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AUTOMATION OF SELECTED ELECTRODYNAMIC PLASTIC METALWORKING OPERATIONS

SUMMARY

The article presents examples of automated seats designed for electrodynamic metalworking, which have been built at the Department of Process Control – the University of Science and Technology (AGH-USC) in Cracow. Electrodynamic technology, which is intensely developed abroad, is one of the methods involving high-power plastic metal forming. It maintains characteristics of other surge-type methods, e.g. explosive or electro-hydrodynamic, regarding working potential, and at the same time it may be fully automated, unlike these methods. Presented material contains descriptions concerning electrodynamic execution of three industrial operations: incandescent lamp unit assembly, convexity forming in teapot bowl and metal sheet forming, all fully automated with pneumatic drives and programmable logic controllers.

***Keywords**: automation, electrodynamic working*

AUTOMATYZACJA WYBRANYCH OPERACJI PLASTYCZNEJ OBRÓBKI METALI REALIZOWANYCH ELEKTRODYNAMICZNIE

W artykule przedstawiono przykłady zautomatyzowanych gniazd przeznaczonych do elektrodynamicznej obróbki metali, opracowane w Katedrze Automatyzacji Procesów Akademii Górniczo-Hutniczej w Krakowie. Intensywnie rozwijana za granicą technologia elektrodynamiczna jest jedną z metod plastycznego formowania metali dużymi mocami, która zachowując cechy innych metod udarowych, np. wybuchowej czy elektrohydrodynamicznej, w zakresie możliwości obróbczych może być, w odróżnieniu od tych metod, w pełni zautomatyzowana. Materiał zawiera opisy elektrodynamicznej realizacji trzech operacji przemysłowych: montażu zespołu żarowej lampy, formowania wypuklenia w czaszy imbryka i kształtowania blach, które zostały w pełni zautomatyzowane z wykorzystaniem napędów pneumatycznych i programowalnych sterowników.

***Słowa kluczowe**: automatyzacja, obróbka elektrodynamiczna*

1. INTRODUCTION

Utilization of innovative high-power working methods increases plastic metal forming potential. Their characteristic feature is conversion within microseconds of explosive charge or electric power accumulated in a condenser into semi-finished product straining work without using conventional tools, as ram, punch, etc.

In the explosive method, exploding charge acts on semi-finished product subject to working either directly or through water or gas medium, which is accelerated to high velocity by detonation products [1]. At the moment, when rushing intermediate medium particles impact material subject to working, the movement kinetic energy is converted into semi-finished product straining work, and pressure exerted then on its surface may reach values in [TPa].

In case if charged condenser is used as a power source, two working variants are possible: electro-hydrodynamic and electrodynamic. The first variant involves condenser arc discharge through a spark formed between electrodes immersed in water, which are connected to condenser covers at the moment, when proper voltage is applied to them. Then, intensely expanding spark channel generates water wave, which, as in the explosive method, hits semi-finished product subject to working at considerable speed, resulting in its strain.

In the electrodynamic method, condenser covers are connected to electric coil called inductor, put near metal semi-finished product surface [2]. The condenser is discharged in the inductor circuit with oscillatory-type momentary current, which generates variable magnetic field around the inductor, in turn inducing rotary currents in metal semi-finished product. In these conditions, the Lorentz force causing mutual repulsion between the inductor and semi-finished product circuits is generated between these circuits conducting opposite electric currents. Proper mechanically strengthened inductors allow to use the Lorentz forces to form semi-finished products, either using matrixes or without them.

Potential to obtain high energy in short time makes the explosive and electro-hydrodynamic methods perfect for plastic forming of large-size flat pieces, or tubes or roll formed elements made of materials that are hard to work using conventional methods. These methods are used mainly to perform individual operations or operations executed at low frequency, determined by relatively long time required for preparation between operations and working station service. During electro-dynamic working, received energy values are lower than those obtained for the other two described methods, this due to limited inductor strength. On the other hand, due to lack of any intermediate medium between the inductor and semi-finished product

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during the working, and owing to extra operations limited regarding the semi-finished product to the "feed-receive"–type action, the electrodynamic method is very susceptible to automation and satisfies principal requirement specified for new technologies being introduced into the industry. The electromagnetic method is suitable for direct working of metal pieces, flat and roll formed, with limited size, in particular made of metals being good current conductors, in mass production conditions. The working is carried out using the effects of electrodynamic compression, expansion or pressing, obtained depending on the inductor shape and location in relation to the semi-finished product. For example, it is possible to compress tube after sliding it into cylindrical inductor (Fig. 1a); a tube slid onto the inductor is expanded (Fig. 1b); whereas sheet placed over the surface of the inductor made as a flat coil is subject to pressing (Fig. 1c) [6].

