2 Design of speakers production: assembly line of capacity 180,000/month, 15 product variants

2.1 Introduction

Modern production techniques for medium to large series products or mass production usually involve assembly conveyor lines. They still use hand labour more or less automated. 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 [1] or other types of automated conveyor lines [2], which provide full automation and human labour replacement.

2.2 Strategy for the "dolly" removal

2.2.1 Speaker design analysis

Let us examine the general design of a standard speaker in serial production and a section along its axis for convenience. It consists of the following parts: (Figure 1)

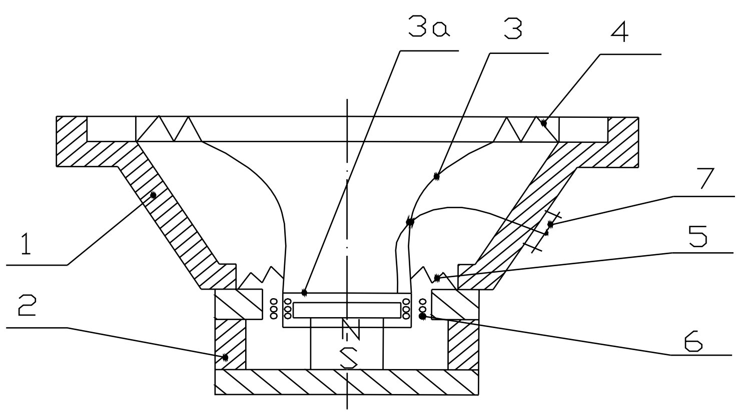

Figure 1: 1. Speaker body case; 2. Magnet system; 3. Conical diaphragm with dust cover (3a); 4. Collar with corrugated concentric folds of the conical diaphragm; 5. Centering oscillator; 6. Voice coil, oscillator; 7. Connection terminals with wires for fixing voice coil.

We could examine the RSW 401/5W, 20Z, 4Ω Loudspeaker shown in Figure 2 for a more detailed view relevant to the particular task for "dolly" removal.

