PNEUMATIC EQUIPMENT FOR MICRO-DEFORMATION OF WIRES AT AN ELECTRIC MICROMOTOR IN THE AUTOMOBILE INDUSTRY

Nicușor BAROIU[1], Daniela DANCI (MÂNCILĂ)[1], Mihăiță MÂNCILĂ[1], Georgiana-Alexandra MOROȘANU[2], Silvian BAROIU[3], Cătălin DUMITRESCU[4]

[1] Department of Manufacturing Engineering, ”Dunărea de Jos” University of Galaţi, Romania
Nicusor.Baroiu@ugal.ro, dd189@student.ugal.ro, mm376@student.ugal.ro

[2] Research Center in Manufacturing Engineering Technology (ITCM), ”Dunărea de Jos” University of Galaţi, Romania, Alexandra.Costin@ugal.ro

[3] Faculty of Electronics, Telecommunications and Information Technology, Politehnica University of Bucharest, Romania, silvianbar@gmail.com

[4] Hydraulics and Pneumatics Research Institute INOE 2000-IHP, Bucharest, Romania
dumitrescu.ihp@fluidas.ro

Abstract: *The design of technical solutions and the serial execution of electrical subassemblies to be integrated into the production of electronic components in the automotive industry requires adaptation to new working conditions and technologies, doubled by the quality of services and products, which must be competitive on a global scale. This can also be achieved by choosing the optimal variants of machines or equipment that are the most profitable from a qualitative and economic point of view for a fully automated technological process, as well as by a maintenance of these systems, which must be performed in accordance with the instructions manufacturer and at regular intervals. In this context, the appearance of new technical resources, of new trends and especially automation, gave to pneumatic technology an ever-rising development, most of the time, pneumatic drives constituting a basic component in intensive production systems. This paper aims to present a description of a pneumatic equipment for microdeformation of wires in the automotive industry, the technological process for obtaining microdeformed components (wires), as well as a calculation of the characteristic parameters of the pneumatic equipment.*

Keywords: *Pneumatic equipment, wires, microdeformation, tehnological process*

1. Introduction

In the last decades, there has been a growing evolution of the automotive industry at the global and European level, correlated with the increase in the share of electrical and electronic components in the construction of vehicles, with the aim of perfecting their performance, the European Commission estimating that the European automotive market will be fully electrified by 2050, as an essential contribution to the future of mobility and the technological base of the automotive industry [1, 2]. This led to the development of automated systems for making numerous elements in the area of microelectronics, such as digital processors, logic and analog integrated circuits, power integrated circuits, sensors, various actuation systems etc. [3]. At the same time, autonomous technology and connectivity, hybridization and electrification of motorization, as well as digitization along the production chain will lead to fundamental transformations in the way the entire automotive ecosystem operates [4, 5, 6]. Their facilitation could be done both by optimizing processes and workflows or data management and control, but also by adopting hardware and software technologies for the automation and robotization of manufacturing processes [7, 8, 9]. Romania is among the European states in Central and Eastern Europe that has a good increase in car production, with significant investments from the manufacturers of various components and car subassemblies and aligns with the trends regarding the production and sales of vehicles, employment, environmental protection or road safety [10, 11]. The production of electrical and electronic equipment that is included in the micromotors for raising-lowering windows, adjusting car seats, opening-closing the tailgate, actuating the wipers etc. from the automotive industry aligns itself with these current trends.

In this entire context, the new automation requirements and the development of technical resources gave pneumatic technology a strong development, placing it as a basic component in intensive production systems. The concept that was initially based only on the execution of the command and the power generating by the compressed air is gradually being replaced by the concept that associates the electrical and electronic control elements with the pneumatic execution elements. The association of the two technologies is done in order to accumulate the advantages offered by each of them in the field of control and power [12, 13].
Since in a pneumatic system the energy-carrying agent is the compressed air, the energy source is the pneumatic generator *GP*, the compressor, Figure 1. It receives the mechanical energy from an electric motor *ME* or thermal and, aspirating air from the atmosphere, *at*, achieves a first energy conversion, the mechano-pneumostatic one. The second element of the converter will be a linear pneumatic motor *MPL* (pneumatic cylinder or membrane chamber) or rotary, *MPR*. The pneumatic motor performs the second energy conversion, in this case pneumo-mechanical, and transmits the mechanical energy thus obtained to an *EE* execution element. In the case of pneumatic systems, the *ACR* apparatus is completed by the apparatus for the preparation of compressed air, which provides it with the necessary qualities to perform the function of energy carrier.