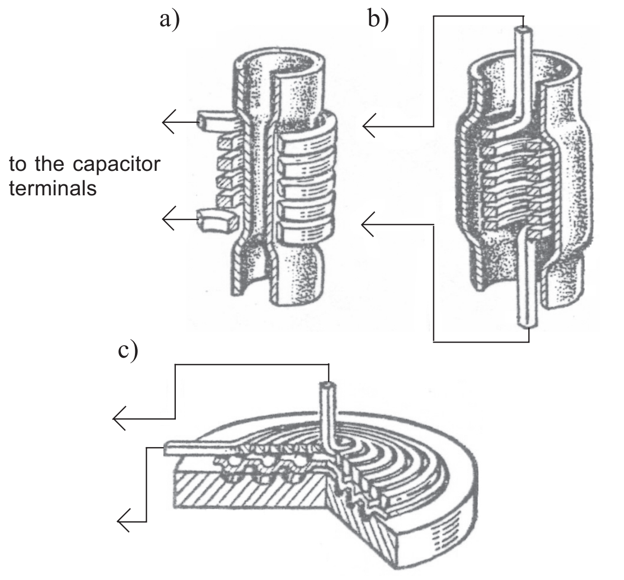

Fig. 1. Effects used during electrodynamic metalworking: a) tube compression; b) tube expansion; c) sheet pressing

Working operations are executed freely or using matrixes put in the way of semi-finished product element being pushed away from stiffened inductor. The electrodynamic metalworking method called by Americans the 21st century technology has found many applications abroad, mainly in strategic industries: military, aircraft, automotive [5]. In Poland, only a few scientific centres carry out research on this method, and there are still no industrial scale implementations so far.

The article presents examples of automated seats developed at the Department of Process Control – the University of Science and Technology (AGH-USC), which are designed to execute industrial working operations by the electrodynamic method, using the effects discussed before. Presented technologies make use of specific toolsets consisting of fixed inductor and matrix, while operations involving semi-finished product transport to the inductor working zone, semi-finished product positioning in relation to the inductor and transport of machined elements to the finished product store are carried out by pneumatic actuators.

2. THE STATION FOR ELECTRODYNAMIC ASSEMBLY OF THE INCANDESCENT LAMP UNIT

Figure 2a shows the lamp unit assembled by connecting metal caps: bottom I, and top II with porcelain fitting III, made according to Figure 2b.

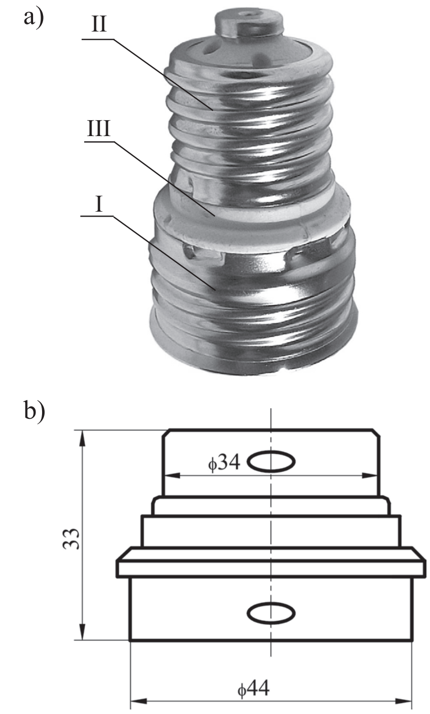

Fig. 2. Incandescent lamp unit: a) assembled unit; b) porcelain fitting
Symbols are explaind in the text

After sliding the caps freely onto the porcelain fitting, the unit assembly involves simultaneous electrodynamic tightening of both caps on outside porcelain element surfaces using the tool head shown on Figure 3. The tool head is a cylindrical clamping inductor 1, equipped with concentrator 2 slid into it, which concentrates magnetic field directly above cap surfaces 3 connected electro-dynamically with fitting 4. Inductor ends are connected to output terminals of surge generator, which is a source of momentary current resulting from discharge of a condenser built-in in the generator.