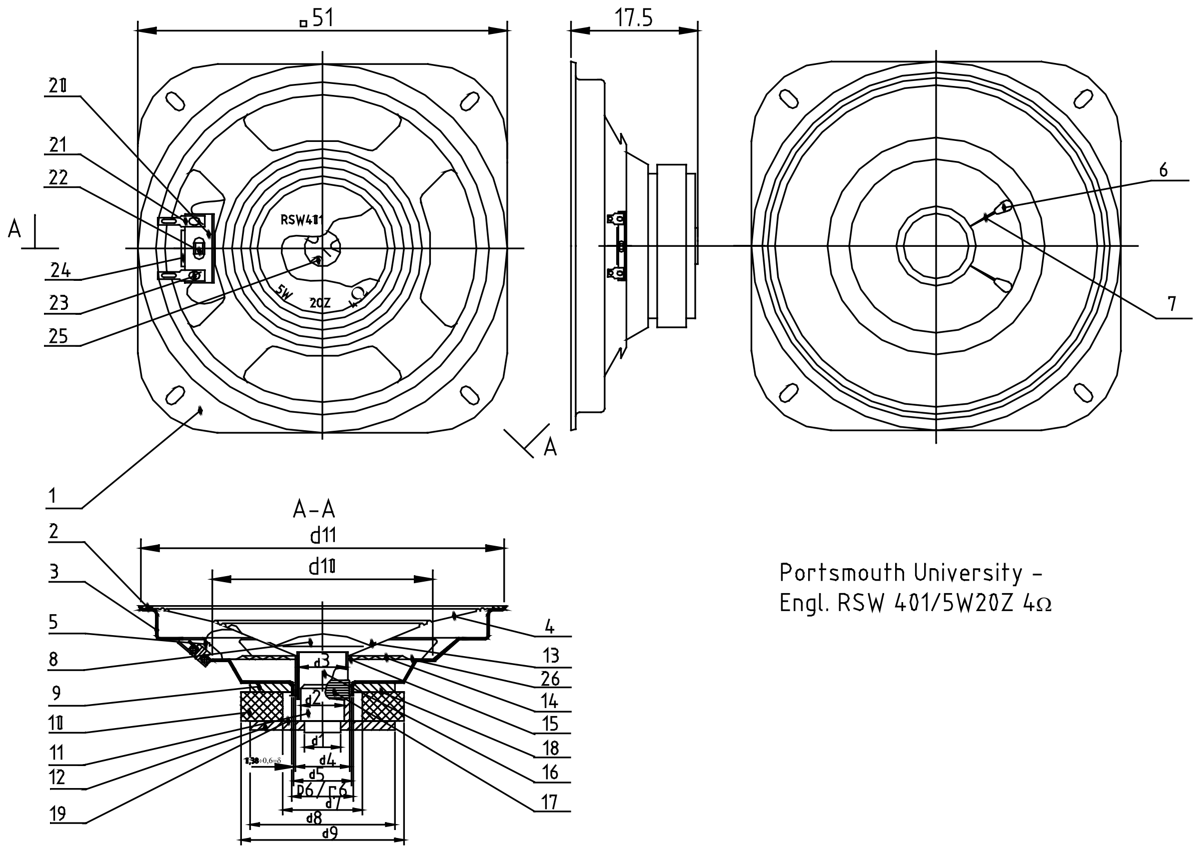

Figure 2

ItemNo.	Name and description	Q-ty
1	Body, speaker support frame	1
2	Rim (collar)	1
3	Adhesive (glued connection between Items 1, 2 and 4)	1
4	Conical diaphragm	1
5	Connection wires, between terminal outputs and oscillator coil	2
6	Soldered connection between Item5 and the wires from the coil 16 with the winding17	2
7	Insulation, for the wires 5 and glue to 4	2
8	Dust cover – oscillator	1
9	Top plate, magnet system (washer)	1
10	Magnet, permanent, ring-shaped	1
11	Central pin – magnet system core	1
12	Bottom plate, magnet system (washer)	1
13	Adhesive, glued connection between 8 and 4	1

ItemNo.	Name and description	Q-ty
14	Centering oscillator, corrugated flat diaphragm	1
15	Adhesive, glued connection between 14 and 16, and 4 and 14	1
16	Coil	1
17	Winding, from an insulated wire of the coil 16 – 4W	1
18	Adhesive, glued connection between 9 and 10	1
19	Adhesive, glued connection between 10 and 12	1
20	Terminal strip	1
21	Terminal	2
22	Rivet, tubular	1
23	Tin solder, soldered connection between 5 and 21	2
24	Protrusion from the body Item 1	-
25	Riveted connection between 11 and 12, depression – 3 off over Item 11	

2.2.2 Design description of RSW 401, Figure 2

The speaker body 1 is a conically shaped part stamped of thin steel sheet material and used to support the rest of the speaker component parts as assembled. The collar rim 2 and conical diaphragm 4 are glued to item 3 by means of an adhesive in a ring-shaped groove provided in the upper section of the speaker body. Terminal strip 20 is fixed by means of the tubular rivet 22 to the protrusion 24 cast into the body 1 as stamped. 3 through holes are provided on the terminal strip 20, one for the rivet 22 and two for threading the connection wires 5 to the terminals 21. The wires 5 are soldered to the terminals 21 during the assembly process using tin solder 23. On the other hand, the terminals 21 are riveted to the strip 20 by means of the protrusions provided on them. Glued by means of the connection 26 to the disc-shaped plane in the bottom section of the body 1 is the centering oscillator 14, which represents a flat corrugated diaphragm. This together with the coil 16 and the conical diaphragm 4 is glued in the position 15 (along its ring). Winded on the coil 16, which is a hollow cardboard cylinder, is the winding 17 made up of an insulated wire (4Ω). A small section along axis of the pin 11 of the driving magnet 9, 10, 19 and 11 enters the opening d_3 of the coil during the assembly process allowing for a very small gap of $d_3 - d_2$. A small chamfer ≈1x45° is provided in the pin 11 to facilitate the assembly process. The wire ends of the winding 17 provided on the 16 run up along the axis over the coil, glued and insulated, and come out from the inside of the cone of the diaphragm 4, between the cover 8 and 4, reaching the position 6 where they are soldered together with 5, insulated and glued to 4 by means of 7.

A cylindrical protrusion of very small length of ≈ the washer 9 with a diameter D is provided in the bottom section of the cone of the body 1. The protrusion is fixed (1) to the upper plate (washer) 9 of the magnet 10 by means of a D6/r6-tight connection. 9 and 10 are connected by means of the adhesive 18 during the assembly process just like the bottom plate 12 is connected to the magnet 10 by means of gluing it along the flat 19.

The centering pin 11 of the magnet system is riveted to 12 along d_1 by means of the three deformed sections 25 provided in it. Thus, d_1 is expanded to a larger size diameter thus ensuring a tight connection between 11 and 12.

The correct performance requirement for the loudspeaker is ensured during the assembly of the gap $\delta = 0.38 \div 0.6mm$*, which is* $(d_5 - d_4)/2$.