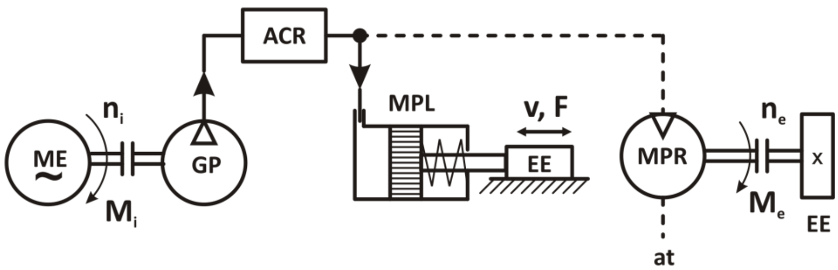
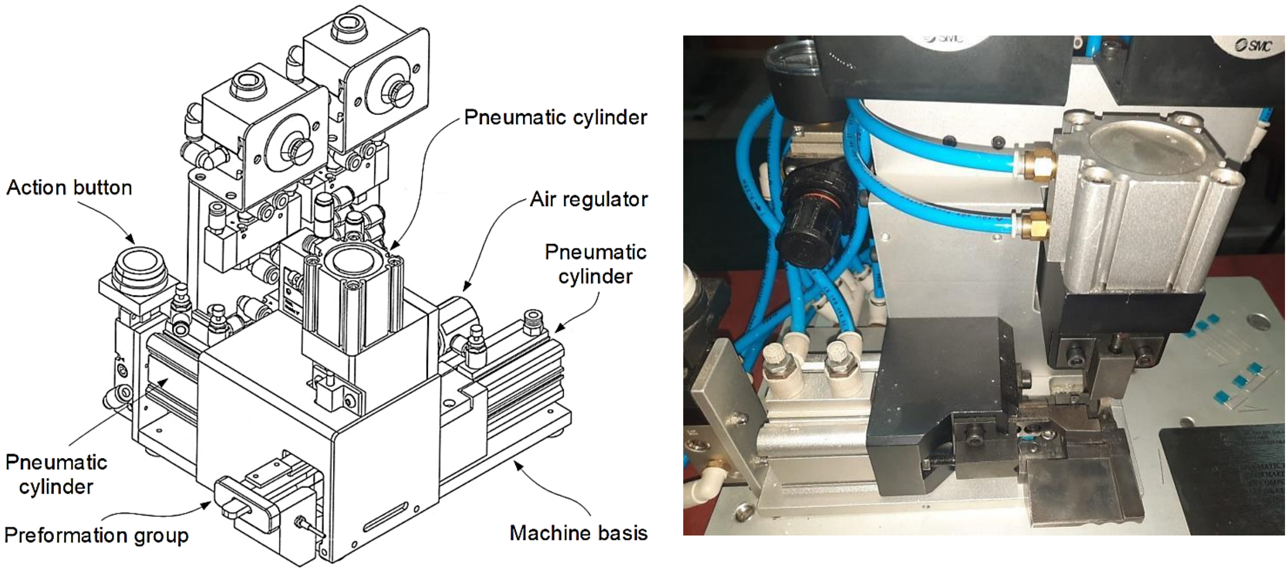


Fig. 1. General structure of a pneumatic system: *ME* - electric motor; *GP* - pneumatic generator; *ACR* - control and regulation equipment; *MPR* - rotary pneumatic motor; *MPL* - linear pneumatic motor; *EE* - execution element; n_i - input speed; M_i - moment of entry; n_e - output speed; M_e - exit moment; *v* - velocity; *F* - force [14]

Pneumatic actuators have found applications in extremely varied fields of technology, for multiple and diverse purposes, the profitability assessment of a pneumatic actuator being made both on the basis of the cost of the energy consumed and on the basis of the installation cost and maintenance and operation expenses. The paper presents a pneumatic equipment for the microdeformation of electrical and electronic components [15, 16, 17], with reference to the electric micromotor for raising the windows that is a part of a vehicle, taken as an assembly from the class of electric micromotors or mechanical-electrical systems.

2. Pneumatic equipment for microdeformation of electrical and electronic components in the automotive industry

The equipment for microdeformation (folding-cutting) of components is a system with a pneumatic drive, which aims to fold the metal arms of the components, as well as to cut the excess material, so that the component element obtains the special shape required for assembly [18]. In general, such equipment operated with compressed air requires a continuous air flow for flawless operation, which is achieved by using a correctly sized compressed air tank. The tank is vertical and galvanized inside and outside. It is equipped with a safety valve, which must be adjusted so that it opens when the air pressure has exceeded the nominal pressure by 10%, with a manometer and a device for purging, mounted in the lower part of the container. The access possibility to the safety valves for their adjustment and verification must be ensured.
The component parts of the wire microdeformation equipment are: the machine basis; air control group; pneumatic cylinder; component insertion unit by clamping; the preforming group, the pneumatic button and the protective housing, Figure 2.



a. b.

Fig. 2. Wire microdeformation equipment: industrial model (a) [18]; laboratory model (b).

3. The components of the microdeformation equipment from the automotive industry

3.1 Air control group

The compressed air reaches into the wire microdeformation equipment through the pressure regulator, which adjusts the pressure received from the compressor group, according to the technical specifications. Figure 3 shows the pneumatic drive system of the wire microdeformation equipment.