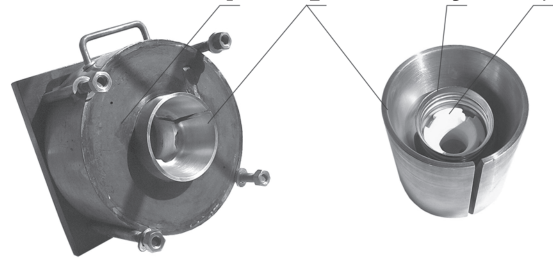

Fig. 3. Tool head used to assemble the incandescent lamp unit: 1 – inductor, 2 – concentrator, 3 – caps, 4 – ceramic fitting

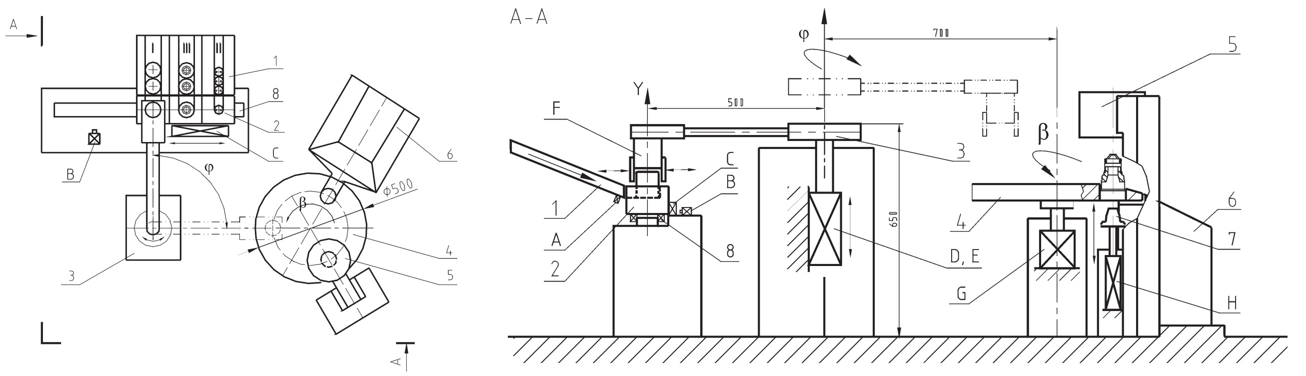

Fig. 4. Schematic diagram of an automated station for the incandescent lamp unit assembly: 1 – container with lamp unit elements, 2 – cassette holding one set of lamp unit elements, 3 – manipulator, 4 – assembly table, 5 – inductor head, 6 – finished product store, 7 – feeding pin
Other symbols are explained in the text

Individual operations taking place during the electrodynamic assembly are executed in the following order: initial cap I and II sliding onto tubular porcelain fitting ends; placing the unit inside the concentrator; charging battery of condensers; discharge of condensers in inductor circuit, resulting in cap tightening on porcelain fitting III; finished unit removal to the finished product store. Fully automated station has been designed at the AGH-USC in order to carry out the lamp unit electrodynamic assembly and "feed-receive"-type actions. The station consists of power block and technological block equipped with pneumatic actuators [4]. A surge generator designed at the AGH-USC would be used as power block. It is a free-standing module adapted for connecting to the inductor terminals with proper electric wires. Figure 4 shows process block diagram, in which main elements are: container 1 with the elements of lamp unit to be assembled; cassette 2 that holds complete set of the unit elements before assembly; manipulator 3; assembly table 4; inductor head 5, connected with wires to the generator (not shown on the drawing); feeding pin 7; finished product store 6.

