1 Automation & Robotics: An Optimized Loudspeaker Assembly for a Mechanized Serial Production Line

1.1 Introduction

Modern manufacturing of products in small and large scale series production utilise conveyors and automated assembly lines. The purpose is usually to reduce and replace as much as possible labour intensive and dangerous assembly operations with automated ones. Thus, productivity and quality can also be increased. Many current production processes involve computerised assembly using robots or flexible automated production systems where manual assembly operations are completely replaced by machines [1].

The aim is to have monotonous and similar in type operations or such causing fatigue, stress and production traumas, gradually replaced by automated assembly cycles, means and techniques. This usually widely involves industrial robots and handlers. Higher productivity, lower cost and higher quality of assembled products are usually required here. Recently, latest assembly techniques for simpler or more complicated products in engineering, device manufacturing and electronics involve computer-aided automated assembly means in Flexible Automated Production Lines or other types of automated conveyor lines, which provide full automation and human labour replacement [1].

In this loudspeaker production case study, we have a typical example of a series production, which provides opportunities for improved and automated assembly. Regardless of the wide variety of loudspeaker types and dimensions, this product is of average and even low complexity: it comprises 15 to 30 component parts. These can be assembled using mechanised assembly means with only a limited number of manually performed operations [2]. This data is used to calculate current assembly and conveyor parameters and eventually, assembly and conveyor parameters after the modifications and improvements in organisation.

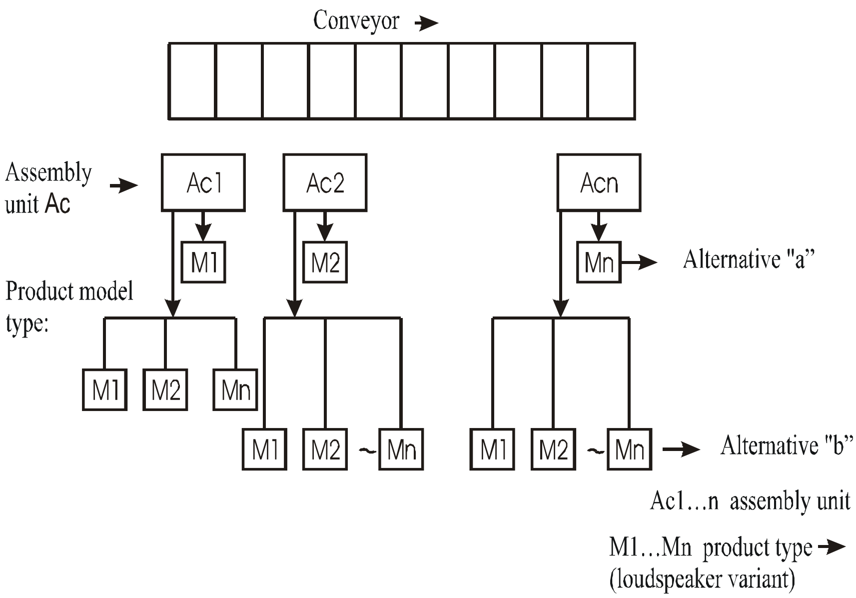

Figure 1 Initial organisation diagram

The work stations are positioned along the conveyor and various types and loudspeakers variants can be manufactured either in parallel time or consecutively in time (consecutive manufacturing of individual variants, individual production lots are run consecutively) [2]. In the alternative "a" each individual assembly unit is used to assemble one or maximum two types of loudspeakers. Therefore, it is equipped with fewer and simpler attachments and assembly equipment. (In this alternative, the skills required for assembly workers are not high) – Figure 1-a.

In the alternative "b" individual workstations included in the assembly unit (section) are supposed to be highly specialised and equipped with the necessary assembly means required to manufacture all variants of loudspeaker types. – Figure 1-b.

From Figure 1 it is understood that the alternative "a" is not applicable in our case since if only a single product type is to be manufactured at a time, assembly units designed for other products will be idle this being unacceptable.

Assembly line output & conveyor operation

For the initial arrangement, 120 000/month – 6 variants (product types), the time required to manufacture a single loudspeaker assembly (T1a) will be:

(1) $T_{1a} = \frac{T_M}{N_M}$, where T_M – operational time for 1 month [hours], and

N_M – the number of products manufactured per month.

$T_{1a} = \frac{50.4}{120000} = \frac{200}{120000} = 0.00166[h/unit]$, where 4 is the number of weeks in a month.

$T_{1a} = 0.00166.3600 = 6[\sec/1unit]$

Thus, with the initial line rate, six (6) seconds will be required to assemble a single loudspeaker unit. After subsequent modifications, we can calculate from expression (1) above for N_M = 180 000 [units/month]:

(2) $T_{2a} = \frac{50.4.3600}{180000} = 4[\sec/unit]$

1.2 Developing a dolly removal strategy

1.2.1 Loudspeaker arrangement

In general, every loudspeaker features the type of design illustrated in Figure 2.

Item	Designation	Number	Material
1	Body (support chassis)	1	Fe, Al metal
2	Magnetic motor unit (system)	1	Fe, etc.
3	Membrane – conical shape	1	Composites
4	Packing – dust cap	1	Composites
5	Oscillator – corrugated, centring	1	Composites
6	Collar – corrugated, together with the conical membrane	1	Composites
7	Voice coil oscillator	1	Constituent assembly with coil
8	Electrical wiring – terminals and cable wiring for the coil	1	Electrical assembly made up of several components
9	Bonding and connecting elements (materials)	1	Glues, etc.

δ = 0.38–0.7 [mm], D – “centring” diameter between item 1 and item 2

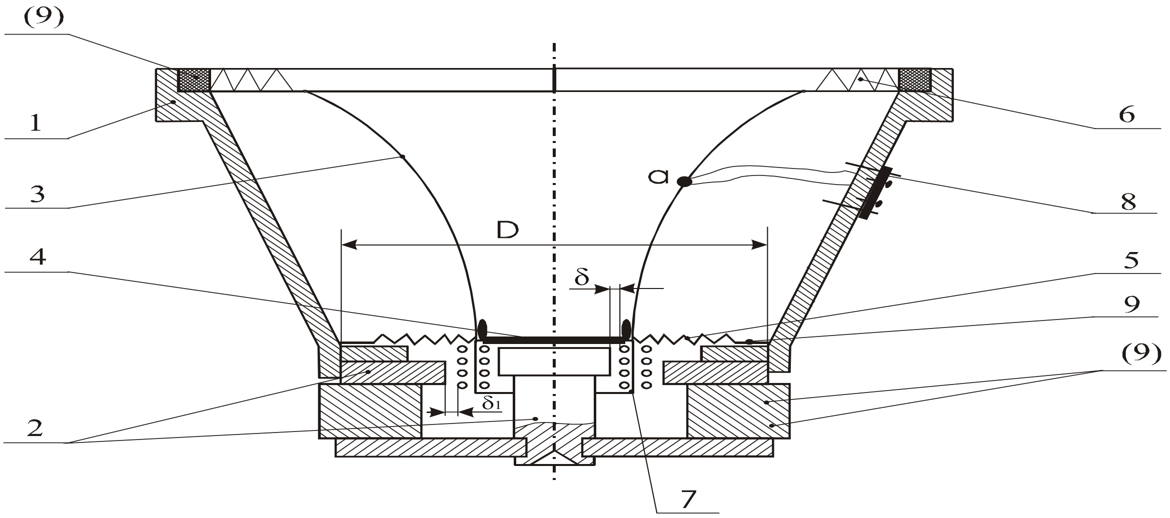

Figure 2

1.2.2 Operation

The electrical pulse transmitted via 8 to the coil 7 causes vertical oscillations as a result of the interaction between the electrical magnetic field of the coil and permanent magnets of 2. Oscillations are transferred to the conical membrane 3 and the centring oscillator 5 which maintains the gap $\delta = 0.38 \div 0.7$ mm (and δ_1) constant.

1.2.3 Description of assembly and characteristic features

The body 1, which is usually made of stamped steel or aluminium sheet is connected to the rest of the component parts by means of glue applied on its contact surfaces (only rarely by means of welding or riveting). The sequence of assembly operations is such that it allows for consecutive addition of individual component parts or sub-assemblies constituting the product and most important, good quality of bonding and connections, ensuring the gap δ (and also δ_1) is maintained.

For the purpose of all said above, sub-assembly 2 (motor unit) could be pre-assembled separately and then in turn assembled with the body 1. Separate pre-assembly can also be made for component parts included in the voice coil and the suspension 5, 7 and this whole assembly can later be glued to 9 to join it with 1 + 2, ensuring the gap δ is maintained for the dolly. The last parts to be assembled should be the cone 3 and the cover 4 and the wiring from the coil 7 to the terminals 8 and point *a* located on the cone 3. This results from the fact that it is impossible to glue 5 to 1 (with 9) when the cone 3 is assembled. If the cone 3 and the corrugated oscillator 5 are assembled at the same time, there is a risk of changing the gap δ after the dolly is removed because of the relatively heavier weight and higher "toughness" of the cone 3 when it has not been manufactured sufficiently precisely. Some lack of concentricity might arise when 6 is not properly glued to the body 1.

1.2.4 Assemblies (sub-assemblies)

Considering Figure 1 and the original assignment, the sub-assemblies involved are:

1.2.4.1 The motor unit assembly

This comprises 4 separate parts usually round in shape (Fig. 3). D, d, d_1 are positioned concentric with each other and $d_1 - d = 2\delta_2$, where δ_2 is sufficient to insert the coil of the voice oscillator (item 7 in Figure 2) and leave a radial gap of $\delta = 0.35 \div 0.7$.