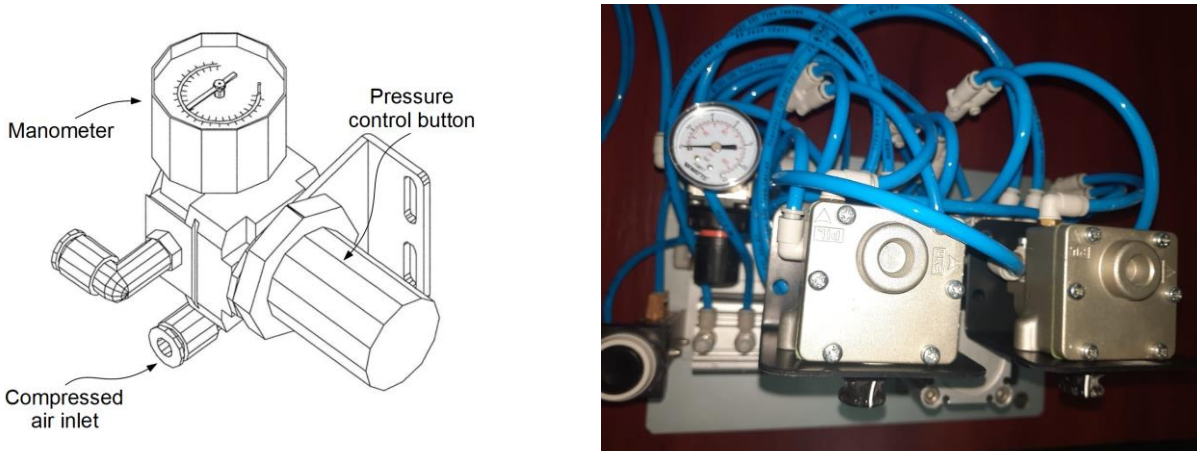


Fig. 3. The pneumatic drive system of the wire microdeformation equipment

3.2 Pneumatic cylinders

The wire microdeformation equipment has in its structure two pneumatic cylinders, Figure 4: a vertical cylinder with a diameter of Ø40 mm, having a stroke of 15 mm and a horizontal cylinder with a diameter of Ø32 mm and a stroke of 4 mm.

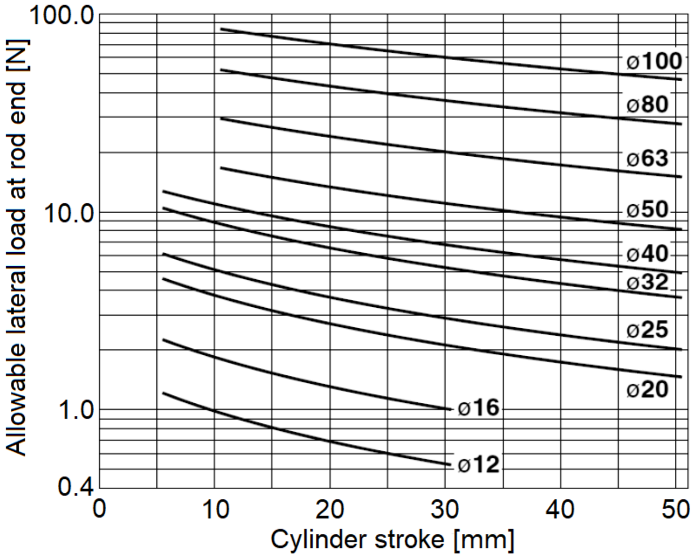


Fig. 4. Pneumatic cylinders: cylinder stroke and allowable lateral load at rod end [19]

The technical characteristics of the cylinders are presented in Table 1 [19].

Table 1: Technical characteristics of pneumatic cylinders

	Cylinder 1	Cylinder 2
Diameter of the cylinder [mm]	Ø40	Ø32
Stroke [mm]	15	4
Cylinder action	Double	
Speed range [mm/s]	30-500	30-500
Absolute maximum pressure [bar]	15	
Maximum operating pressure [bar]	10	
Minimum/ Maximum operating temperature [°C]	-10/70	-10/70

3.3 Pneumatic valves

The purpose of the pneumatic valves is to direct the compressed air along certain directions depending on the commands received from the outside. In an actuation system, the valve is primarily tasked with reversing the direction of movement of the engine's output and, in certain situations, stopping it. The valves used for this purpose are also called main valves. Valves can also be used to generate pneumatic control signals, in which case they are called auxiliary valves; this category includes: pneumatic buttons, stroke limiters and solenoid valves [19]. Table 2 and Figure 5 show the types of pneumatic valves included in the wire microdeformation equipment from the automotive industry, respectively, their technical characteristics.

Table 2: Technical characteristics of pneumatic valves [19]

	Pneumatic valve	No. crt.	Pneumatic valve
Mounting style	stand-alone	**Maximum flow rate**	578 Nl/min
Number of ports	5/2	**Minimum operating pressure [bar]**	1
Thread size [mm]	G 1/8	**Maximum operating pressure [bar]**	7
Actuation type	pilot/pilot	**Maximum operating temp. [°C]**	60