Container 1 (Fig. 4) is provided with three parallel gravity guides to be filled with assembled elements I, II, III. Three pneumatic actuators (not shown on the drawing) are responsible for buffering freely sliding down elements before they are fed into already filled up cassette 2. Proximity detectors indicate presence of elements I, II, III in cassette 2 chambers. Joint operation of stop ***B*** and two-position actuator ***C***, which pushes the cassette along the strip 8, allows to set it in three positions, in which assembled elements are positioned in relation to manipulator 3. Manipulator 3 with two degrees of freedom is equipped with two drives: linear ***D***, moving the manipulator arm in direction *y*, and rotary ***E***, shifting the arm in φ angle plane. Using a three-finger gripping device ***F***, the manipulator carries elements I, III and II one by one from the cassette to the assembly table and initially combines them by sliding them one on another. Turntable 4, driven by self-aligning actuator ***G***, works as a divider for lamp unit being assembled. Three round through seats spaced every 120° are made in flat turntable top. During the turntable stepwise movement, the above-mentioned seats, one by one, are set up in three positions: first one in the gripping device ***F*** axis, second one in the inductor 5 axis, and third one in the axis of an ejector located before finished product store 6. After elements I, III and II are initially combined, the turntable 4 rotates and brings joint lamp elements under the inductor 5 head. Then, feeding pin 7 connected with piston rod of actuator ***H*** moves upwards and shifts initially combined lamp unit to inductor 5 work area, and keeps it there during the assembly operation. As soon as the elements are electro-magnetically combined, feeding pin 7 moving downwards lowers the assembled unit and sets it in the turntable 4 seat. This is the moment, when making of another set of elements I, III, II begins in a free table seat. Self-aligning actuator ***G*** is activated after the signal indicating that the above operation is complete. The cylinder ***G*** rotates the table top and positions finished lamp unit across from finished product store 6, and initially combined unit is moved under the inductor head. At this moment, spring ejector slides finished product down onto track ramp going to the container with finished products, and this completes one full work cycle at the station. At the same time, initially combined elements I, III, II are brought to the inductor work area and the machine starts another work cycle. Linear control algorithm has been employed at the station, and it is executed by a programmable logic controller, while the sequence of successive steps (operation states) is conditioned by the occurrence of specific events signalled by binary proximity detectors.

3. THE STATION FOR FORMING CONVEXITY IN ALUMINIUM TEAPOT BOWL

During the teapot production, special convexity 1 (Fig. 5b), is made in the cap, which makes the pot body. The convexity stiffens the bowl spherical cap and at the same time provides a decorative ornament for the final product.

Figure 6 shows picture of a toolset for electrodynamic forming of the above-mentioned bowl, consisting of inductor (Fig. 6a) and matrix (Fig. 6b). As soon as the inductor is slid into the cap and matrix is put on its outer surface, we obtain a unit (Fig. 6c), which is ready for cap working. While current from generator flows through the inductor for fraction of a second, the convexity is formed resulting from the inductor expanding action.

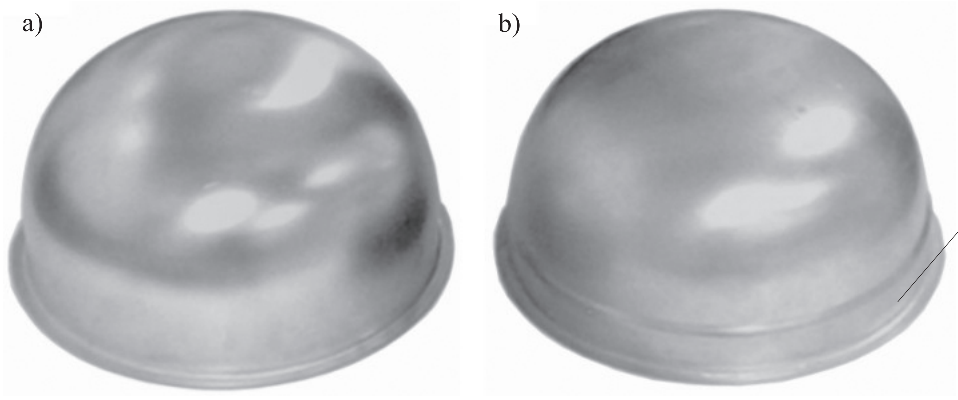

Fig. 5. Teapot bowl: a) before working; b) after convexity 1 forming

Fig. 6. Toolset for electrodynamic convexity forming:
a) inductor; b) matrix; c) toolset with teapot bowl ready for working

Described technology for bowl electromagnetic working has been used at the Department of Process Control AGH-USC when developing an automated seat provided with pneumatic drives, designed to execute this operation cyclically without personnel involvement [3]. The following units may be distinguished in the station, shown schematically on Figure 7: I – positioner, II – manipulator, III – matrix, IV – inductor. The diagram does not show generator module. It is connected with working seat using freely laid electric wires, which supply the inductor and allow to transmit electric command signals between seat and generator.

