Utilization of SCARA Robots in the Assembly of Electrical Contacts

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***Abstract*—The article deals with increasing production assembly of two types of electrical contacts. Currently, use of manual assembly is insufficient, since production increases up to twofold. The solution is to deploy SCARA robot with the task of not only individual parts inserted into the mounting nests, but the assembled contact subscribe afterwards. The article proposed two similar solutions, which vary by time the autonomous operation of 3 or 5 hours. The difference lies in the use of a larger pool of necessary components. Their storage and subsequent use is realized by means of vibratory conveyors**

***Index Terms*—SCARA, assembly workplace, electrical contacts**

I. Introduction

Increasing the productivity of forcing companies deploying automated and robotic equipment. The current trend in assembly operations seeks to ease the burden human from repetitive work, wherein during the mounting of there are no frequent modifications. Automated assembly compared to manual assembly is distinguished mainly higher productivity and stability of quality. It can say that automation of these of workplaces is based on the development of special-purpose equipment based on pneumatic or electric actuators, supplemented by automatic feeding of input objects. For entry precise positioning and orientation objects are used vibratory trays. In the achievement event of a larger assembly times are used for the administration of more complex components, a variety of robotic devices. These workplaces have repeated cycles of assembly and for control of such workplace is sufficient regulation PLC or industrial computer [1].

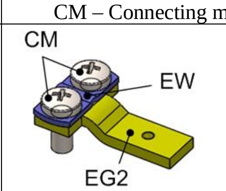
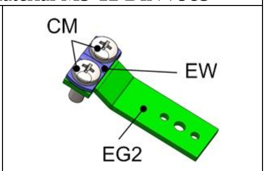
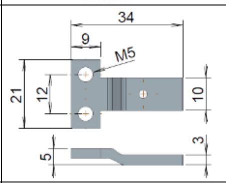
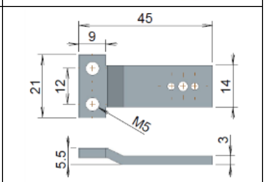
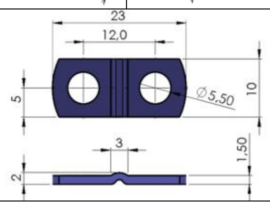
The use of a robot represents is primarily an increase in productivity while preserving or improving the resulting quality. Based on the research and calculations, it was found that the cost of a medium-sized robot is around the value of 0.75 cents per hour. For smaller robots, for example: a SCARA robot can cost up to 0.60 cents per hour [2].

In less advanced economies, such as the Slovak Republic, the average hourly wage of the worker is 8.3 € / hour [3]. The minimum wage is 2.5 € / hour, which represents more than four times the labour costs of the robot. The return on purchase and the robot operation is increasing each year as the minimum wage rises. Another specific problem is the uneven distribution of free labor within the country. In the city of Kosice, where the company is located, the registered unemployment rate is 4 to 9%. What it means to find a suitable (skilled) labour force is problematic and wage demands are greater. The average monthly salary in Kosice is around 976 €/ month, which is around 5.6 €/per hour. For this and other reasons mentioned above, the use of a robot for mounting electrical clamps appears to be justified

II. Type of Electrical Clamps

A complete clamp (EC1, EC2) consists of three components, Table I, the connecting material (CM) and the washer (EW) is the same for both clamps. The only difference is in the size of the components EG - girder.

TABLE I. PARTS FOR CLAMPS EC1 AND EC2

Type of clamps	EC1	EC2
Component	EG1 – Girder 1	EG2 – Girder 2
	EW - Washer	
	CM – Connecting material M5-12 DIN 7985	
Figure of assembly clamps		
EG – Electrical Girder		
EW – Electrical Washer		

Currently ongoing assembling the various parts of the terminals by hand with the participation of a human operator. Man during assembly performs monotonous work with relatively small parts that extracts already correctly oriented from the vibration tray. Inserting screws into the corresponding holes is done using a

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magnetic tip screwdriver, which ensures retention screws on the tip of a screwdriver during its handling. Use screwdrivers are driven by the air, with ability of setting torque. Removing assembled parts of the mounting nest is realized using a mechanical ejector, foot control operator [4].