Additionally, the gap between d_2 and d_3 should be relatively small, i.e. the opening in the coil 16 and the pin 11. This is due to the fact that the coil moves axially in both directions during operation and enters deeper between 11.

2.2.3 Analysis of the assembly operation ensuring the gap "d"

It can be seen from the particular design of a modern loudspeaker examined above that the assembly "dolly" to be removed after the operation should be installed over the winding 17 inside the opening d_5, in other words the nylon thickness is = 0.6mm.

When the magnet is in assembled state 1+9+10+11+12 the "dolly" cannot be removed in the upward direction (section A-A, Figure 2), as the coil 16 has to be glued to the corrugated diaphragm 14. The axial alignment of the coil relative to the axis of the opening d_5 is ensured by the radial displacement of 16 and 14 before the glue 26 has set.

Above considerations define the assembled position of the body 1 at the time of "dolly" removal in the axial direction. Moreover, the magnet system consisting parts 9, 10, 11 and 12 should not be assembled in its position by the time this removal operation is to be carried out or at least the 11 and 12 part of it, which is actually the obstacle for the "dolly" removal. Another alternative is to leave the bottom section of the speaker open until the time when the coil 16 is centered and the "dolly" removed. These considerations significantly predetermine the sequence of individual assembly operations that have to be carried out on the conveyor and the specialised working stations to be provided along its length.

2.2.4 Assembly technique sequence for coil 16 and center oscillator, corrugated flat diaphragm 14 in body 1

The sequence of individual assembly operations could be the following:

Item No.	Designation		Description	Fixture or manually	Time [sec]	Remarks
	Operation No.	Stage				
1	2	3	4	5	6	7
1	I	01	Positioning diaphragm 14 with the coil 16 in the work station	fixture	3	Specialised work post No.1
2	I	02	Installation of dolly on d_4	manually	5	Specialised work post No.1
3	I	03	Applying the adhesive 26 on d_{10}	manually	10	Specialised work post No.1
4	I	04	Positioning body 1 face down on 14 and 16 with the dolly inserted through d7	manually	5	Specialised work post No.1
5	II	01	Moving 1 with 14 and 16 horizontally along with the dolly until dolly engages with mechanical jig	fixture	3	Work post No.1 or besides (or on the conveyor)
6	II	02	Time for glue setting	fixture	10	
7	II	03	Dolly removal in axial direction	fixture	3	Using conveyor movement

2.2.4.1 Diagrams showing assembly operations to be performed – Figure 3

Note: Part designation numbers of the loudspeaker is identical with Figure 2.

1. Operation I, Stage 01

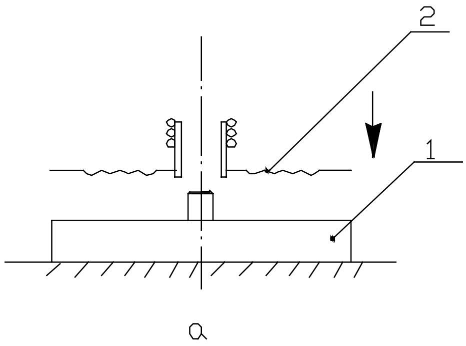

Figure 3a: 1. Fixture in work post No.1 F01; 2. Parts 14 + 16; 3. "Dolly"; 4. Surface with applied glue; 5. Part No.1.

2. Operation I Stage 02

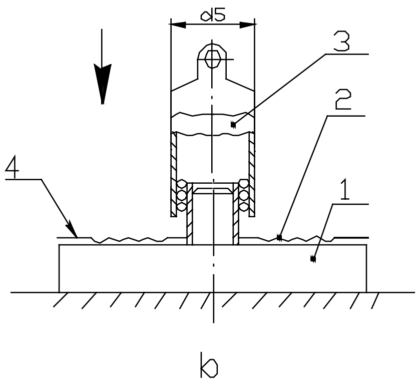

Figure 3b:

3. Operation I Stage 04

Position 3 is fixed – to be held manually until inserted through opening d_5 into part No.1. Pressed to be glued along 4.