Guide 3 with metal track makes the main element of positioner. The bowl is moved along the track side edge by pusher 2 fixed to the end of linear cylinder 1 piston rod. The cylinder is activated at the moment when pulse from proximity detector 4 is received. The detector signals cap presence in positioned location on the track.

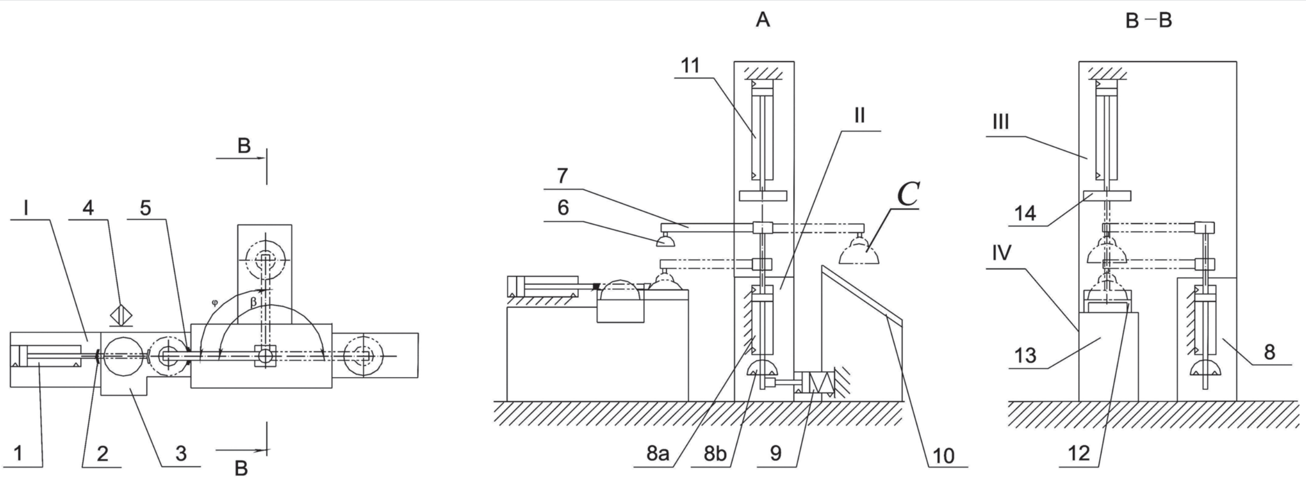

Fig. 7. Schematic diagram of an automated station for electrodynamic convexity forming on teapot bowl: I – positioner, II – manipulator, III – matrix, IV – inductor
Other symbols are explained in the text

Stop 5 equipped with rubber shock absorber fixed to the guide allows to position the bowl unequivocally in relation to the manipulator.

The manipulator executes the following operations:

– transports cap from positioned location in the track towards the inductor,
– positions semi-finished product in the inductor work area,
– moves roll formed bowl over the ramp, which guides finished product to the container.

The manipulator main subassembly is a linear-rotational drive 8 equipped with linear actuator 8a and oscillatory actuator 8b. Arm 7 connected with actuator 8a piston rod ends with vacuum gripping device 6 designed to manoeuvre bowl ***C*** subject to working. The manipulator unit is provided with sliding out stop connected with linear actuator 9 piston rod. Sliding out stop halts the manipulator arm in its intermediate position (above the inductor), after it has rotated 90° angle from its initial position.

Inductor 12 (picture on Fig. 6a) is the working tool. It is a stationary element, permanently fixed to base 13. Required shape for worked bowl is given by matrix 14, (picture on Fig. 6b), mechanically connected to linear actuator 11 piston rod. Electrodynamic bowl working is initiated as soon as the bowl is seated in the inductor using the gripping device, and matrix is slid onto it. Electrodynamically formed bowl is moved by manipulator gripping device from the inductor work area over the ramp 10 and as soon as gripping device suction cup is released, it drops to the finished product container owing to gravitational force. Next steps carried out in the scope of work cycle at presented station are executed by the controller, according to non-branched linear algorithm, which uses transition conditions obtained from proximity detectors, track connectors, and generated from outside push-buttons.

4. SHEET FORMING AUTOMATIC MACHINE

The device has been designed as an independent station for electrodynamic sheet forming, using flat inductor shown on Figure 8, and matrix mounted alternately in a grip belonging to the station.