Average time installing one clamps and with its delivery to an outlet belt conveyor is 6.5 sec, which represents the average throughput through 4000 pieces. Fig. 1 shows a view of the mounting system nests and human operator.

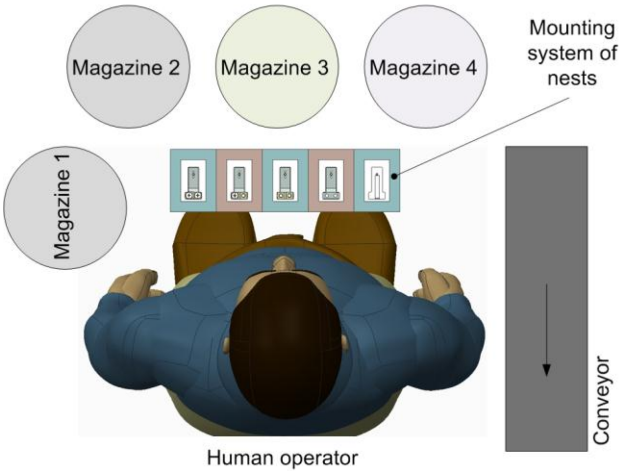

Figure 1. Current state of the workplace.

Because of the increased productivity for 1 change is the need to reduce production time to achieve throughput through 7100 pieces. Human operator is not able to achieve the desired values of productivity. Deployment of another operator, the cost to the wage unprofitable. It was therefore necessary to propose an automated device allowing to operate in a relatively small workspace without further interference in nearby devices.

TABLE II. SPECIFIED PARAMETERS

Defined parameters	Unit
Number of types (electrical clamps)	2 types
Optimal production dose	7100 pieces
Max. dimensions of workplace	3 x 3.5 m
Reserve of components in the trays	2 - 4 hours
Removal of assembled parts	After 2 - 4 hours
Human intervention in assembling	Without operator
Permitted types of drives	Pneumatic, electric

Another requirement sponsor was to ensure replenishment of necessary work was carried out before the changes and twice during the change. First is completed for a short 15 min breaks that occur after three hours of work. Second replenishment during the lunch break that occurs after 5 hours from the beginning of the shift. That requirement was defined due to continuous production of non-standard parts, which the company makes on other flights [5].

In Table II are shown the specified parameters that have to be followed for proposals workplace.

III. Calculation of Productivity

The requirements for solutions:

- Required quantity for one work shift (7hour and 15 minutes) – 7100 piece.
- Assembly of two types of clamps (EC1, EC2) at one workplace after necessary adjustments.

Simplified calculation of productivity:

1. Calculation of tact for 7hour and 15 minutes (26 100 seconds):

Tact = time per shift / required number of clamps

$$Tact = \frac{Time}{Pieces} = \frac{26100\,\text{sec}}{7100\,pieces} = 3.68\,\text{sec}. \qquad (1)$$

The theoretical tact of one shift (7hour and 15 minutes) will have 3.68 sec/piece. To ensure the reserve due to unforeseen influences we propose the value of tact (3.50 – 3.60 sec / piece).

2. The time required to manufacture 7100 pieces of clamps:

$$C_{7100} = 7100\,piece * time\ assembly\ on\ one\ a\ clamp$$
$$C_{7100} = 7100 * 3.55\,\text{sec} = 25205\,\text{sec}. \qquad (2)$$
$$C_{7100} = 7100 * 3.6\,\text{sec} = 25560\,\text{sec}.$$

Time needed for assembly: (25 205 sec → 7.0 hour), (25 560 sec → 7.1 hour).

Required number of 7.100 pieces assembled of clamps can be reached in 7.0 (7.1) hours. This means a reserve on the time of downtime is 15 (9) minutes (900 (540) seconds) during work shift.