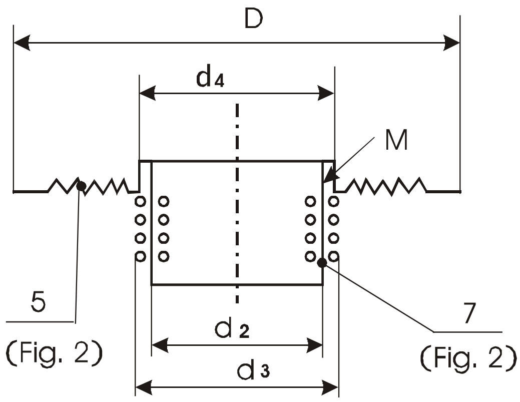

Figure 3 Key: 2.1 – central stud; 2.2 permanent magnet; 2.3 – top plate; 2.4 – bottom plate.

Component 2.1 riveted or pressed into 2.4 and 2.3, 2.2 and 2.4 are glued. The diameter D also serves to centre the sub-assembly in the body 1 (Figure 2) during the assembly operation.

1.2.4.2 Voice coil and suspension

It comprises 2 parts (Figure 4):
Oscillator, corrugated, centring (5 – Figure 4);
6. Coil (7 – Figure 4).
$d_3 < d_1$ (Figure 3) and $d_2 < d$ (Figure 3)
$d_2 - d = \delta$ and $\delta = 0.35 \div 0.7$[mm].
Components 5 and 7 are glued in between in the section M and the flange D_1 is used to glue the sub-assembly to the body 1 (Figure 2).

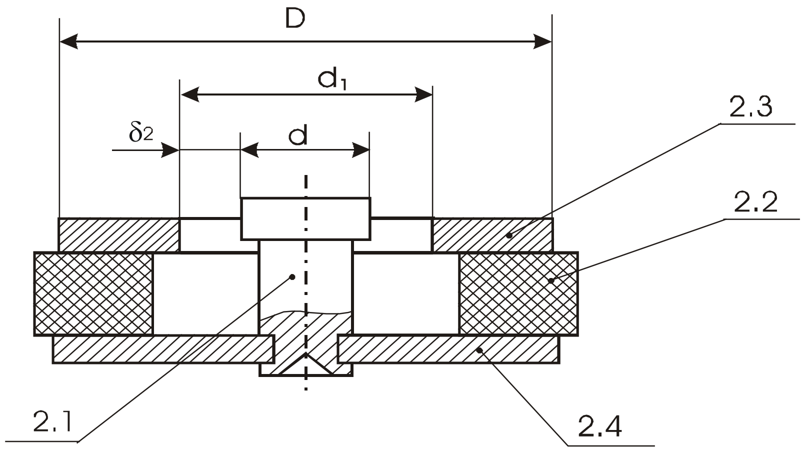

Figure 4

1.2.4.3 Cone and dust cap (Figure 2)

This comprises 2 parts and is glued to 1 and to the voice coil and suspension with the glue applied to d_4 (Figure 4).

1.2.5 Involvement of the dolly in the coil assembly operation, motor unit assembly and dust cap cone

The dolly must be positioned between diameters d_2 and d thus ensuring concentricity and maintaining the gap δ = 0.35 ÷ 0.7δ = 0.35 ÷ 0.7 (Figure 5) when the voice coil and suspension are glued along D to the body 2.

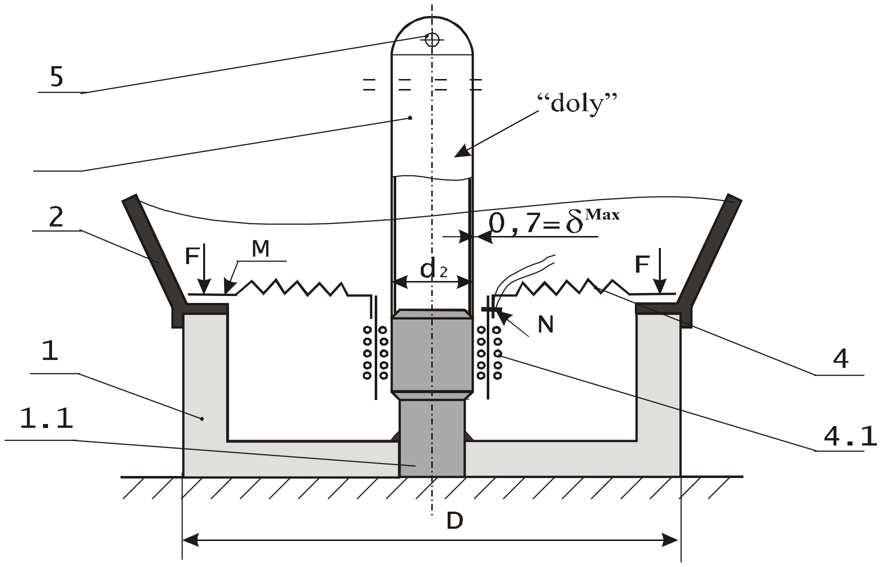

Figure 5 1. Device; 2. Loudspeaker body (chassis); 3. Dolly; 4. Oscillator, corrugated, centering; 5. Hole for installing the pulling handle (of the dolly); 1.1. Central stud; 4.1 Voice coil – constituent part of Item 4.

The arrangement shown in Figure 5 with an installed dolly in a "ready to remove" position is rather universal. The bottom section of the loudspeaker comprising the magnetic motor assembly is not shown in this arrangement but this is replaced by a simulation attachment, item 1.1.1, centred along D to item 2. Other alternatives of this arrangement are also possible where the "motor" (magnet and plates) can be pre-assembled in 2.

Figure 5 shows the operation of gluing the oscillator 4 to 2, applying the glue on the flange M and pressing on it using the force F, with the dolly, item 3, carefully pre-inserted in d_2 of the coil and then or at the same time installed over d. Before this operation is carried out, the oscillator 4 and the voice coil 4.1 are also assembled (glued) on N. Due to the difference in various designs of loudspeaker variants, the arrangement given in figure 5 also allows for observing the opposite order of operations for the assembly of the body 2 to match the order of adopted assembly operations [3].

1.2.6 Recommendation for mechanisation of the manual operation for the Dolly removal

A considerable number of methods and schematic diagrams for Dolly removal are possible using the movement of the conveyor in the area of this specific assembly work station. Figure 6 shows a diagram of a suggested semi-automated mechanical device (attachment) [4].

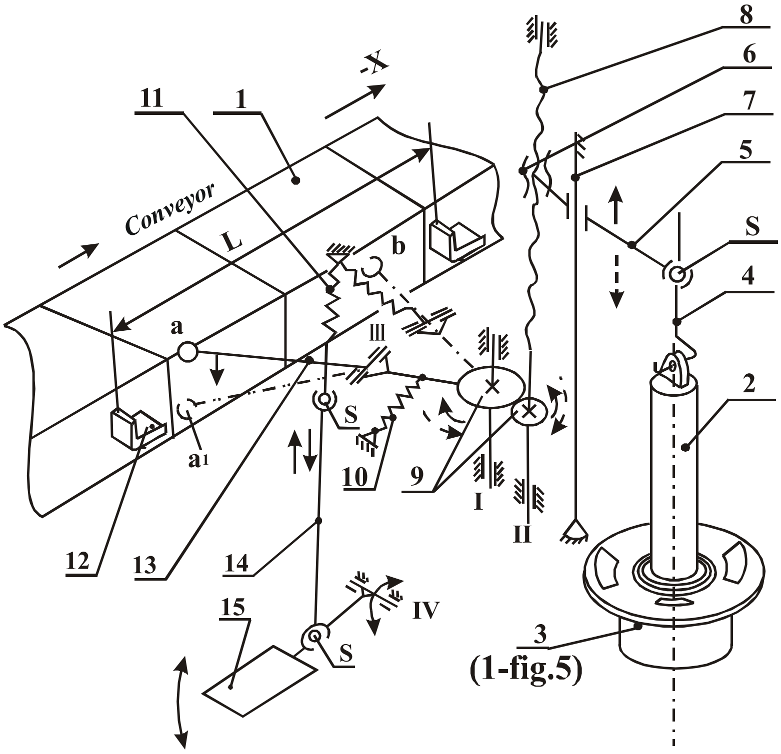

Figure 6: 1. Conveyor; 2. Dolly; 3. Product (loudspeaker); 4. Hanger hook; 5. Horizontal arm; 6. Nut; 7. Guide; 8. Screw; 9. Gear drive; 10. Spring – horizontal; 11. Spring – vertical; 12. Rest; 13. Actuating lever; 14. Vertical lever; 15. Pedal; S – Spherical hinges; D – Gap between rests item 12 – pitch.

1.2.6.1 Structure of the device and mode of operation

The device comprises the component parts as listed in Figure 6. The dolly 2 is located on the assembly work station where the centering oscillator is assembled to the loudspeaker body. The dolly is hung to the arm 5 by means of the hanger hook and the arm moves vertically along the guide 7 installed on the assembly device. The arm 5 ends on the nut 6 installed on the screw 8, which moves in both directions (clockwise and counterclockwise). The screw is seated on the pin II (z) and is driven by the gear drive 9 – pin I to pin II. The gear 9 (the larger one) is connected to the lever 13, which is equipped with an auxiliary hinge – pin III, such that the end section of the lever can move around the pin III at a certain distance along the ± Z axis. The entire lever 13 rotates at a specific angle around the pin I, for example at ± 90° (in the X0Y plane). The lever 13 is connected via a spherical hinge "S" to the vertical lever 14, which is in turn connected to the pedal 15 via "S" and the pedal moves in the clockwise and counterclockwise directions around the axis IV (Y). The lever 13 is kept horizontal and parallel to the X0Y plane by the spring 11 and it is kept in its starting position "a" by the spring 10.