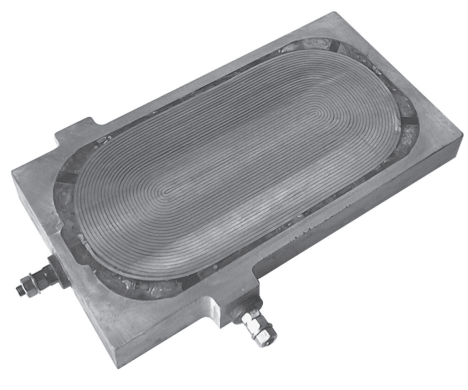

Fig. 8. Flat inductor for electrodynamic text pressing

The picture shows one of matrixes being used (Fig. 9a), and copper sheet formed using it. On the sheet you can see electrodynamically pressed company logo (Fig. 9b). The device designed at the Department of Process Control is provided with pneumatic drives used to: transport metal sheets to be worked and already worked elements; position sheets; relocate certain station subassemblies [5].

a)

b)

Fig. 9. Matrix (a) and metal sheet with electrodynamically pressed text (b)

The station design schematic diagram is shown on Figure 10, where the following subassemblies may be distinguished: I – sheet feeder, II – inductor, III – matrix with receiving unit, and IV – openwork supporting structure.

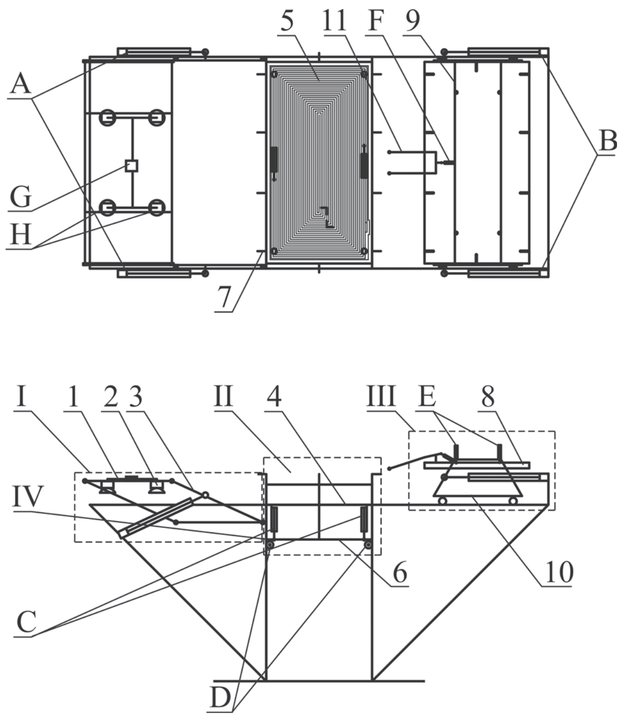

Fig. 10. Schematic diagram of an automated station for electrodynamic text pressing: I – sheet feeder, II – inductor, III – matrix unit, IV – supporting structure
Other symbols are explained in the text

The diagram does not show generator, which, same as in previously described devices, is a separate module connected to the inductor terminals with electric wires.

The task of unit I is to transport sheet to be worked from raw sheet store to the inductor work area. Unit I is provided with frame 1 made of aluminium sections with four gripping devices 2 fixed to it. The gripping devices have suction cups fitted to take sheets from pile. The frame has self-aligning connection through eight articulated joints with four arms 3, which are moved by two actuators ***A*** extorting the frame swinging motion between the sheet metal store and the inductor unit. Moreover, vacuum generator working with gripping devices 2 is fixed onto frame 1.

Unit II is provided with seat with inductor fixed permanently in it. The inductor is designed for direct sheet metal working. Unit II is equipped with supporting plate 4 with inductor 5 mounted on it (Fig. 8). Frame 6 is also located under plate 4, which works as a supporting element for one part of the lock mechanism, used to close and lock the matrix when it is in working position above the induc-tor. The lock is provided with ten rotational bars 7, which would be inserted in holes provided in matrix housing 8, which contains second part of the lock. Four actuators ***C*** built-in in unit II are used to move frame 6 with bars 7 up and down during the first lock closing stage. Two actuators ***D*** are used to rotate bars in order to block housing 8 motion when matrix is slid onto the inductor (second lock closing stage).