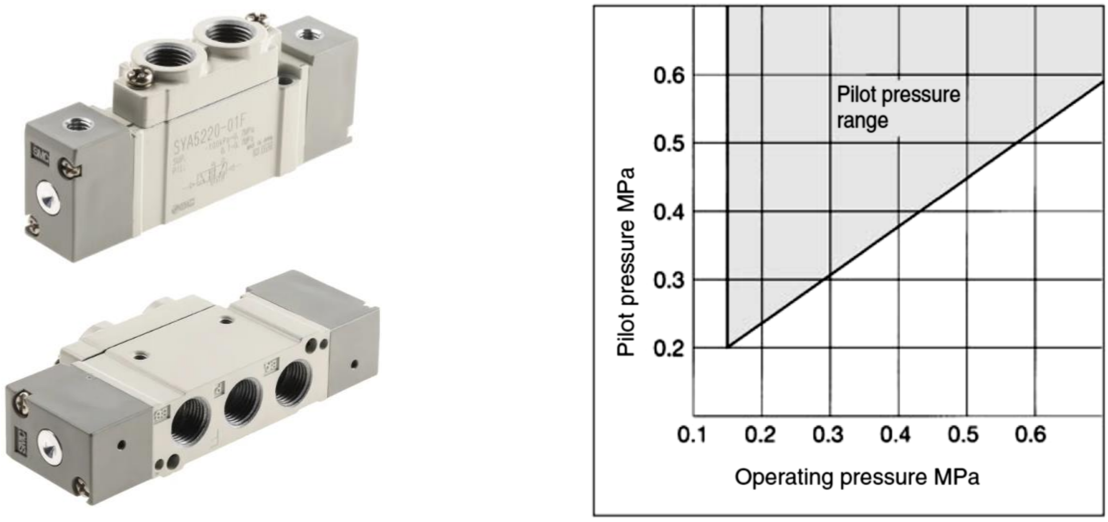


Fig. 5. Pneumatic valves: operating and pilot pressure [19]

3.4 The electric drive system of the pneumatic equipment and the mechanical system

The wire microdeformation equipment of components is manually controlled by pressing a button and is equipped with a mechanical preforming system, Figure 6.

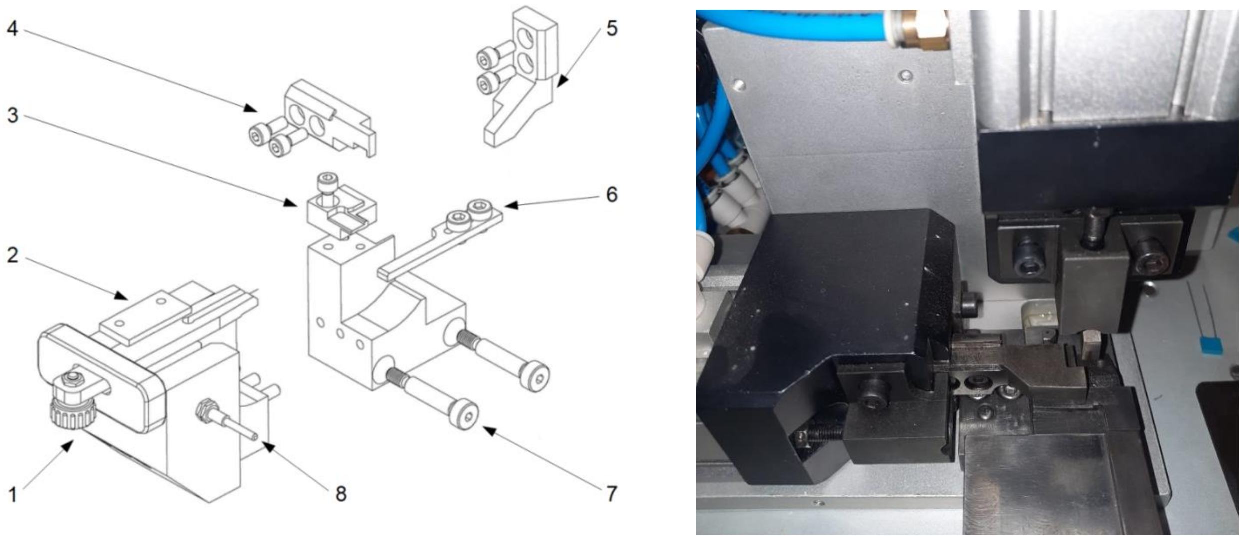


Fig. 6. The mechanical system of the folding-cutting equipment [18]: *1* - support; *2* - guide plug; *3* - matrix; *4* - bending profile at a *90°* angle; *5* - cutter for folding and cutting excess material; *6* - cutter for folding at an angle of *180°*; *7* - profiled support for microdeformation; *8* - stud bolt.

The structure of the actuation group includes both the elements necessary for the command and those for the protection of the actuation. Avoiding incidents that lead to damage to materials and installations is mandatorily fulfilled by protection against short circuits and protection against overload, which are ensured by anti-short circuit and/or anti-overload fuses, protection relay and circuit breaker. Switches and circuit breakers have the role of connecting or disconnecting direct current or alternating current circuits, the contact system comprising two elements, one fixed and one mobile. The switching consists in establishing or interrupting the energy from a receiver and is ensured by switches and contactors, the fuses being the switching elements that have the role of opening the circuit when the current passing through it exceeds the safety value.

The technological process of microdeformation of the wires for the capacitors within the micromotor for acting the window of vehicles, has the following stages, shown in Figure 7.