The mode of operation of the device involves pressing by hand of the lever 13 in the Z direction or pressing the pedal 15 by operator's foot until the end section of 13 moves from position "a" to position "a_1"with the rest 12 installed on the side of the conveyor, resting against 13 and rotating it in position "b", where it becomes disengaged from 13. Thus, the gear drive 9 is moved and the screw 8 is rotated and it in turn moves the nut 6 by means of the arm5r, the hinge S and 4 and dolly 2, respectively in the +Z direction, pulling on it directly along the direction of the axis from the product (the loudspeaker). Springs 10 and 11 restore the starting position of the hanger hook 4 ready for the next product, retracting the lever 13 in its "a" position.

1.2.6.2 Involvement of the conveyor

According to the arrangement described above, the conveyor moves the device and pulls out the dolly in the +Z direction by means of the rests 12 installed at a specific pitch L along the conveyor. Thus the involvement of the worker is reduced to moving the lever 13 down using a low effort, not requiring a very high effort or alert attention (for accuracy of movement) [3]. This movement can be performed manually or by the foot using the pedal 15. One opportunity for improving this strategy for dolly removal is to move 13 until it engages with 12 of the moving conveyor by means of an electrical magnet and a simple electrical diagram (contactor and a time relay) with the operator only pressing on an electrical button. Another alternative exist for the pedal 15 to move the screw 8 or 5 directly, but the use of the conveyor is then eliminated [5].

1.3 General assembly strategy

1.3.1 Review of assembly operations and assessment of their mechanisation suitability

The assessment of the suitability of a given product to be assembled in series production condition – conveyors, process flow lines and automated lines – should be made before introducing any sort of mechanisation whatsoever. Additionally, a more detailed differentiation can be made by complexity of realisation, duration, internal links and place of performance relative to other assembly operations, as well as a cost analysis [5]. A large number of assembly operations in various types of manufacturing processes currently involve manual labour since they are difficult to mechanise. A number of operations are still currently available which are hard or impossible to carry out when using assembly devices (manipulators, robots) [6]. There are also assembly operations where insufficient cost effectiveness makes them useless and not applicable in practice. Examples of such operations are:

- Insertion, centring and matching of more that a single component parts at the same time or simultaneous assembling of an assembly or a group of several component parts [7].
- When complex movements of the hand (manipulator) are performed to carry out the assembly operations, such as rotations along more than 1–2 axes and movements along such axes; insertions into tight spaces and gaps [8].
- Many assembly operations exist that require auxiliary manipulations involving secondary operations: additional support of the work piece, rounding edges, welding and soldering, screws and rivets in locations that are hard to access, angles, and openings [9].
- Operations that are difficult to mechanise and automate are also gluing and sealing with glue packings and pastes of a specified amount, running electrical wires or steel wire through holes (such as the voice coil wires) [7].
- Fragile, tender and low-size (or very heavy) component parts.
- In general, the assembly characteristics of the product involve the analysis of all these elements. On the other hand, the structure of the product shall be modified to a maximum extend to suit the assembly requirements aimed at introducing some mechanisation and automation into processes [8]. In our specific case we make an assessment of all described above relative to loudspeaker assembly processes.

1.3.2 Selection of an assembly unit

In accordance with the original assignment, we selected the motor unit assembly (item 2.1) as a suitable assembly unit for mechanisation – pole plate, magnet, top plate and a central stud. According to the specific variant of product design model (type of product) and the overall assembly process involved, we can also add here the metal body (casing) of the unit. We considered a ready-made and assembled loudspeaker motor unit assembly in series production [10].

1.3.2.1 Grounds for making this particular selection in view of possible mechanization

The motor unit assembly is made up of mainly rotating and simple shaped component parts. These are sufficiently easy to grip and move using mechanised gripping means, such as manipulators, and robots [11]. It is also possible and fairly convenient to move these using some simple devices, such as pallets and crates. The material they are made of – iron and ferrous alloys, can also be used to transport them by means of using their magnetic properties [12].

1.3.3 Stage: Assembly of motor unit – Figure 7

1.3.3.1 Component parts and features

The "motor unit assembly" comprises 4 individual sections. We can also regards as parts of this assembly the body of the loudspeaker item 5, which is pressed into the assembly along d_4 (D6/k6).

We must clarify here that more than one possible assembly techniques exist for this specific assembly depending on the adopted assembly process pertaining to the "oscillator with voice coil" stage (5 in Figure 2).

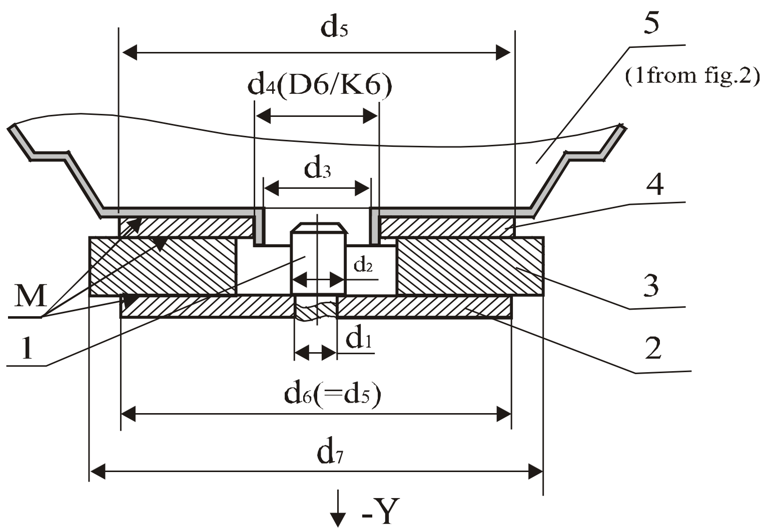

Figure 7: 1. Central stud; 2. Bottom plate; 3. Magnet; 4. Top plate; 5. Loudspeaker body.

a) The oscillator can be assembled with 5 before the motor unit assembly is assembled, as shown in figure 5. Components 1, 2, 3, 4 (Figure 7) are assembled afterwards.
b) Vice versa, where the oscillator is assembled with 5 after the overall assembly of the motor unit is complete (again using the arrangement illustrated in Figure 5)
c) The plate 4 (Figure 7) can be assembled with 5 in advance and the last to be assembled are components 1, 2 and 3 which are assembled separately and then glued along surfaces M. This operation is performed after the oscillator is assembled. With this specific assembly sequence, 1 and 2, 4 and 5, 1 + 2 and 3 are assembled in advance and the last to be assembled are 1 + 2 + 3 with 5 + 4.

In alternative "c" above, component 5 is installed into the oscillator gluing attachment facing back (rotated at 180°) (Figure 5) and the dolly is used to define the gap between d_3 and the outer diameter of the voice coil. In this specific case the dolly is pulled in the direction – Y (Figure 7).

1.3.3.2 An example for an assembly process

We draw up a process flow map (Table 1) in order to clarify the assembly process at the "motor unit" stage (A). The map is made such that it gives an idea for the observed sequence of assembly operations, the means adopted to perform them, possible means of mechanisation and automation and operation time.

No	Operation	Transition	Description of stage, operation, transition in operating condition a_1, c_1, d_1 Item No in fig.7	Feasibility of operation		Machine-M Tool – T Fixture – F Robot – R Manipulator – D Baseline:		Possible use of conveyor	Moves Between Pos Fig.8		Approximate duration	Notes, other data and description Moves from pos. No. to pos. No.
				manual	mechanical	robot (CNC)			from	to	sec	
1	2	3	4	5	6	7	8	9	10	11	12	13
	I	A1	Assembly 1 and 2									
1	I	01	Pick 1 from pallet or feeder and insert in fixture – operating position "a"	+	+	+	Move by R; D to press M_1 (Fixture)F1/d_2	-	a	a_1	2	Position a – pallet location; a_1 operational position for assembly
2	I	02	Pick 2 from pallet or feeder and place on 1	+	+	+	Move by R; D Baseline $d_1(d_6)$	-	b	a_1	2	Forms sub-assembly 1+2
3	I	03	Riveting (on d_1) of 1 to 2	-	+	+	Press M1 or R and T	-	a_1	c_1	1	Subassembly 1+2 is assembled
	II	A2	Assemble 1+2 with 3									
4	II	01	Pick 3 from pallet or feeder and place in c_1	+	+	+	Move with R or D/face and d_7	-	c	c_1	2	Possible to use multi position rotating device
5	II	02	Apply glue to 3 face b/n d_6-d_1	+	+	+	On a cotton stab with R or D	-	c_1	-	2	
6	II	03	Remove 1+2 from a_1 and place on 3 in c_1	+	+	+	Move with R or D	-	a_1	c_1	1	Allow glue to dry in c_1
	III	A3	Assemble 4 and 5									
7	III	01	Pick 5 from pallet or feeder and insert in fixture	+	+	+	Move with R or D/d_4 Move with R or D/d_4(on internal face D5-d3)	-	d	d_1	2	
8	III	02	Pick 4 from pallet or feeder and place on 5	+	+	+	Move with R or D/d_4	-	e	d_1	2	Press with effort to fit D6/k6 (from robot)
	IV		Assemble 4+5 with 1+2+3									
9	IV	01	Apply glue to face D_5-d_4 of 4 (4+5)	+	+	+	With second grip of R or D	-	d_1	-	3	
10	IV	02	Pick 1+2+3 from c_1 and place on 4+5 in d	+	+	+	With first grip of R or D	-	c_1	d_1	2	Press with effort to fit D6/k6 (from robot)
11	IV	03	Pick 4+5+1+2+3 from d_1 and move to k	+	+	+	With first grip of R or D	-	d_1	K	2	or to work place WP2

Table 1: Process flow map for analysis of the assembly operation

STAGE A Motor unit assembly – Figure 7 Items 1 thru 5

Key: yes = +; no = -; Example: 1+2 = assembled parts 1 and 2.