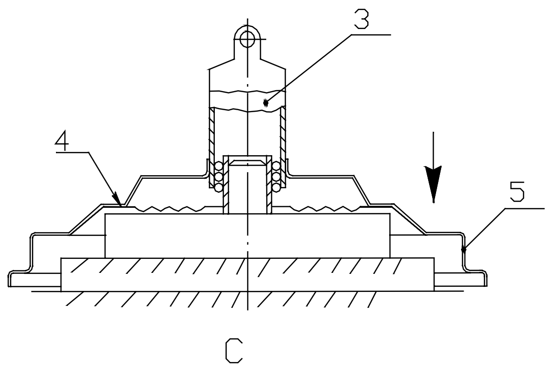

Figure 3c

2.2.5 Concept for mechanised "dolly" removal, Figure 4

Removal of nylon "dolly" from the coil winding and the opening d_5 on part No.1 (Figure 2) could be carried out by means of exerting axial pull action (+Z) using a special pulling device. This device could be installed on work post No.1 or close to it. Alternatively, it could be mounted in the area between work posts No. 1 and No.2; one used for assembling items 1, 14 and 16 of the product and No.2 used for subsequent assembly operations in the assembly process sequence.

2.2.5.1 Description and operation (Figure 4)

When assembly operation I 04 is complete we proceed with operation II 01 with the fixture F01, item 2 moved along with parts 1, 14, 16 and the "dolly" installed over them to Z_1- until inserted into the opening of the horizontal arm 1b of the pulling device. It in turn performs operation II 03 with the arm 1a moving vertically along the +Z axis along with 1b sliding along the guide 1c, which represents a bracket-supported fixed column.

The arm 1a is fixed statically to another column 1e, which is in turn fixed along ±Z. A reel is installed on a pin in the bottom section of the column 1e such that the column 1e slides into two guides 1d, which are in turn fixed to 1c.

Items 1, 14 and 16 are supported to prevent movement along the Z-axis in position Z1by the support 6.

2.2.6 Using conveyor movement for the removal of the "dolly" (Figure 4)

The lever, column 1e moves vertically in the +Z direction after the reel 1f contacts the slanted "lifter" plane 5 mounted on the conveyor's side. Items 1f, 1e, 1a and 1b move by gravity and forced by the "dolly" and the tension spring 1g.

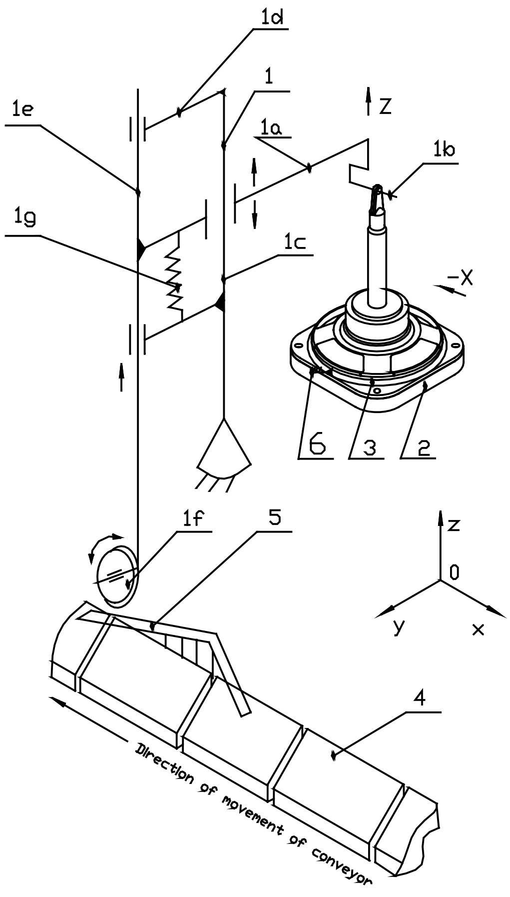

Figure 4: 1. "Dolly" removal device
2. Assembly fixture for items 1, 14 and 16 of the loudspeaker
3. A certain (model of) product having items 1+14+16 assembled on it
4. Conveyor (assembly line)
5. Lifter (slanted double plane)
6. Support along the Z axis

1a to 1g are components constituting the removal device (Item 1 above)

2.2.7 Possible organisation of work posts No.1 and No.2 and mounting of the "dolly" and the conveyor (Figure 5)

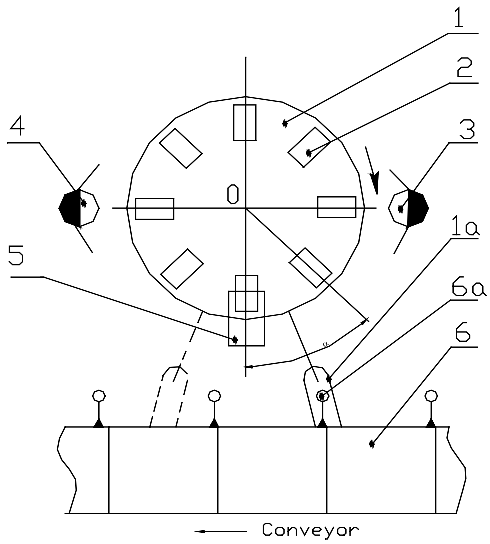

Figure 5: 1. Work table between 3 and 4
2. 1 to n-number fixtures for performing assembly operation I (Table 1)
3. Work post and operator No.1
4. Work post No.2 (for subsequent assembly operation(s)
5. Dolly removal device according to item 1.5 and figure 4 above
6. Conveyor or assembly line