Unit III contains matrix housing 8, and matrixes not shown on the drawing will be fixed to it alternately. This housing plate is connected to piston rods of four actuators ***E***, and their cylinders are seated in supporting frame 9 made of aluminium sections; these actuators move housing 8 with matrix up and down. The unit design includes two trolleys 10 moved horizontally by two actuators ***B*** towards the inductor. Additionally, formed sheet receiving unit is installed on plate 8, and its arms 11 are connected with actuator ***F*** piston rod through lever system not shown on the diagram.

Full machine work cycle includes fourteen successive steps executed by programmable logic controller, which receives binary signals sent by detectors installed in the device, informing that executive elements have reached certain positions. The device operation is initiated by pressing START push-button on the control panel. This activates vacuum generator 7 connected with gripping devices 2 with suction cups, which grip metal sheet on pile. At the same time, sliding out piston rods of actuators ***A*** move sheet over inductor 5. At this moment, as soon as gripping devices are released, metal sheet drops on the inductor, and frame 1 with gripping devices returns to its initial position. The next step is to activate actuators ***B***. As a result of this trolleys 10 move and matrix is slid over the inductor. Then, matrix is guided over the inductor after activation of cylinders ***E***. In the next step, housing 8 with matrix is lowered down onto sheet laying on the inductor. Next device work cycle stages concern lock elements. Activated actuators ***C*** move upwards frame 6 with lock bars 7. The lock bars slide out and thus additionally position metal sheet in relation to the inductor. When bars 7 slide out, actuators ***D*** make them rotate, which results in lock snapping. As a result of this, matrix is immobilised. Lock closing signal initiates operation of surge generator (not shown on the diagram) connected with the inductor, which involves condenser charging and then discharging. Metal sheet plastic forming operation is carried out during the discharge. The pulse received from generator during condenser discharge initiates sequence of operations aimed to discharge the matrix-inductor set. These operations include the following steps: rotation to bars 7 initial position and lock opening; lowering frame 6 with bars 7 sliding out of matrix housing; lifting matrix with housing 8. At this moment, an electro-valve is activated, which supplies compressed air to nozzles (not shown on the diagram), resulting in momentary pushing metal sheet above the inductor surface. Next, the receiving unit is activated, and its arms 11 are lowered towards the inductor and stop just behind formed metal sheet edge. Then, while trolleys 10 move to their original positions, metal sheet receiving unit arms slide finished product down to the store, and then they are lifted back.

Three operation types are provided for in the designed seat, and selected with a switch installed in the control desk:

1) ***AT*** – automatic work,
2) ***KR*** – step work,
3) ***RR*** – zeroing.

Automatic work cycle starts after setting the switch in the ***AT*** position and brief pressing the START push-button by operator. During the ***AT*** operation, the above steps are executed one by one, until the device is stopped by pressing the STOP push-button. Step work option (switch in the ***KR*** position) involves executing one of the next work cycle steps each time after pressing the START push-button. When the switch is set in the ***RR*** position, the device drive elements will be brought to their initial positions after pressing the START push-button.

5. CONCLUSION

The article presents three examples of automated working seats designed at the University of Science and Technology (AGH-USC) in Krakow, using the unconventional electrodynamic metalworking technology. This material contains simplified station design schematic diagrams, allowing to describe their work, whereas complete station specifications are kept at the Department of Process Control, AGH-USC. Two of presented stations have been designed for operations carried out currently in Polish industry, whereas text pressing is proposed by the AGH-USC team. It should be stressed that proper electrodynamic working operation duration is milliseconds. At the same time, owing to the use of pneumatic drives, durations of other operations executed at presented work stations may be adapted to industrial line needs by easy change in executive element movement speed, using programmed valves choking air flow.

References

[1] Babul W.: *Metal Straining by Explosion.* WNT 1980

[2] Bednarczyk J.: *Metal Plastic Working Using Electrodynamic Method*. Krakow, FSI 2002

[3] Bętkowski Ł.: *Design of An Automated Station for Electrodynamic Forming of Aluminium Teapots.* Dissertation, AGH-USC 2003

[4] Juszczyk M.: *Automated Seat for Electrodynamic Incandescent Lamp Unit Assembly.* Dissertation, AGH-USC 2002

[5] Zdebski A.: *Automated Seat for Electrodynamic Metal Sheet Pressing.* Dissertation, AGH-USC 2004

[6] Internet; http://www.magneform.com/pres.html

[7] Internet; http://www.magnepress.com