Note: Column 1 – [sec] for mechanised arrangement

1.3.4 Recommendation for most suitable form of mechanisation and automation

1.3.4.1 Basic assembly scheme resulting from the above analysis

According to the indications in Table 1, we can then draw up the following diagram – Figure 8.
I01….IV03 – assembly operations and transitions – 12 off

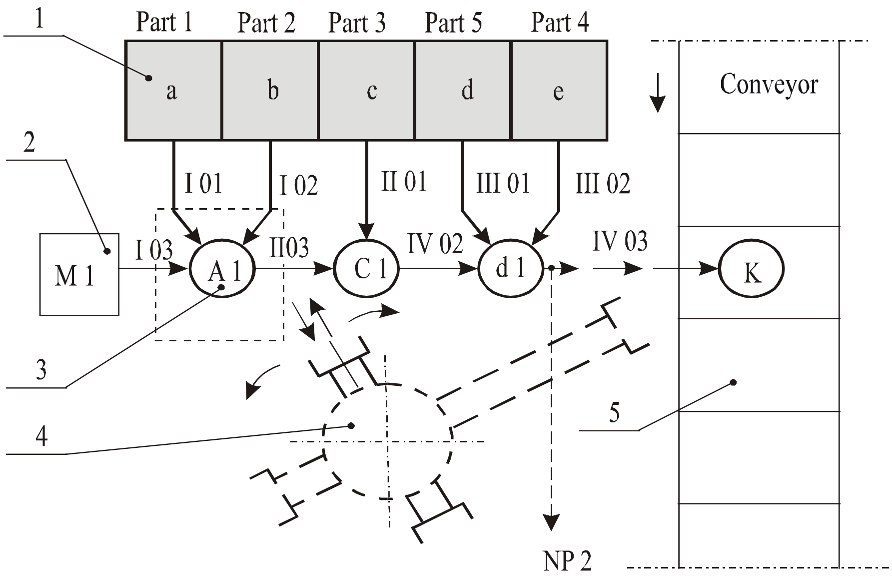

Figure 8: 1. Pallets for p[arts 1 thru 5 or feeding devices; 2. Press; 3. Assembly jigs a_1, c_1, d_1,; 4. Robot or CNC-controlled manipulator; 5. Conveyor.

1.3.4.2 Nature of the proposal for automation (Figure 8)

The assembly of the motor unit assembly (figure 7) is performed in working positions a_1, c_1 and d_1 which represent assembly fixtures suitably selected for the purpose and size of assembled components [12].

The component parts to be assembled are picked up from feeder devices or pallets from *a* thru *e* in the described sequence (Table 1) by a CNC controlled robot or industrial mechanical manipulator. Riveting of component parts is performed in working position a_1 (press work table) and in d_1 by means of the robot. Gluing and waiting for the glue to set is carried out in positions c_1 and d_1 to put together pre-assembled (mechanically) sub-assemblies 1+2 and 4+5. The finished assembly is then transferred from position d_1 to the conveyor "k" or work position WP2 in an alternative process organisation to proceed with further assembly operations required for the loudspeaker [13].

1.3.4.3 End effector design

The design of the end effector is pre-defined by the proposed idea for mechanisation and automation of the process. In this particular case the end effector is the "arm" of the robot or the manipulator [14]. It performs all moving operations of components from the pallet (feeder device or cartridge bin), to riveting or gluing work positions and for staving component 4 into component 5. The arm then transfers the finished assembly to the conveyor "k" or straight at work position WP 2 for further assembly of other loudspeaker component parts. The arm shall be widely universal or adjustable for several types of component parts to allow handling of other product variants. It should feature two grips of varied operating position within a range of 180° and capable of applying a certain amount of force to press the D6/k6 subassembly in between 4 and 5. A suitable method of transferring component parts is via an electrical magnet built into the arm and providing reverse polarity (demagnetisation) or mechanical ejectors to insert parts securely into working positions a_1, c_1 and d_1.

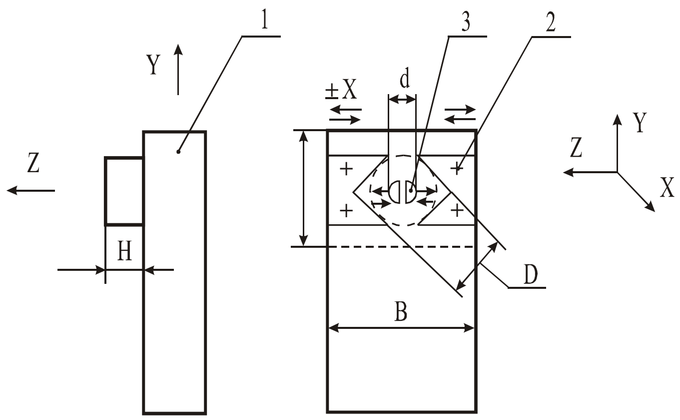

Figure 9

Figure 9 illustrates one example of an implemented design idea for a robot arm grip or manipulator ensuring fast, accurate and secure gripping of rotational components similar to most of those involved in the motor unit assembly. The jaws 2 (2 off) grip the outer diameter D of the component part and the jaws 3 (2 off) – the inner diameter d of openings in component parts. Some minor movement of the arm in the radial direction ± x ensures handling of component parts with large difference between inner and outer diameters d and D. The flat section of the arm A × B can also be an electrical magnet with possibilities for demagnetisation. This ensures secure transfer and facilitated placement of handled component parts. Jaw height *h* is of suitable size to handle the specific components and can be changed by means of readjustment or replacement.

Another significant element of the end effector unit are the assembly fixtures in a_1, c_1 and d_1. These are relatively simple and low-cost to make. They represent seats for inserting and locating at least one component 1 thru 5 (Figure 7). The fixtures do not require any additional elements for holding or tightly fitting the component into them. Moreover, it is possible to make one fixture capable of holding several variants of shape and size of components or made readjustable as appropriate. One example of such fixture is illustrated in Figure 10.

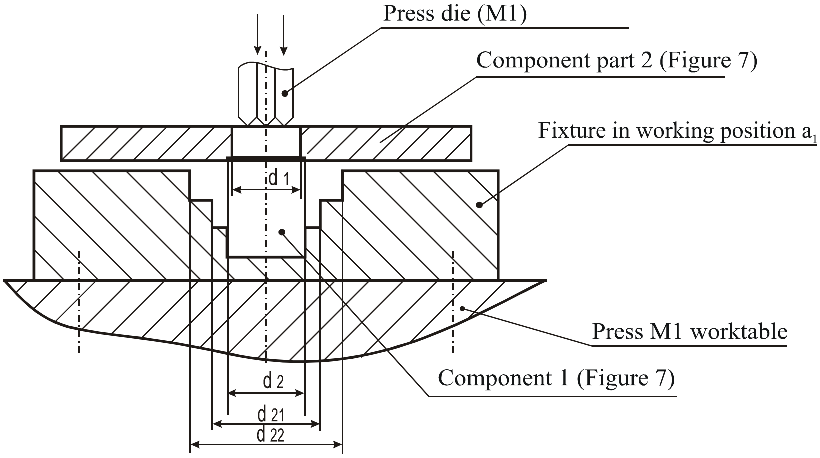

Figure 10

The fixture used to insert component 1 to be riveted to component 2 can be used for 3 and more variants of the size d_2: $d_{2,}$ d_{21}, d_{22}, …d_{2n} of component 1.

1.3.4.4 Conveyor and its role in the organisation and mechanisation of the assembly process

The conveyor is used to provide transport of semi-finished products from the store in pallets or stacks of components and auxiliary materials. It is also used to transport finished assemblies and finished loudspeakers further down the line. According to the proposed mechanisation arrangement, no other involvement of the conveyor in the assembly process for the "motor unit assembly" is envisaged [15].

1.3.4.5 Feeding and storage of parts

According to the above description of the proposed assembly arrangement parts are delivered in pallets or preferably stacked into special cartridges. Pallets containing component parts can be delivered from the store by means of the conveyor, which transports them to the relevant assembly cells arranged around the conveyor [16]. Parts 1–5 should be stacked in pallets a–e (Figure 8) only if a robot or manipulator is available to pick them up from a specific location. This can also be done by an operator servicing at the same time more than just one single assembly cell, depending on the number of parts and the time required to assemble them.

When part feeder devices are employed, parts are stacked by the device itself and can then be loaded into attached feed stacker bins. Parts can also be delivered from the store to pallets items a–e by means of electric trucks or robo-trucks independent of the conveyor [14]. Additionally, parts can also be stored in the assembly cell itself in quantities sufficient to meet the requirements for 1 work shift plus some spare quantity. This depends on the overall size of the part and the space available. Parts are transported within the assembly cell automatically by means of a robot or manipulator [13].

Assembled finished sub-assemblies (for the motor unit assembly) are transported on the conveyor or fed directly to the neighbouring work position (WP2) to assemble other parts employing the same means (a robot or manipulator). It is also possible to have a buffer stock quantity of finished assembled motor units between individual assembly operations if this is required to facilitate the overall process organisation and to improve the operational reliability of the assembly line [17]. Such an opportunity will be available when the output of this stage A of the overall assembly process is higher than that required for the cyclic operation of the assembly line.