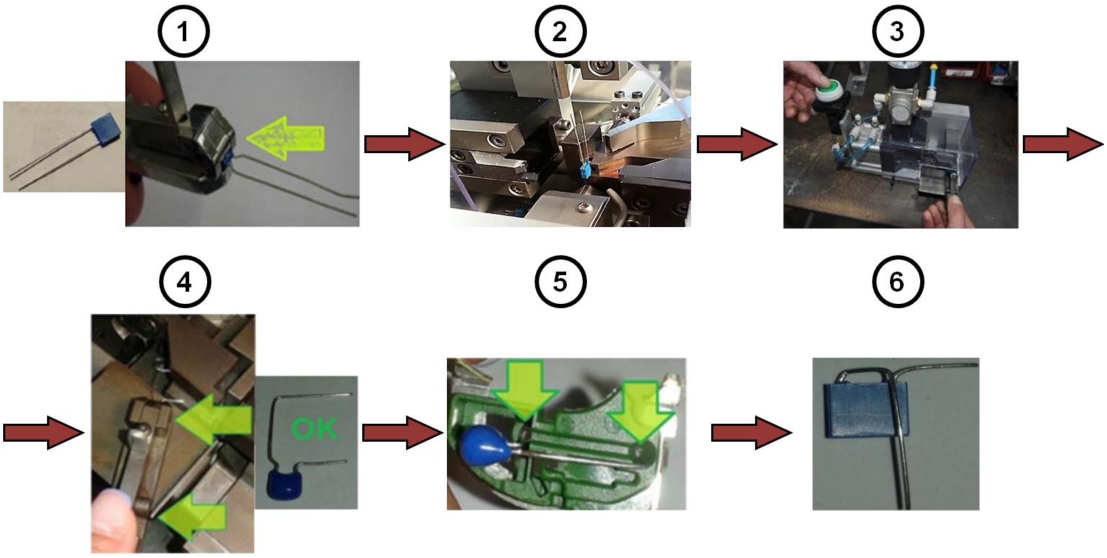


Fig. 7. The technological process of microdeformation of the wires for the capacitors within the micromotor for acting the window of vehicles

The blank is inserted into the tweezers provided with a special fixing channel (1), Figure 8. It is placed in a horizontal position with the arms facing forward and by pressing the machine button, the cutter system executes the cutting and folding of the arms of the blank according to the technical specifications (2 and 3). After bending and cutting, the caliper of the pliers is actuated to the right to be removed from the rail and the part is released with the help of the stud bolt fixed on the module housing, specially intended (4 and 5). A visual check of the cutting-folding operation is made by comparing it with a reference product (6). The final result is shown in Figure 8.

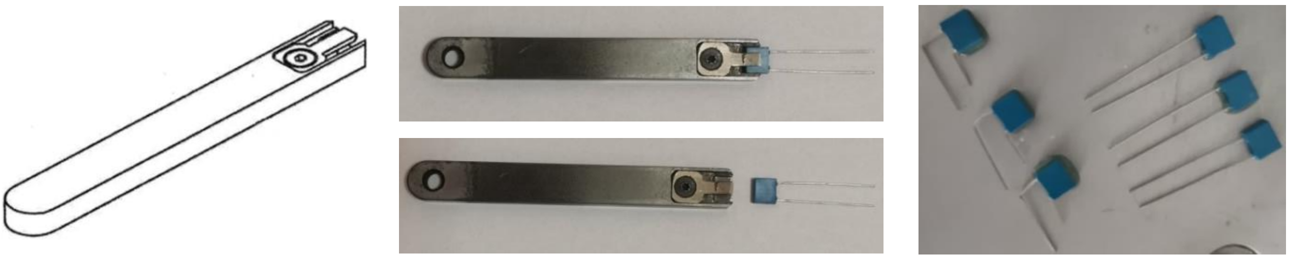


Fig. 8. Inserting the capacitors into the tweezers and the result after deformation

If the force acting on the capacitors is not optimal, component microdeformation defects can occur, Figure 9.

a. b. c.

Fig. 9. Component microdeformation defects:
deformed arms (a); arms cut too short (b); arms cut too long (c).

3.5 Calculation of the axial forces developed by the rod-piston subassembly

In order to perform the correct cutting and bending of the condenser arms, the axial displacement force of the rod-piston subassemblies must be determined, depending on the diameter of the piston and its stroke. The axial force *F* is defined as a theoretical effort available at the output of the rod depending on the direction of movement of the rod-piston subassembly and is calculated with the relation:

$$F = p \cdot S \left[\mathrm{daN}\right], \quad (1)$$

where: *p* is the required pressure in the surface chamber *S* of the pneumatic cylinder.
Since the frictions due to the piston and rod seals are neglected, a coefficient τ, called the load coefficient, can also be used in the calculations to evaluate the real effort obtained. If it is considered that the double-action pistons each push a load - the cutters for folding and cutting the excess material, then the axial force is obtained by a displacement, in the form of dynamic effort. The load coefficient used under these conditions has the value $\tau = 0.6$.

$$F = p \cdot S \cdot \tau \; \left[\mathrm{daN}\right]. \quad (2)$$

The active surface *S* depends on the piston diameter, *D*, Table 1:

$$S = \frac{\pi \cdot D^2}{4} \; \left[\mathrm{mm}^2\right]. \quad (3)$$

Table 3 and Table 4 show the values of the axial forces associated with the movement of pneumatic cylinders in the range of Ø40 mm and stroke *l* = 15 mm, respectively Ø32 mm and stroke *l* = 4 mm, for working pressure values between 5÷10 [bar].

