 60 mm
Tube height range	120 ÷ 600 mm
Product height range	120 ÷ 1000 mm
Maximum product weight	8 kg
Oil dosing volume	60 ÷ 600 ml
CTS[1] – test force	-6500 ÷ 6500 N
CTS – stroke range	0 ÷ 400 mm
CTS – test speed	0,5 ÷ 1000 mm/s
CTS – maximum acceleration	10 g
CTS – acceleration curves	sin, triangle, trapezoid
CTS – test frequency	16 Hz
Damper Closing Force (EPICS)	45 ÷ 150 kN
Gas pressure (EPICS)	2,5 MPa max.
Gas force control	20 ÷ 500 N
Cap diameter	40 ÷ 80 mm
Spring bed ring – diameter	30 ÷ 300 mm
Spring bed ring – position	25 ÷ 100 mm
Transport pallet size	320 x 320 mm

[1] CTS – functional characteristics tester.

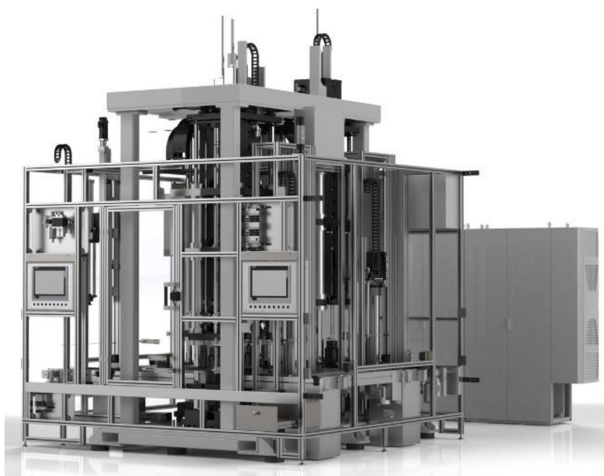

Fig. 14. CTS testing module/station 3D model

2.4. Piston rod valve assembly line

A line consisting of several stations for assembly and visual inspection of the piston rod valve for monotube and twintube dampers (Fig. 15). The first section is a set of automatic and manual stations, where the manual assembly of components, valve crimping and riveting take place. In the second section, a special cartridge and sealing is assembled. Finally robotic unloading takes place.

Fig. 15. Piston rod valve assembly line

2.4. Leak testers

Autonomous station (Fig. 16) for damper leak testing using the pressure drop measurement method equipped with integrated ATEQ devices. Easy-to-use test station for dampers, supporting products with a cylinder diameter of 30÷80 mm, cylinder length up to 600 mm. Test pressure: 400÷700 kPa.

Fig. 16. Leak tester measurement devices

3. Research and development of robotic assembly and testing line for dampers and gas springs

3.1. Project main objective

The objective of the project was to develop an innovative, robotized, technological process for the assembly and testing of dampers and gas springs, enabling Tier 1 end-users to enhance the efficiency and flexibility of production. The planned research, development, and implementation work was expected to yield a more versatile product for interested customers. Due to the scope of work and the results anticipated, the project aligns with the Polish National Smart Specialization 14: Automation and Robotics of Technological Processes, specifically Section I: Process Design and Optimization, subsection 6: Design, Optimization, Automation, and Robotics of Production Processes. It also aligns with the thematic scope of the competition in Research Area I: Innovative Technologies for Production, Regeneration, Recovery, and Recycling, within Research Group A: New Technologies for Production, Regeneration, Recovery, Recycling, and Disposal, and Development of Existing Technologies, particularly under Research Issue I.A.1: Improved or New Technological Lines and Production Technologies for Vehicles and Automotive Parts.

3.2. Target market

The target recipients of the project results have been defined as Tier 1 manufacturers. These companies are engaged in the production of all components essential for vehicle manufacturing. In this case, they are manufacturers of dampers and gas springs. During the project's implementation, the global damper market responded to increasing demand for cars` by continuously expanding its production capacities, which contributed to an upward trend in the industry's revenues. Similar growth prospects exist for the gas spring market, which is projected to reach a global value of USD 10.5 billion by 2026, with a compound annual growth rate (CAGR) of 5.8% over the period 2018–2026 (Persistence Market Research, 2023).

3.3. Analysis of competitive entities and solutions

In the target market, there are competing entities; however, they do not present direct competition, as they do not offer a single universal solution but instead separate solutions for dampers and springs. Brief list of main competitors in this area:

- Inova GmbH,
- Tekno Alfa S.R.L,
- Samac S.R.L,
- MTS Systems Corp.,
- Mondragon Assembly S Coop.,
- SIASUN Robot & Automation Co., Ltd.

List of other main issues encountered by users of machines and equipment:

- use of hydraulic motors, which significantly increase the likelihood of high-scale errors. Testing using hydraulic motors, due to its mechanical limitations is less precise than testing with a linear electromagnetic drive,

- electromagnetic linear drive and high accuracy measurement used – but testing devices intended exclusively for laboratory use and cannot be applied in industrial inline testing,
- processes – not demonstrate adequate thermal resistance under industrial conditions,
- mediocre or poor measurement during testing with significant errors (up to 10%), resulting in the rejection of components that could potentially pass the full test,
- closed systems not designed for integration with other modules or for process automation, which makes them not universal and not flexible.