If special feeders are provided for feeding parts 1 thru 5, the operations of the robot or manipulator will be greatly facilitated. It is also possible to provide for direct feeding of parts into working positions a_1, c_1 and d_1 (Figure 8) by the feeders.

1.4 Feeder design

We assume the feeder(s) will be used to feed component parts comprising the motor unit assembly – Item 2.1 in the original assignment. These are described in more detail in Para 3.4.1 – Figure 3 and Para 4.3.1 – Figure 7 above. Parts are of perfectly round shape and relatively small thickness to outer diameter ratio (h/D) i.e. a shape similar to spacers with only the central stud having elongated cylindrical shoulder shape. The body of the loudspeaker, item 5 in Figure 7, which we also included in the assembly operation, features considerably larger size and more complicated "conical" shape. Handling of this component during transportation would require specialised feeder devices or it can be picked up directly from a special stack cartridge (where several parts are stacked in order) by the arm of the robot (or manipulator). We assume the following specific sample dimensions of parts for the initially required provisions for part size and output data and re-filling cycle – Figure 11 (Note: designations and names are identical to those given in Figure 7).

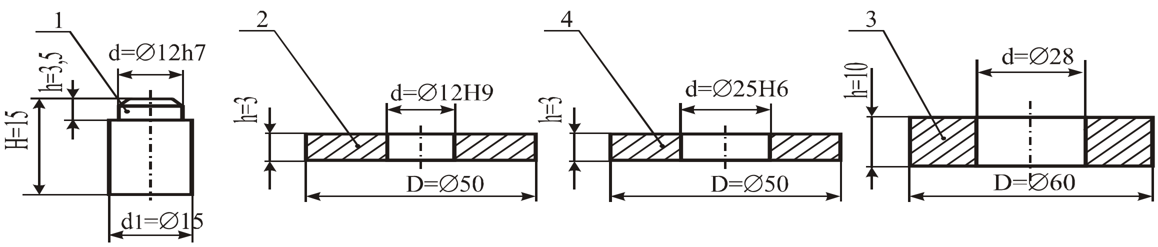

Figure 11

Due to the similar shape they feature, parts 2, 3 and 4 can be fed using a feeder design based on a single concept. Figure 12 illustrates one design solution for feeding this type of component parts.

1.4.1 Description – Figure 12

The feeder illustrated in the above figure features a part stacker bin 1 with double tilted bottom. The stacker bin is supported freely on rollers 2 and can be moved to a certain extend in the ± y directions along the guides 3 fixed in position. A gap of a size h_1> h of the part is provided between the two bottom of the stacker bin which are tilted at angles α and α_1. Connected detachable to the gap along the partition flange I-I is a trough having an inner section area larger than the cross sectional area (across the diameter) of the part being fed. A crank mechanism 12 is connected to the stacker bin and driven by the motor 13. An electrical sensor 11 and lock 10 are installed at the exit of the trough 5. The sensor is connected via the electrical wiring 14 to the motor 13. Optionally, or as an auxiliary attachment, a working position (a_1, c_1 and d_1 – Figure 8) can be installed next to the exit of the trough 5 and the assembly fixture 7 for the relevant assembly operation, transition and part size can be provided in this position.

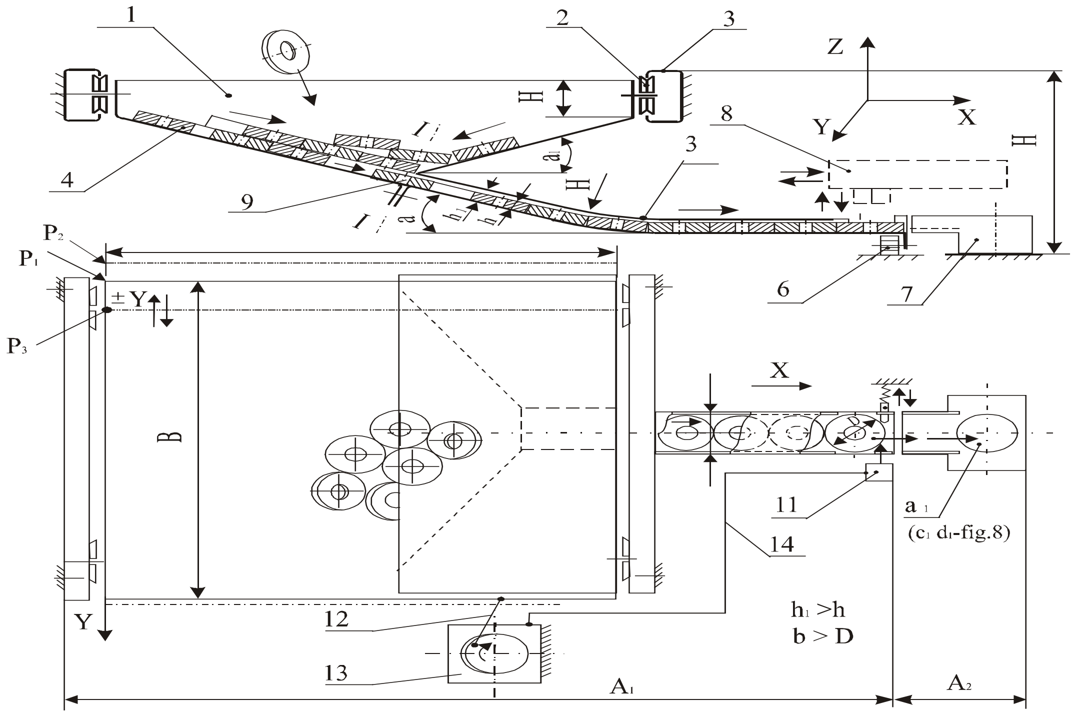

Figure 12: 1.Parts stack bin; 2. Roller; 3. Guide roller; 4. Component parts (of the 2, 3 and 4 type in Figure 11); 5. Trough; 6. Roller; 7. Assembly fixture (working positions a1, c1 and d1); 8. Robot arm (manipulator); 9. Gap; 10. Lock; 11. Electrical sensor; 12. Connecting rod – crank mechanism; 13. Motor; 14. Electrical wiring.

1.4.2 Operation

Parts are dumped in bulk into the stacker bin 1 and arranged and stacked in heights of 5 or 6 with their flat side facing the bottom of the bin. Some of them fall the right way into the trough and move down the slope under their own weight towards the exit of the trough. In this end position the part 4 is locked by the lock 10 and actuates the sensor 11. The sensor 11 shuts off the motor 13 via the electrical wiring. The motor can be either electrical, pneumatic or hydro, etc. type motor depending on the available installations. The bin performs reciprocating movement along the ± Y under the action of the crank mechanism which is in turn driven by the motor. It is also possible to use a solenoid (electrical magnet) here to induce vibrations into the stacker bin 1. Vibrations of the bin cause the parts to be arranged in the right way and fall into the trough 5. When the part reaches the end position at the exit of the trough the grip of the robot (manipulator) 8 moves along X, Z and in radial direction relative to D to grip the part and transfer it to the required working position (a_1, c_1, d_1…). As an option the device allows installation close to a_1 where the robot can move the part in the + X direction without lifting it (direction Z), until it falls into a_1.

1.4.3 Cycle time

Considering the total time T_Σ of operations I 01 thru IV 03 (column 12 in Table 1) involved in the motor unit assembly stage:

(3) $T_\Sigma = 22$ [sec], the cycle time required to feed a single part 2 (Figure 11) is

(4) $T_2 = T_\Sigma = 22$ [sec], since there is only one such part in the assembly and it is handled by a single robot. In other words, the next part shall be fed in position a_1 after 22 seconds.

If we introduce more than one robot in the assembly cell for the specific stage of the process or only part 1 and 2 are handled by a single robot or manipulator,

(5) $T_{21} = \Sigma\, T_{Io1} + T_{Io2} + T_{Io3} = 2 + 2 + 1 = 5$ [sec]

also, $T_{11} = 5$ [sec] (until the sub-assembly 1 + 2 is finished).

1.4.4 Storage capacity

Considering the expected increase in output of the assembly line to 180000/month and increased number of servicing workers $N_w^{max} = 46$, we can calculate the number of assembly cells, the cycle time of operation of a single assembly cell and the minimum number of parts that must be assembled to provide for continuous operation of the line and meeting the required production output.

If we assume 15 assembly cell are located along the entire length of the conveyor (60 m) each served by 3 workers as the product is assembled over three basic assembly stages (3 assemblies make up the entire product), then:

(6) $N_W = N_{AC} \, . \, n_{WC} = 15 \, . \, 3 = 45$ and one worker will not be occupied in the assembly process for the time being.

Here N_W is the total number of workers servicing the assembly line;
n_{WC} is the number of workers in a single assembly cell; and
N_{AC} is the number of assembly cells along the line.

From para 2.2. (2) above we have $T_{2C} = 4$[sec]

(7) $\therefore T_{AP} = T_{2C} \, . \, N_{AC} = 15 \, . \, 4 = 60$ [sec], where T_{AP} is the cycle time for a single assembly cell.

Above conclusion results from the assumption that the time available for each worker to complete a particular job to ensure a certain output is directly proportionate to the number of workers.

From (7) above we can calculate the required number of parts to provide for normal production run during one working shift:

(8) $Q_{WS} = \dfrac{10.3600}{60} = 600$ parts, where:

Q_{WS} is the minimum quantity of parts assembled within 10 hours (one working shift).

From (8) above we can draw the conclusion that 600 parts of each specific type required for the motor unit assembly (1, 2, 3 and 4 – Figure 11 and part 5 in Figure 7(body)) shall be delivered and be available in each assembly cell for one working shift (10 hours).