Table 3: The force values of the vertical pneumatic cylinder, D=40 mm

No. crt.	*p* [bar]	*D* [mm]	*l* [mm]	τ [mm]	*F* [daN]
1.	5	40	15	0.6	37.68
2.	6				45.22
3.	7				52.75
4.	8				60.29
5.	9				67.82
6.	10				75.36

Table 4: The force values of the horizontal pneumatic cylinder, D=32 mm

No. crt.	*p* [bar]	*D* [mm]	*l* [mm]	τ [mm]	*F* [daN]
1.	5	32	4	0.6	24.12
2.	6				28.94
3.	7				33.76
4.	8				38.58
5.	9				43.41
6.	10				48.23

In general, the effective useful force developed by a pneumatic cylinder at a given pressure is, as a rule, lower than the theoretical value. The efficiency of the cylinder η_c is defined as the ratio between the real useful force and the theoretical force. The efficiency of pneumatic cylinders is considered to have values in the $\eta_c = 0.7 \div 0.95$ range, increasing the higher the working pressure and the larger the cylinder diameter are. Figure 10 shows, in comparison, the force values of pneumatic cylinders of diameter *D*=40 mm, respectively *D*=32 mm.

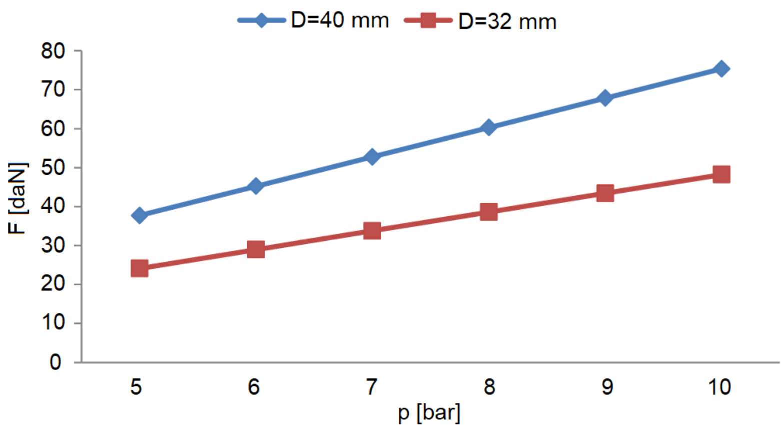


Fig. 10. Values of axial forces *F* for pneumatic cylinders of diameter *D*=40 mm and *D*=32 mm

4. Technological flow for assembling a micromotor for the automatic raising-lowering system of a vehicle windows

The purpose of the wire microdeformation machine is to bend the metal arms of some capacitors in the construction of a mechanism for the automatic raising-lowering of some vehicles windows, Figure 11.

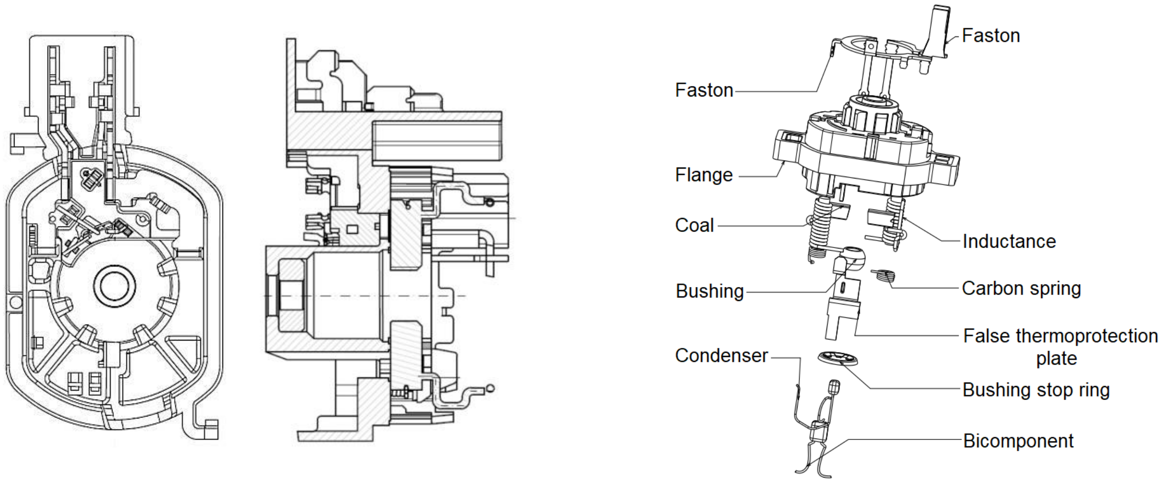


Fig. 11. The micromotor from the construction of the mechanism for the automatic raising and lowering windows of a vehicle [20]

Regardless of the type of motor, it is built from two component parts: the stator and the rotor. The stator is the fixed part of the motor, generally external, which includes the housing, the power terminals, the stator ferromagnetic armature and the stator enveloping. The rotor is the moving part of the engine, usually placed inside. It consists of a shaft and a rotor armature that supports the rotor enwrapping. Between the stator and the rotor there is a portion of air called the air gap that allows the movement of the rotor relative to the stator. Air gap thickness is an important indicator of engine performance. When is actuated from a constant frequency power supply, the electric motor is essentially a constant velocity drive, with the velocity dropping only 1% to 5% as the load torque is increased from zero to rated value.
Usually the starting current is thus limited to about four to seven times the rated current when started at full voltage. The starting torque is usually in the range of 1.75 to 2.5 times the rated value. If the stator has a higher starting current than is allowed from the electrical supply system, the motor can be started on a reduced voltage of about 70% to 80% using a step-down transformer. Alternatively, the stator envelopings may be connected at the start and switched as the speed approaches the rated value. Such measures reduce the starting torque substantially.