IV. Proposals for Individual Assembly Operations

The sequence of individual operations based on the manufacturing process, which defines the steps. The proposed installation consists of the development of two of assemblies designated EC1 and EC2. Producibility of the individual assemblies is not the same, based on an analysis of orders for the last calendar year can be concluded that the ratio is 2: 1. This means that it remains EC1 the production of approx. twice as many as assemblies EC2. Within the individual assemblies there is only change one part and the EG (EG1 and EG2). Standard parts (screw M5-12 DIN 7985) and the portion Washer Electrical EW apply equally to both assemblies.

Since one of the requirements is to limit the working area, it is appropriate quick-change system nests for settling parts EG1 and EG2. Therefore, it is possible to propose the following procedure for each assembly operation.

The assembly process is derived from the system of exchange nest of parts (Electrical Girder - EG1 / EG2), Fig. 2.

To figure axis labels, use words rather than symbols. Do not label axes only with units. Do not label axes with a ratio of quantities and units. Figure labels should be legible, about 9-point type.

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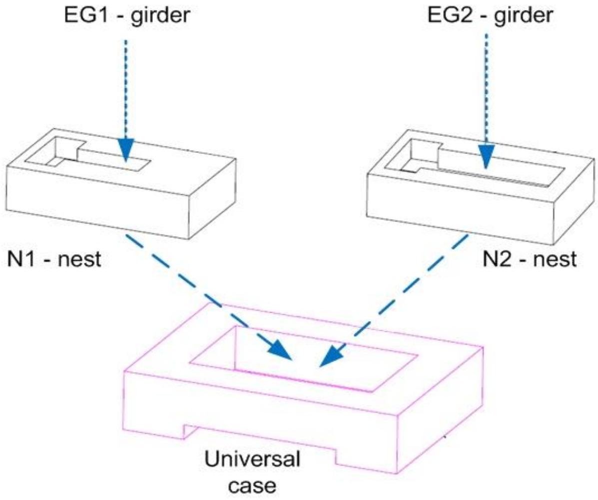


Figure 2. Changeable nest.

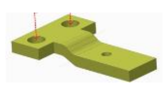
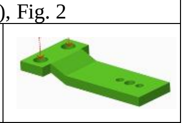
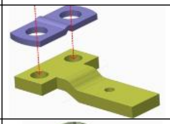
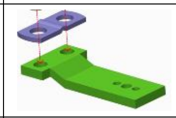
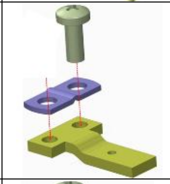
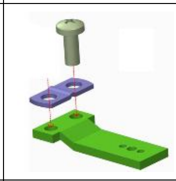
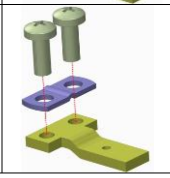
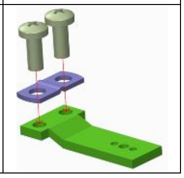
When the need a change the production of clamps EC1 to EC2, or vice versa, the operator proceed as follows:

- Empties the each nest filled with clamps.
- Empty the stack finished parts filled with clamps.
- Replacing individual nests on the equipment by means of quick-change system (the total number of nests of 6 pieces).
- Supplement of the component clamps into the respective vibrating hopper (vibratory conveyors).
- Adjust the in the control panel realization changes production – assembly.
- On the control panel SCARA robot selects the appropriate program.
- Start assembly of clamps.

The nest is made of tool steel (1.2080 (X210Cr12, 19 436) to increase resistance and for prevent corrosion during the life of the device. The proposal is based on the assembly procedure divided into three basic steps Table III.

Using a vibrating conveyors is can be achieved by running time of workplace without operator intervention 2- 4 hours. Before the expiry of two hours light signal alerts the operator of require additions to components into vibrating trays and conveyors. If will not be located the components at the output of the vibration trays, will stop working the workplace. Inserting one piece component EG1/EG2 and one piece component EW lasting a total of 3.55 – 3.6 seconds [6].