1.4.5 Basic dimensions (Figure 12)

From (8) above we can draw the conclusion that if part dimensions are according to Figure 11, a maximum of 600 parts 2, 4 (1,3) can fit into the bin 1 (Figure 12). With parts 2 and 4 stacked next to each other at several layers (layers of H1), we calculate the dimensions A, B, H, H1 of the feeder device:

The volume of space occupied by a single part 2 (4) is $V_{2(4)}^{\max} = h + D^2$ (Figure 11)

$$V_{2(4)}^{\max} = 0{,}3x5^2 = 7 \text{ [cm}^3\text{]}$$

from (8) above $V_{2(4)}^{\max} . Q_{WS} = 7{,}5x600 = 4500 \text{ cm}^3$.

Therefore ∴ The dimensions of the stacker bin 1 – V_S are:

$$V_S^{min} \geq 4500 = A.B.H_1$$

If we assume: A = 400mm; B = 400 mm and H_1 = 100, then:

(9) $V_S = 40 \,.\, 40 \,.\, 10 = 16000 \text{ cm}^3 > V_S^{min}$.

The dimensions of the feeder are approximately as follows:

A = 400, B = 400, H_1 = 100, A_1 = 800, H = 400 [mm] and is capable of loading sufficient quantity of parts to provide for one working shift production = 10 hours operation.

If we consider parts 1 and 3 (Figure 11), this stacker bin is sufficient to hold 600 parts 1 and 300 parts 3 as above:

$$V_3^{max} = 1x6^2 = 36\,[\text{cm}^3] \qquad V_3^{max}.Q_{WS} = 36x600 = 21600\,[\text{cm}^3]$$
$$V_1^{max} = Hxd_1^2 = 1{,}5x1{,}5^2 = 3.375\,[\text{cm}^3]$$
$$V_1^{max}.Q_{WS} = 3{,}375x600 = 2025\,[\text{cm}^3] \leq V_3.$$

Considering the existing differences in parts 1 and 3, the design of the feeder mechanism is further explained here.

1.4.6 Method of re-filling

From all mentioned above we can draw the conclusion that the feeder device shall be loaded once in a working shift for parts 1, 2 and 4 and twice for part 3. This can be done when parts are delivered in a pallet in bulk (not arranged and stacked in the pallet) and these pallets are dumped into the stacker bin 1of the feeder device.

This technique is not suitable for parts 1 and 3 for the illustrated design because of the peculiar shape of part 1 and the magnetic properties exhibited by part 3. A modified feeder device for these two parts is illustrated and they shall be fed by means of stacked cartridges for parts 1 and 3 or through modification of the bottom and trough of 1 in the feeder device.

1.4.7 Stacker bin for feeding type 1 parts stacked and properly arranged

The device illustrated in Figure 12 is not suitable for feeding parts of the type 1 due to their different geometry. Instead, we could use the stacker bin 1 as illustrated in Figure 13 still keeping the rest of the feeder mechanism unchanged to stick to the basic idea (unified with the idea adopted in Figure 12).

1.4.7.1 Arrangement

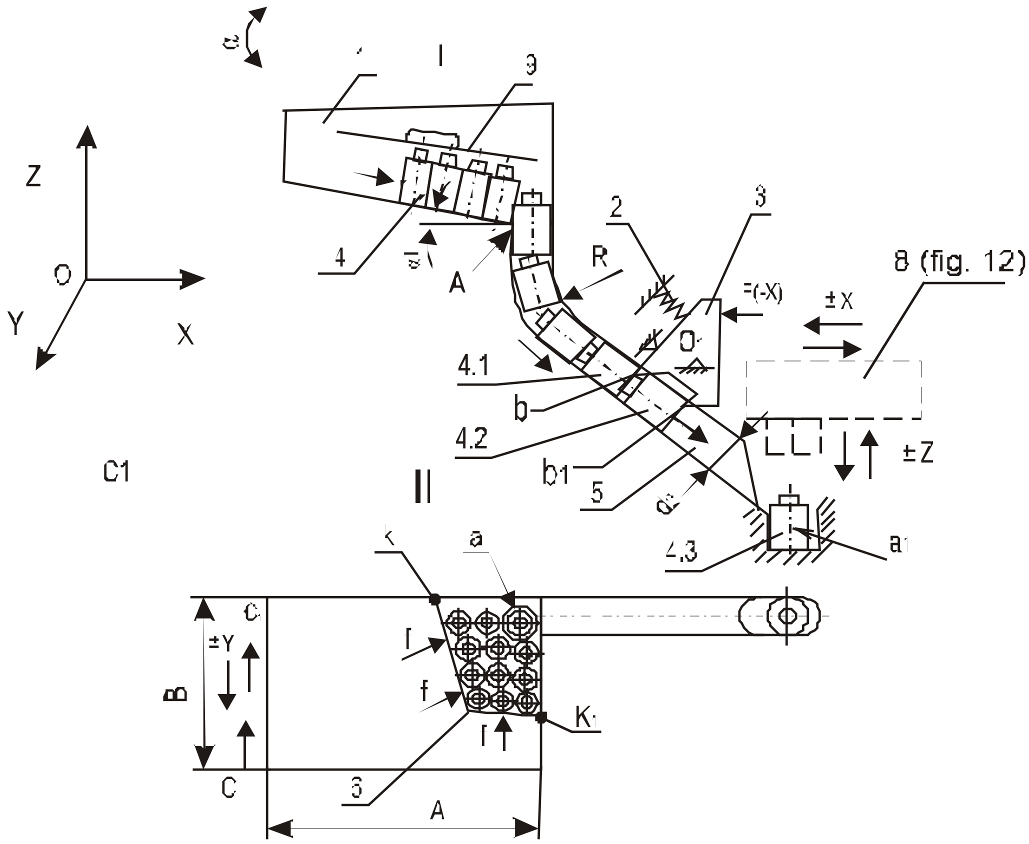

Figure 13: 1. Parts stacker bin (modified for part 1 from Figure 11); 2. Spring; 3. Gate lock (anchor); 4. Parts; 5. Trough (pipe); 6. Rubber rope or band; 7. Robot arm (manipulator); 8. Cover; f, F – Pressure forces; k – points of attaching 6.

The stacker bin has a slightly tilted bottom ($\angle \alpha_1 < \angle \alpha$ – Figure 12). A slight slope is also provided from C to C_1. Parts 4 are stacked and arranged in the bin in a single layer. Stacked parts are banded by the elastic band 6. The trough 5 starts from "a" and represents a pipe of diameter $d_2 > d_1$(of the part).

1.4.7.2 Operation

Parts 4 are stacked and arranged in the bin 1 under the action of gravity and bin vibrations cause them to move tightly stacked from the band 6 to the end of trough 5 – the opening in point "a" and they fall inside one at a time and move down to the rest "b_1" of the gate lock 3 held in this position by the spring 2. When the robot arm (8) presses on (3) with a force F along X, it rotates around O_1 counter clockwise and releases part 4.2, which falls into the trough and reaches the seat a_1 – position 4.3 where it is picked by the robot arm. Meanwhile, part 4.1 moves in position 4.2 after 4.2 is released, guided by the "tooth" b of 3. The "tooth" b ensures part 4.1 and other parts stacked above it in the trough 5 are kept static while part 4.2 is released.

Output and dimensions

With dimensions A = 400 and B = 400, stacked in a single layer are more than 600 parts, which ensures sufficient supply of parts required for one working shift.

The area of bin occupied by a single type 1 part (Figure 11) is:

$$S_1^{max} \leq d_1^2 = 1.5^2 = 2{,}25 \ [cm^2]$$

The area of the bin is $S_T = 40 \times 40 = 1600$ [cm²], where $S_T = A \times B$

The number of inserted parts is: $N_1^{min} = \frac{S_T}{S_1^{max}} = \frac{1600}{2.25} = 711 > 600$ parts

Method of re-filling

Parts are stacked manually and arranged in the proper way, as shown in Figure 13. Re-filling time approx. 5 minutes in the beginning or end of each work shift.

1.4.7.3 Other applications of the device

The feeder mechanism for part 1 (Figure 11) illustrated in Figure 13 II can also be implemented as an almost horizontal alternative, the X0Y plane, with the trough 5 having a rectangular cross-section. It is also possible to feed parts to a_1 directly (Figure 13). In this case we do not need the gate lock 3 and other elements that go with it. Parts will move thanks to the slight slope ($\angle \alpha_1$) and the elastic band 6 – Figure 14.

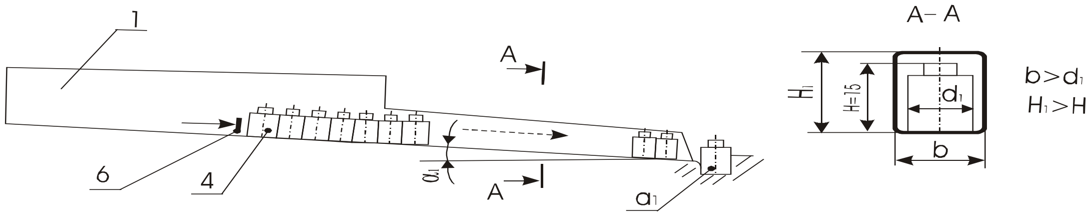

Figure 14

1.5 Assembly cell design

1.5.1 Initial provisions

From the assumed basic assembly stages in the production of the loudspeaker "General strategy": 1a, 2, 3, we can assume that their duration is approximately identical. If we designate these assembly stages as A, B and C, then stage A involving the assembly of the motor unit assembly would be the most complicated and labour consuming operation. The assembly stage B involving the voice coil and suspension assembly comprises less operations and transitions involving mainly manual operations because of the nature and characteristic features of these operations. The situation with stage C – cone and dust cap – is very similar. The cone and dust cap are glued together and the cables from the coil are soldered to the appropriate terminals. These operations are again suitable to perform manually.