A reduction in starting voltage to 75% results in a reduction in supply current to 56%, but results in only 56% of the starting torque that would be provided at full voltage.
The flow of the assembly process of the parts from the construction of the electric micromotors used for the automatic raising and lowering of the windows of a vehicle is presented in Figure 12.

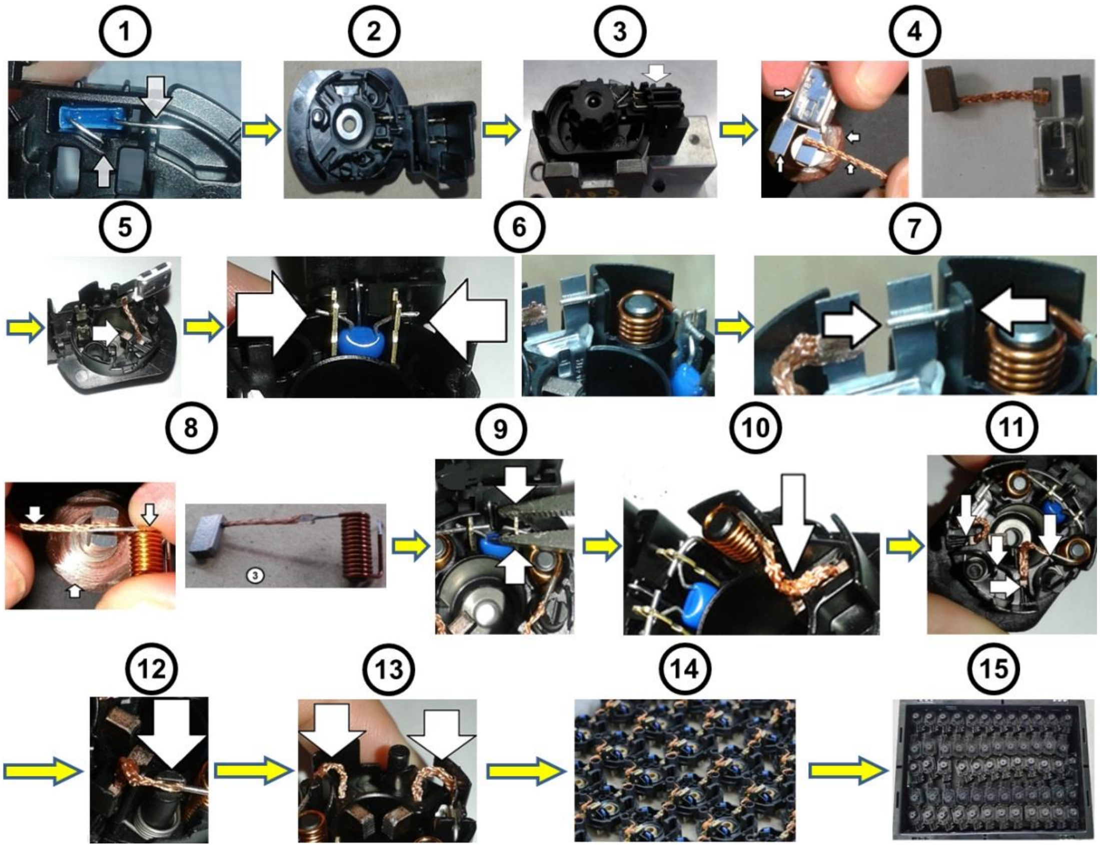


Fig. 12. The process flow for the realization of the parts

The capacitor is mounted on the cutting-folding machine, the operation being performed manually (1). At the same time, the bushing and the connector will be mounted in the flange (2 and 3). An electric welding will be performed by heating with coal wire. The metal blade expands by heating and will make contact (4). Both the group thus welded and the capacitor will be mounted on the flange, the operation being performed manually (5 and 6). Next, a non-welded resistance will be mounted on the flange, with the help of tweezers, and an electric welding of the resistance with carbon wire will be performed again (7 and 8). The assembly of the resistance-carbon welded group will be manually mounted on the flange, with a minimum of 1 mm space between the impedance arms (9 and 10). The springs will be mounted with the help of a special device (11) and the carbon-welded wires will be positioned with the help of the tweezers (12 and 13). Finally, a visual control of the assembly will be done, based on a standard product and, for packaging, barcode labels and special packaging will be used, after which it will be stored until the transport to the customer (14 and 15).

Conclusions

In order to carry out the technological process of microdeformation of the wires, a device containing pneumatic, electrical and mechanical working components was created. In order to provide a constant compressed air pressure, calculations were made of the characteristic parameters of the pneumatic cylinders - the effort to move some loads, such as vertical axial cutting force, respectively horizontal axial force of deformation of the arms of some capacitors.