TABLE III. ASSEMBLY PROCEDURE

Step	Description	EC1	EC2
1	The first step is to insert the exchange nest in universal case in the rotary table (carrousel), Fig. 2		
2	The second step is to insert the girder EG1 or EG2 into mounting nest		
3	The third step is to insert on the girder washer EW		
4	In the fourth step is realized inserting and screwing of first screws CM (M5-12 DIN 7985)		
5	In the fifth step is realized inserting and screwing of second screws CM (M5-12 DIN 7985)		

Automated workplace at position (P1) is provided with two vibrating trays for shipment of parts EG1, EG2 and EW. When mounting can be run only one vibrating tray by type of production which is ensured by means of control system. When mounting clamps EC1 is running vibrating tray of components EG1 and when fitting clamps EC2 is running vibrating tray of components EG2. Adding the components EG1 / EG2 to vibrating trays during operation is realized by vibratory conveyors.

At position (P2 and P3) are located pneumatic screwdriver from DEPRAG. At each of these positions is carried screwing one screw C (M5-12 DIN 7985), which is conveyed from the vibrating tray to the head screwdrivers by means of pipework. Refilling of screws to vibrating tray during operation of the solution is analogous to the positions 1 by means of vibratory tray [7].

Position (P4) is used to check correct installation using a camera Omron F150. The camera can detect the correct positioning of washers and connecting material. In case, that in clamps is not fitted on the screw, or screws in the rather wide angle, as recommended, the camera control system will send information on dumped assembled clamps at position 5. In the event that camera system evaluates the assembly as a good, the control system sends information of the release finished clamp in the position the 6. On the basis the information sent from the camera system to the control system devices can be accurately determine the number of good and bad assembled clamps EC1 and EC2 [8].

Positions (P5 and P6) is for releasing of clamps from the rotary table. At the fifth position occurs when poorly assembled clamp to its removal from the nest. Releasing clamps in (P5) is solved by a pneumatic cylinder, where rotation of the nest to a suitable position for releasing the clamp is carried out by turning nest from horizontal to the vertical position of 90°. After releasing the clamps it is realized return the nest on starting position and is ready to movement on position 6.

On the sixth (last) position is carried the removing the clamps assembled by means SCARA-type robot. Proposals the work position on the turntable is tackled by the carousel, containing the six position. The individual steps are described in the Fig. 3 [9].

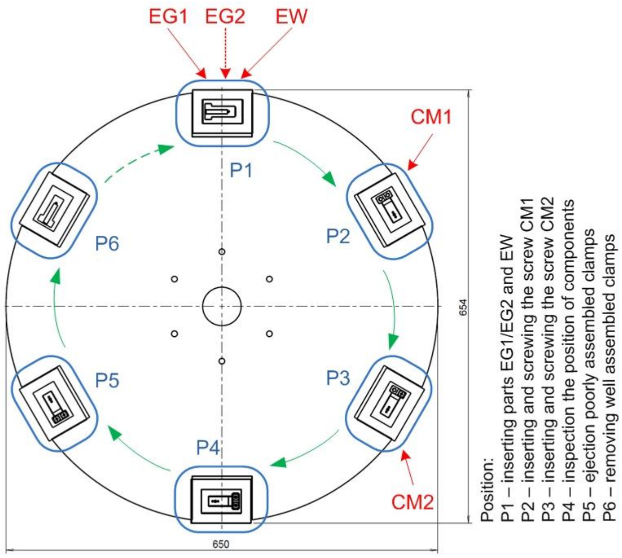


Figure 3. Work position on the carrousel.