3.4. Patent analysis

Before project start was independently conducted an analysis of available and protected solutions, technologies, and research and development outcomes, the existence of which could potentially pose a barrier to the ongoing pro-innovative activities. This analysis covered documents contained in the following patent databases:

- Polish Patent Office;
- World Intellectual Property Organization;
- European Patent Office;
- Baz-Tech (databases of Polish technological journals);
- online patent database lens.org

The subject-based search was carried out based on the names of companies identified as main competitors, including: MTS Systems, Mondragon Assembly S. Coop., SIASUN Robot & Automation Co. Ltd., Techno Alpha Co. Ltd., Industrial Gas Springs Inc., Kayaba Industry Co. Ltd., Ahaus Tool & Engineering Inc. The object-based search was carried out using the following keywords: assembly and testing line for hydraulic dampers, method of testing automotive gas springs, method of measuring damping force in gas springs, nitrogen dosing control inside the damper. The subject of the research was classified according to the International Patent Classification as F01 – machines or engines in general, power plants in general, steam engines, and F16F – springs; shock absorbers: means for vibration damping.

As a result of the research, 5 solutions related to damping testing devices were selected, but they do not possess the characteristics that distinguish and define the Project outcome. However, the three closest solutions were identified, including:

- CN101441130A – Durable test stand and test method of gas spring for automobile – a test stand used to assess the physical stretchability level of gas springs;
- US 8844345 B1 – Imparting motion to a test object such as a motor vehicle in a controlled fashion – a device for testing that imparts controlled motion to the test object, based on a linear electromagnetic motor with a non-iron core;
- US6360580B1 – Device and method for testing vehicle shock absorbers – a device for testing vehicle shock absorbers that achieves more accurate measurements by normalizing the resonance amplitude and adopting a fixed wheel suspension elasticity value before starting the tests.

The state of the art as of August 8, 2018, indicated that the available solutions do not possessed the key functionalities planned for development in the Project, which eliminated any barriers for the implementation of the Project results arising from intellectual property rights.

3.5. Project result

An in-depth analysis of market needs, available solutions, and our own expertise resulted in the successful completion of the project. All stages were conducted, from design through part manufacturing, assembly, programming, and concluding with commissioning and a full set of documentation. During the work, 3D models of the line were created, one of which is shown in Fig. 17. A photograph of the constructed line during commissioning stage is visible in Fig. 18.

Fig. 17. Robotized assembly line 3D model

Assembly line main features:

1. Stationary machine for testing the CTS characteristics of gas springs.
2. Robot for handling gas springs.
3. Autonomous trolley – AMR robot.
4. Robot for handling dampers.
5. Stationary machine for testing the CTS characteristics of dampers.

6. Stationary machine for rolling and gassing EPICS – dampers.
7. Hydraulic unit.
8. Data collection system – TRACEABILITY.
9. AMR robot charging station.

Fig. 18. Line commissioning at Company R&D facility

Developed line meets several conditions:

Universality of the technological line devices – the "all-in-one" solution takes up 32% less usable space and consumes 90% less oil (reduction from 500 to 50l of oil per year) compared to solutions with a characteristic tester module with a servo-hydraulic drive,

Scalability and compactness of the technological solution through modularity and compatibility – both parts (dampers and gas springs) or each one can be supplied / operated independently,

Increased measurement accuracy – reduction of measurement errors from 4% to 1.5%,

Shortening the loading time in the production cycle due to robotization (~20%),

High work autonomy thanks to the use of robotic logistics service (AMR vehicle).

4. Summary

Development work related to the implementation of a modular production line for the assembly and testing of automotive dampers has been completed. The work was carried out as planned, from November 1st, 2019, to April 30th, 2022.

The line, featuring an improved method for the assembly and testing of dampers and gas springs for the automotive industry, has reached Technology Readiness Level (TRL) 9 upon completion of the Project. Achieving this TRL level was possible through the development of a technological line consisting of separate yet compatible elements/modules:

- a tester for assessing damping force characteristics for dampers and gas springs,
- a technological line for assembling and gas-filling dampers,
- a technological line for assembling and gas-filling gas springs.

Although the R&D work commenced at TRL 4, no industrial research was planned within the Project. The technology advanced through the appropriate combination and transformation of existing scientific and technical knowledge in the relevant area. Achieving the final result involved a series of tasks:

- developing the operational schema and design of the devices and the entire technological line,
- designing a dedicated control system for each device and the entire technological line, enabling automation in the transportation of damper and gas spring components,
- integrating and fully automating the technological line, as well as tasks aimed at its final validation and demonstration.

Acknowledgments

Work on the POIR.01.02.00-00-0056/18-00 project "Development of a product innovation in the form of an innovative technological line for the assembly and testing of dampers and gas springs, for use in international manufacturers of components at the Tier1 level in the automotive industry" received funding under the Smart Growth Operational Program 2014-2020.

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