In order to ensure the tightness and guidance of a pneumatic cylinder, it is necessary to use seals and guide rings. However, these elements will generate friction that will influence the operation of the cylinder. In order to take these frictions into account when determining the forces developed by a cylinder, a load factor was taken into account. The determination of the effort provided by the cylinder when the rod is withdrawn was not taken into account, since the efforts provided at the output of the rod are important for cutting and deforming the capacitor arms.
The continuous verification of the work flow, as well as the quality of the execution of the microdeformation operation determines the productivity of the work by completing this operation on time and sending the components to the next operation, namely the assembly of the micromotor flange.

References

[1] Agostino, M., A. Nifo, S. Ruberto, D. Scalera, and F. Trivieri. "Productivity changes in the automotive industry of three European countries. An application of the Malmquist index decomposition analysis." *Structural Change and Economic Dynamics* 61 (20220: 216-226.

[2] Guga, Şt. "Industria auto, încotro? Tendințe globale, perspective periferice", *Syndex, Friedrich-Ebert-Stiftung România*, Accessed September 12, 2022. http://library.fes.de/pdf-files/bueros/bukarest/15195.pdf.

[3] Măgdoiu, A. "Quality Improvement Using Poka Yoke Systems." PhD Thesis. "Lucian Blaga" University of Sibiu, 2014.

[4] Yang, Y., K. Arshad-Ali, J. Roeleveld, and A. Emadi. "State-of-the-art electrified powertrains – hybrid, plug-in, and electric vehicles." *International Journal of Powertrains* 5, no. 1 (2016): 1-29.

[5] Un-Noor, F., S. Padmanaban, L. Mihet-Popa, M.N. Mollah, and E. Hossain. "A Comprehensive Study of Key Electric Vehicle (EV) Components, Technologies, Challenges, Impacts, and Future Direction of Development." *Energies* 10 (2017): 1-82.

[6] Chiver, O., N. Burnete, I.R. Şugar, L. Neamț, and E. Pop. "Study on gear ratio of battery electric vehicles." *Ingineria automobilului* 59 (2021): 11-16.

[7] Djurdjanovic, D., L. Mears, F.A. Niaki, A.U. Haq, and L. Li. "State of the art review on process, system, and operations control in modern manufacturing." *Journal of Manufacturing Science and Engineering* 140, no. 6 (2018): 061010.

[8] Universal Robots. Accessed September 16, 2022. https://www.universal-robots.com/.

[9] Robital Industrial Supplier. Accessed September 16, 2022. https://robital.ro/en/home-en/.

[10] European Automobile Manufacturers' Association (ACEA). *Automobile Industry Pocket Guide 2022-2023*, Accessed October 3, 2022. https://www.acea.auto/publication/automobile-industry-pocket-guide-2022-2023/.

[11] Ispas, N., M. Năstăsoiu, and T.D. Ioniță. "Assessing potential cars occupant's injuries in three different collision scenarios between a car and a truck." *Ingineria automobilului* 62 (2022): 5-8.

[12] Abela, K., P. Refalo, and E. Francalanza. "Design and implementation of an energy monitoring cyber physical system in pneumatic automation." *Procedia CIRP* 88 (2020): 240-245.

[13] Taheri, K., and R. Gadow. "Industrial compressed air system analysis: Exergy and thermoeconomic analysis." *CIRP Journal of Manufacturing Science and Technology* 18 (2017):10–7.

[14] Baroiu, N., D. Vișan, and O.D. Ciocan. *Technological hydrostatics and pneumatics - laboratory guide / Hidrostatică și pneumatică tehnologică - îndrumar pentru laborator*. Galați, Academica Publishing House, ISBN 978-606-606-007-3, 2018.

[15] Gujar, A.N., T.D. Kadam, V.V. Shinde, G.E. Chavan, and A.J. Mane. "Design and Development of Pneumatic Stirrup Bending Machine." *International Journal of Advance Engineering and Research Development* 4, no. 3 (2017): 479-485.

[16] Suryawanshi, V.N., N.V. Wakade, and P.A. Narwade. "Design and Development of Pneumatic Punching Machine." *International Research Journal of Engineering and Technology* 6, no. 5 (2019): 1140-1145.

[17] Tambat, V., N. Rane, O. Savant, and P. Yadav. "Pneumatic Shearing and Bending Machine." *International Journal of Recent Research in Civil and Mechanical Engineering* 2, no. 1 (2015): 9-18.

[18] Olamef. Manuale d'uso e manutenzione macchina mod. SP 20.08, Accessed October 3, 2022. https://www.olamef.net/.

[19] SMC Pneumatics. Accessed September 16, 2022. https://www.smcpneumatics.com/.

[20] Moroșanu, G.A., V.G. Teodor, V. Păunoiu, R.S. Crăciun, and N. Baroiu. "Quality characteristics analysis for the assembly of the elements from the construction of a mechanism for adjusting the seats in the automotive industry." Paper presented at The 7th International Conference on Advanced Manufacturing Engineering and Technologies - NewTech, Rennes, France, September 08-10, 2022.