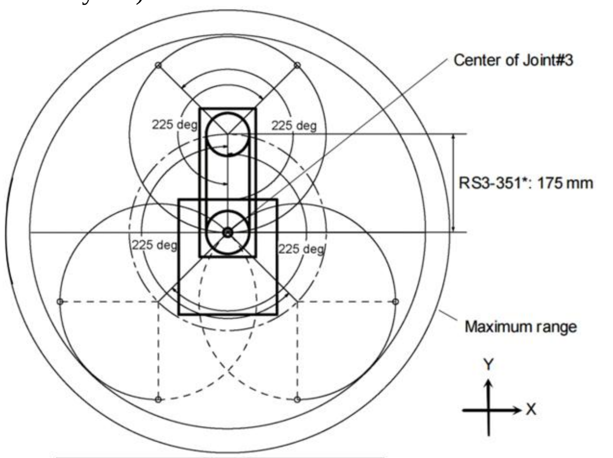
For manipulation with components EG1 / EG2 and EW was selected industrial SCARA type robot from Epson Spider (RS3-351S) with a control system Epson RC620 [10]. The robot parameters are shown in Table IV.

TABLE IV. ROBOT PARAMETERS

Defined parameters	**Unit**
Payload	nominal 1 kg
Repeatability Horizontal/Vertical	±0.01 mm
Repeatability Orientation	±0.01 °
Insertion force	150 N
Moment of Inertia	nom. 0.005 kg*m ²
Product weight	17 kg
User Wires Pneumatic	(1x Ø4mm, 2x Ø6mm)
Max. operating speed (#1, #2)	6237 mm/s
Max. operating speed (#3)	1100 mm/s
Max. operating speed (#4)	2600 deg/s

The robot's workspace is based on Max. Motion range (Ø 700 mm). The length of each arm is 175 mm. Fig. 4 shows the robot workspace viewed from above.

To achieve the desired productivity of, it is designed tact 3.50 - 3.60 seconds. The robot not only serves to insert the individual components to the nest (2 components), but also the transfer of ready clamps (EC) from the nest. For this reason, it is necessary to ensure that the robot executes a total of three operations in one cycle. The first two operations are in position (P1 - components EG and EW) and the third operation is in position (P6 or P5 - assembly EC).



	RS3-351*
Arm #1 Length	175 mm
Arm #2 Length	175 mm

Figure 4. Workspace of the robot - Ground plan.

The maximum speed of the SR robot is dependent on the speed of each arm (# 1 to # 4). The movement speed of the robot arms (# 1, # 2) in the plane (X-Y) is max. 6237 mm / s. The linear velocity of the robot is based on the axis movement velocity (# 3). The maximum rotation speed is dependent on the robot axis (# 4):

$$S_{LIN(X,Y)} = S_{\#1,\#2} = 6237 mm/s. \tag{3}$$

$$S_{LIN(Z)} = S_{\#3} = 1100 mm/s. \tag{4}$$

$$S_{ROT} = S_{\#4} = 2600°/s. \tag{5}$$

Based on robot measurements, we have arrived at optimal motion speed values: Speed of movement in the plane (X-Y) - 5000 mm; Stroke speed of 1000 mm / s; Rotational speed 2000 °/ s.

From a time perspective, it is also possible to assign the individual maximum speeds to the maximum time needed to perform the desired operation, in tab. 5.

TABLE V. MAXIMUM OPERATION TIME

Speed	**Time (max. 3.6s)**
Axis (X-Y) - #1, #2	0.17 s
Axis Z - #3	0.13 s
Rotation - #4	0.14 s

When inserting a component (EG, EW) and removing a clamp (EC), it is necessary to overcome the path and realized rotation according to the formula:

$$Tact_{3.55} = Time_{EG} + Time_{EW} + Time_{EC} \tag{6}$$

$$Tact_{3.55} = 1.04 + 1.17 + 1.21 = 3.56s.$$

where,

$$Time_{EG} = 3 \times S_{\#3} + S_{\#1} + 2 \times S_{\#2} + S_{\#4} \quad (7)$$

$$Time_{EG} = 3 \times 0.13 + 0.17 + 2 \times 0.17 + 0.14 = 1.04s$$

$$Time_{EW} = 4 \times S_{\#3} + S_{\#1} + 2 \times S_{\#2} + S_{\#4} \quad (8)$$

$$Time_{EW} = 4 \times 0.13 + 0.17 + 2 \times 0.17 + 0.14 = 1.17s$$

$$Time_{EC} = 3 \times S_{\#3} + 2 \times S_{\#1} + 2 \times S_{\#2} + 2 \times S_{\#4} \quad (9)$$

$$Time_{EC} = 3 \times 0.13 + 2 \times 0.17 + 2 \times 0.17 + 2 \times 0.14 = 1.35s \cdot$$

Based on the realized calculation, it is possible to state that the use of the robot allows to keep the production cycle on value 3.56 s.