From what we discussed above we assume that each individual assembly cell has three basic working positions where the operations and transitions involved in the three basic assembly stages which we designated as A, B and C are performed.

1.5.2 Organisational arrangement of the assembly line for the current production output

If we consider the current output of the assembly line, 120 000 loudspeakers/month, as indicated in Para 2.1 – (1) T1a = 6 sec. In other words, one finished loudspeaker comes out in every 6 seconds. With the total number of assembly cells NAC = 15 and nWP = 3, as calculated in Para 5.4 (6) "Storage capacity", the general organisational arrangement of the assembly line could be as illustrated in Figure 15.

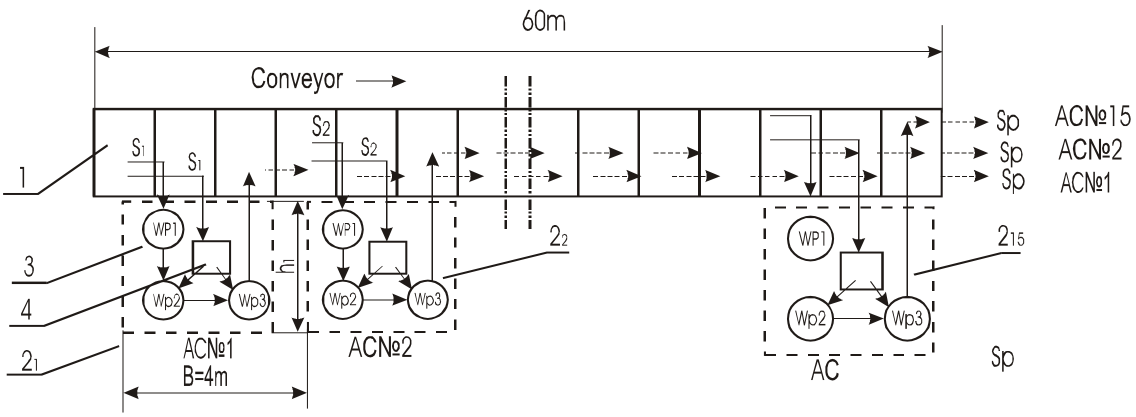

Figure 15

Each individual assembly cell AC No.1 …… No.15 comprises 3 working positions: WP 1, 2 and 3, where assembly stages A, B and C are carried out. In Figure 15: 1 Conveyor; 2_1 …. 2_{15} are assembly cells AC1 to AC 15; 3 working (assembly) positions WP 1, 2,3: 4 is the auxiliary assembly table (reserve stock) with parts required for the assembly operation; $S_{1,2}$ is the movement of parts or pallets (cartridges) with parts arriving at the assembly station.

Working position WP1 performs operations in stage A of the assembly process and WP2 and WP3 – stages B and C. The parts required for each of these working positions arrive as follows: WP2 – from WP 1 and 4, and WP 3 – from WP 2 and 4 and the finished product Sp, loudspeaker, is then placed on the conveyor to be transported to the store.

1.5.2.1 Cycle time of the assembly cell (AC1 … AC15) – T_{AC}

(12) $T_{AC} = 1.5$ [min], since $T_{AC} = N_{AC} \cdot T_{1a}$

$$\therefore T_{AC} = 15.6 = 90 \text{ [sec]}$$

(since: $N_M = \dfrac{T_M}{T_{1a}} = \dfrac{200.3600}{6} = 120000$ parts/month),

where: N_{AC} = 15 off
T_{1a} = 6 [sec]
N_M = quantity of loudspeakers produced for one month
T_M = working time for one month = 200 hours

1.5.2.2 Dimensions of AC $(_{1 \dots 15})$

The area of space occupied (available) by one assembly cell is:

$$S = l^{max} \text{ x } h. \text{ If we assumed } h = 1;\ l = \frac{L}{N_{AC}} = \frac{60m}{15} = 4\,[\text{m}],$$

$$S = 4^2 = 16\ [\text{m}^2].$$

1.5.3 Alternative organisational arrangement of the assembly line for the suggested mechanisation – N_M^{max} = 180000/month

According to the developed "General strategy", (Task 2) above and the organisational arrangement illustrated in Figure 8, a mechanised assembly cell can be introduced into the assembly line as illustrated in Figure 16.

All assembly cells are located in one line next to the conveyor and one double automated assembly cell MAC1 serves two neighbouring "manual" cells (work stations: AC1 and AC2, etc.) For example: MAC2 → AC3 and AC4, up to MAC 11 → AC21 and AC22. MAC1 … up to MAC11 are as illustrated in Figure 8, Para 4.4.1, with the only difference that they have been doubled to be symmetrical and to provide better organisation in servicing the other (second) "manual" assembly cell. It is not necessary to double the feeder devices a, b, c, d and e (pallets or cartridges with parts) but it would be more convenient if neighbouring assembly cells AC1 and AC2 … up to AC 21 and AC22 assemble two different product variants featuring different size and overall design.

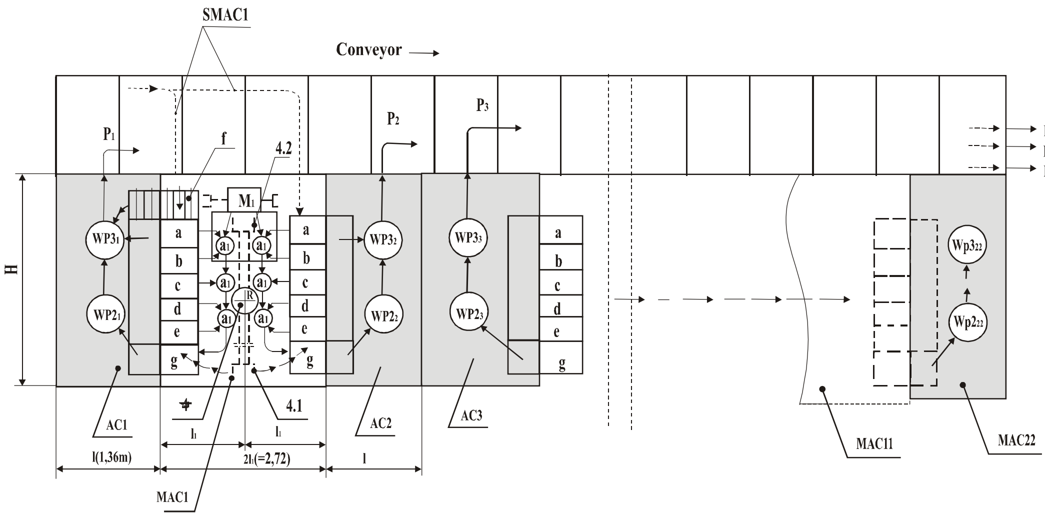

Figure 16: $P_{1\ \dots\ 22}$ – product (loudspeaker)
SMAC1 … C11 – pallets (cartridges) carrying parts for MAC1 … 11.
MAC1 … C11 – mechanised (automated) assembly cell – total 11 off
Item 4 – Robot ¼.1; 4.2 – Arm grips
M1 – Press or robot 2
g – operational reserve stock for finished "motor unit" assemblies for $WP2_{1\ \dots 22}$
f – auxiliary operational reserve stock for $WP3_{1\ \dots}$
$WP2_{1\ \dots\ 22}$ – working position for assembly stage "B"
$WP3_{1\ \dots\ 22}$ – working position for assembly stage "C"
$AC_{1\ \dots\ 22}$ – manually operated assembly cell – 22 off

1.5.3.1 Operation and features of the introduced flexible mechanised assembly cell MAC (MAC1 ÷ MAC11) – Figure 16

All parts required for MAC and AC cells are delivered by the assembly conveyor and re-filled with new pallets or cartridges at feed positions: a, b, c, d, e and robots item 4 also transfer assembled sub-assembles to AC1 and AC2 … (up to AC 21 and AC 22). The robot 4 also feeds pallets with parts to working positions WP21, $WP3_{1\dots}$, $WP2_{22}$, $WP3_{22}$. The use of a second robot M1 is also considered to perform some of the assembly operations carried out at $WP3_1$… over the auxiliary tables *f*. Since one mechanised assembly cell MAC serves two AC, the total number of workers serving manual work stations WP2, WP3 …is still 44 for 22 AC (15 workers for an output of N_M^{max} = 120 000/month).

The flow of semi-finished products, as well individual operations and finished products are illustrated by means of arrows.

1.5.3.2 Assembly line output

When $N_{AC} = 22$, $T_{2a} = 4$[sec], $N_M^{max} = 180000$/month

$T_{AC1} = N_{AC} . T_{2a}$ [from para 6.2.1; (2), (2), para 2.2; 2.1]

$T_{AC1} = 22.4 = 88$[sec]

$$N_M = \frac{T_M}{T_{2a}} = \frac{200.3600}{4} = 180000$$ units (T_M is the working time = 200 hours/month)

$N_M = 180000$ units.

The cycle time of an assembly cell comprising AC + ½ MAC is $T_{AC1} = 88$[sec], which is 2 seconds less in exchange for the reduced working time at WP1 or WP2, which is rather possible, since the longest assembly operation is the operation carried out at stage A (motor unit assembly). This is also achieved by performing some of the assembly operations using robot No.2 (M_1) to help WP3 if necessary. The cycle time for MAC = 22 [sec], as indicated in Table 1, column 12 and the cycle time for 2 manually operated assembly cells is = 44 [sec] (AC1 + AC2). A large time reserve is available for MAC – robot 1 (or for MAC in general). $T_{AC1} - 44 = 44$[sec]. It is also possible to additionally reduce the number of MAC to less than 11, which currently represents a reserve for increasing the assembly line output.