Gripper robot uses for handling threaded holes in components EG1 / EG2 and EW having of both fitting parts of the same diameter and pitch. Rotation of parts to correct position is solved by means of a pneumatic rotary table Festo DHTG-90-6-A. Design of automated workplace of supply parts for three hours shown in, Fig. 5.

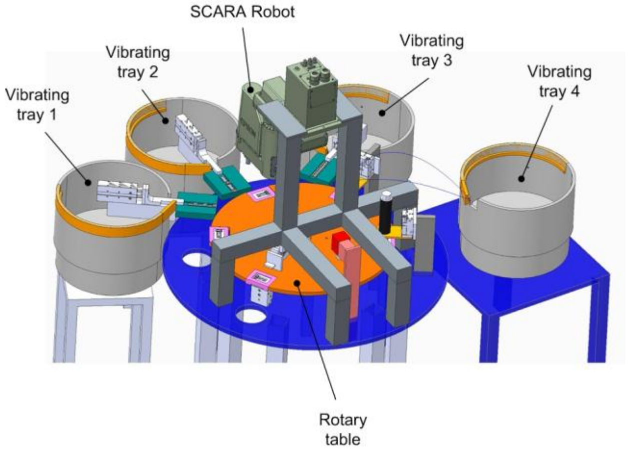


Figure 5. Automated workplace - 3 hour.

Supplementing workplaces of three vibratory conveyor can reduce the need for replenishment of parts to four hours. Dimensions of work increased to a maximum value of 2.5 mx 3.2m. Design of automated workplace of supply parts for five hours shown in, Fig. 6.

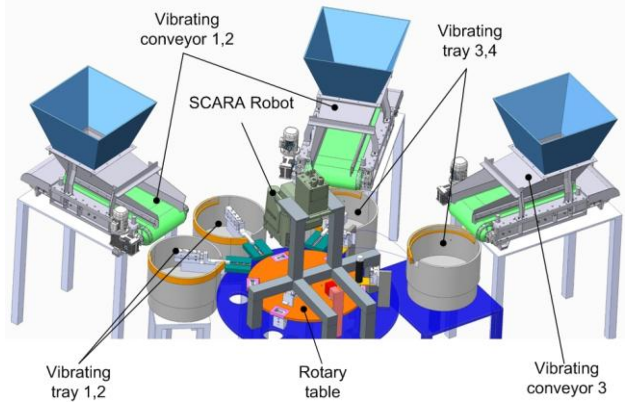


Figure 6. Automated workplace - 5 hour.

V. Conclusion

The article describes the proposal of automated assembly clamps for the electrical industry. With regard to the entry imposed requirements by customers is in article displayed a schematic proposal of the automated the mounting of clamps. Furthermore, article describes the proposal itself automatized system as a whole as well as the design of the individual components of mounting the workplace. The project is elaborated into stages of implementation, the proposed solution meets the stated requirements. Estimated daily productivity of the workplace during one shift without downtime is 7100 pieces.

Acknowledgment

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Jan Semjon was born in 1979 in Snina, Slovak republic. After graduation from the Department of Production System and Robotic at the Technical university of Kosice (TUKE) in 2003, He also worked as a researcher at the TUKE, Faculty of Mechanical Engineering in the design of welding products for the automotive industry. In 2009, he received his PhD degree and in 2014 his degree assistant professor. He authored more than a hundred publications published in conferences and magazines, and published two monographs in the mother tongue.

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