1.5.3.3 Assembly line operation for a minimum output of 40 units/hour and a maximum output of 1000 units/hour

1.5.3.3.1 Operation time for stages A + B + C

Without changing the time required for assembly cell AC + ½ MAC to perform assembly stages A, B and C, which we assumed is 1.5 min = 90 sec, then for the minimum volume of assembled products per hour $N_h^{min} = 40$, the time required to make one product T_1 is calculated as follows:

$$(13) \quad T_1 = \frac{T}{N_h^{min}} = \frac{3600}{40} = 90\,[\text{sec}],$$

where: T – is the time period = 1 hour and N_h – is the number of products produced for a time of T.

a) From (13) above we can draw the conclusion that only a single flexible assembly cell will be operating since this time of 90 sec is usually sufficient for it.
b) For $N_h^{max} = 1000$ [units/hour] and from (13) above:

$$(14) \quad T_1 = \frac{3600}{1000} = 3.6\,[\text{sec}].$$

In this case we can draw the conclusion that 22 AC + ½ MAC are insufficient to meet this production volume (22 . 3,6 = 79,2 [sec]).

The required additional quantity is : T_{AC1} – 79.2 = 88 – 79.2 = 8.8[sec] (T_{AC1} is 88 [sec] from para 6.3.2).

We found out in para 6.3.2 above that MAC has a large reserve of operational time for robot 1 = 44 [sec]. To allow for an output of N_h^{max} = 1000 [units/hour] we shall have to use this spare reserve of 44[sec] with robots 1 and 2 performing some of the operations at stages B and C. In other words, the assembly process shall be such that the time required to perform stages B and C is reduced by a total of 8.8 [sec] and these operations are performed by the mechanised automated assembly cell ½ MAC, which has a spare reserve of unused operational time.

1.5.3.4 Required investment – K

The required investment to incorporate the flexible automated assembly cell illustrated in figure 16 and made up of MAC, can be calculated as the sum of the required funds for inst constituent elements: these include feeder devices, cartridges, etc., a, b, c, d, e; attachments a_1, c_1, d_1, robot(s) item 4 and M1, installation and modification of the assembly layout, etc.

If we assume: $K_1 = a . b \dots e + a_1, c_1, d_1 \leq 2500$ [US Dollars]
K_2 = robot 1 – I off ≤ 5000 [US Dollars]
K_3 = robot 2 (M1) – 1 off ≤ 3500 [US Dollars]
K_4 = other expenses – 1 MAC ≤ 1500 [US Dollars], then

(15) $K_{AC} = \Sigma K_i$
$K_{AC} = K_1 + K_2 + K_3 + K_4 = 2500 + 7000 + 3500 + 1500 = 13\,200$ [US Dollars]
$K_{AC}^{I} = 14\,500$ [US Dollars}

(16) $K = K_{AC} . N_{AC}$
K = 13 200 . 11 = 145 200 [US Dollars]
K ≈ 100 000 GB Pounds, where:

K_{AC} – is total investment per single flexible assembly cell in US Dollars
K – is the investment for the assembly line, and
N_{AC} – is the number of assembly cells and N_{AC} = 11.

1.5.4 Analysis and assessment of the assembly cell AO24

The assembly cell AO 24, Appendix 2, is illustrated schematically in Figure 17. This cell incorporates a rectangular conveyor with 4 work tables in all corners and a size of 2m × 4 m. It is equipped with 4 robots operating in a set sequence. The conveyor moves automatically and synchronised with the operation of functioning robots.

Additional work tables e … i are provided for each robot 2 … 4 relevant to the performed assembly operations. These work positions are equipped with special assembly fixtures to facilitate the assembly process.

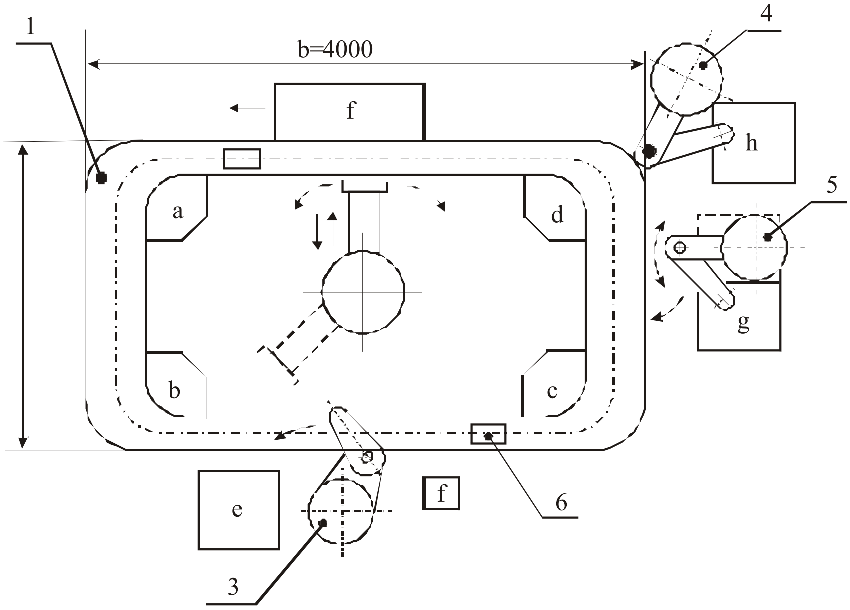

Figure 17: 1. Conveyor – 1 off; 2, 3, 4 and 5 – Robots – 4 off; 6. Moving pallet – ; a, b, c, d – work tables – 4 off; e, f, g, h, i – work tables – 5 off.

The cell operates with all assembly operations performed by the robots in the corresponding working positions – tables. The assembly operations involved in stages A, B and C (as described in the previous paragraphs) are distributed among robots 2, 3, 4 and 5 relevant to their individual capabilities. Robot 2 is the most widely universal one and can perform loading of the conveyor and unloading of finished products, as well as transfer sub-assemblies to robot 3.

1.5.4.1 Assembly of loudspeakers

If we assume robot 2 can perform assembly operations from stage A of the process – "motor unit assembly", together with the conveyor 1 and robot 3 they can replace the flexible mechanised assembly cell MAC (Figure 18). Robot 3 here replaces M1 (robot 2). Robots 4 and 5 can perform assembly operations involved in stages B and C instead of manually operated WP2 and WP3 in AC.

1.5.4.2 Time to complete stages A, B and C of the assembly process

The time required to complete the operations involved in stage A (p. 6.1) here is again 22 [sec] (Table 1, column 14), but this time could be lower since parts and sub-assemblies are transported between individual robots by the conveyor. This time coincides (flows in parallel) with the time of operation of robots.

If we assume robots 4 and 5 will carry out the operations for stages B and C for 1,5 min, then the total cycle time for the assembly of a single product is $T_{AO24}^{max} \leq 1.5$ min.

Since a large time reserve is available in robots 2 and 3, then:

(15) $$T_{AO24}^{\max} = \frac{T_A + T_B + T_C}{3}$$

$$T_{AO24}^{\max} \leq \frac{22 + 90 + 90}{3} = 67.3 \text{ [sec]}$$

1.5.4.3 Number of AO24 incorporated in the assembly line and production output

We assume a monthly production schedule of N_S = 200 000 units/month.

For T_M = 200 hours $$T_1 = \frac{T_M}{N_S} = \frac{200.3600}{200000} = 3.6 \text{ sec, where:}$$

N_S – is the number of loudspeakers, and
T_M – is the monthly amount of working time.

For T_1 = 3.6 [sec],

(16) $$N_{AO24} = \frac{T_{AO24}^{\max}}{T_1} = \frac{67.3}{3.6} = 18.69$$, so we assume 18 units.

1.5.4.4 Conclusion

With the given data and described conditions, the number of AO24 required to produce a volume of 200000 units/month is 18. It is also possible to achieve this production volume with significantly less AO24 due to the possibility to increase the operation speed of robots 2 … 4 and improve the overall assembly process.

1.5.4.5 Conveyor featuring incorporated AO24

One alternative of incorporating an AO24 into the existing conveyor is illustrated in Fig. 18.

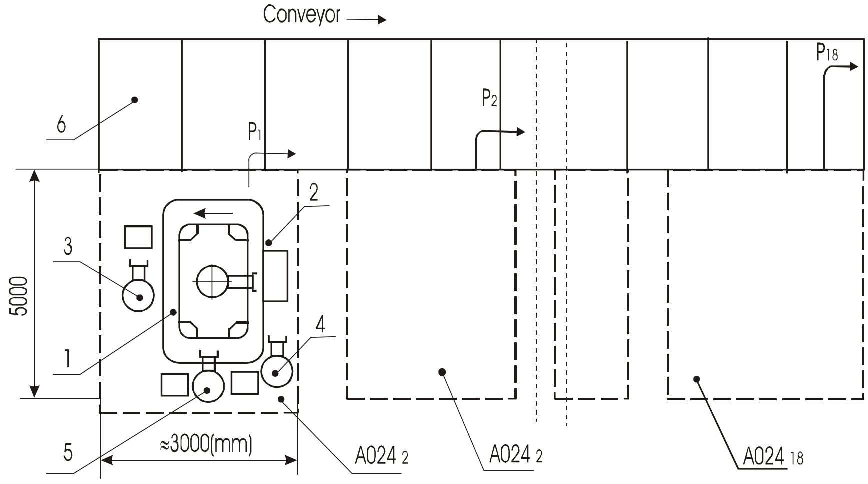

Figure 18: 1 – Conveyor (for AO24); 2 – Robots in AO24; 3 – Assembly line conveyor

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