1a, 6a – parts from 1 and 6

2.2.7.1 Description of operation

Operator No.1 performs assembly operation I 01 thru 04 on 1 and 2. The conveyor provides angular movement of 1 – a Geneva stop 1 along with the parts and (F01) 2 via the yokes 1a and reels 6a. The number of items 2 and the size of the angles α correspond to the time necessary for the glue to set and the speed rate of the conveyor so that there is sufficient number of semi-finished products available for operator No.2 to proceed.

2.3 General strategy

2.3.1 Analysis of the assembly process techniques

In order to be able to assess the suitability of the conveyor assembly technique for a specified product, such as the loudspeaker in this case, and the automation possibilities available for the particular process it is necessary to first make more detailed differentiation of individual assembly operations [3]. Additionally, it is also necessary to consider individual assembly stages in view of duration, performance complexity, and time and location relationship with other operations along with their economical evaluation. It is a well-known fact that for many products significant portion of assembly operations is still hard to be automated or assisted by robotics [4].

Manual handling is still a preferred process technique for many of them. Using industrial assembly equipment, handling machines or robots makes many operations impossible or hard to perform or such automation proves to be economically inefficient and is therefore considered groundless and useless [4]. An example of such operation, for example is the insertion and fitting of more than a single component simultaneously or when this necessitates complicated cycle movements. There are also a number of components requiring some additional operation, such as holding the component in place, deburring of edges, welding or soldering in hard to access locations [5].

Other operations considered hard to be fully automated or mechanised are applying a specified quantity of adhesives or pastes, threading very thin wires through holes drilled in advance, etc. From the above differentiating analysis of the subject, i.e. assembly components, we could draw up a preliminary general but still very necessary evaluation of their suitability for automated assembly techniques.

The technical characteristics of various assembly components comprise: the structure and characteristics of the subassembly, interconnections between individual elements, types of connections and fastening means between parts. General requirements could also comprise the following: the design of the product should allow for the assembly to be performed in complete interchange ability of individual components and on a continuous basis [6]. Dimensional tolerances should also allow for interchange ability between components and avoid operations, which are considered hard to perform, such as twisting wires, spring washers, spilling resins or plastics, etc. Some fragile and tender elements are also considered hard to be involved in automated assembly techniques, as is the case of the oscillator coil. This would require very precise alignment and avoiding possible damage [6].

In order to be able to make a preliminary visualised estimate of the loudspeaker's suitability for automated assembly techniques I made up the following "Assembly analysis chart" (Table 2). A detailed consideration of all required assembly operations and additional handling transitions could help us in our precise and good-quality selection of the types of operations, which are most suitable for automated assembly [7].

Additionally, preliminary information has been compiled for the connections between individual operations and the transitions between them in view of time and location, as well as duration, suggested automation equipment required, such as devices, machines, tools, and robots. This analysis provides grounds for drawing up an organisational chart and a work post layout diagram for the location of individual workstations along the conveyor. This also provides data for production capacity evaluations, conveyor speed rate estimations and assessment of some other technical and economical parameters [7].

2.3.1.1 Assembly analysis chart, Table 2. Selecting a suitable assembly stage, which can be efficiently automated

The assembly process flow model, which was selected for the Mod. RSW401 loudspeaker and visualised in the above Table 2 gives clear picture of the specific features and suitability of individual process stages A, B, C, (D) (A1) for automation.

The process stage in Table 2 and the described above in p.2.1, which is the most suitable to involve some automated assembly techniques is stage A (group A). The reason for this selection is that this stage involves mainly rotational regular-shaped components and convenient and sufficient in number base planes and planes suitable to be supported in automated handling devices [8]. Moreover, handling units will feature very simple design. The additional small stage D allows for some savings in operational time and multi-position assembly operation (possibility for simultaneous assembly of more than a single set).

The stage, which is considered most unsuitable for automation in this particular case is the stage B (group B components) and this is due to the high precision required in the positioning of the components being assembled and possible damage of coil winding. The stage C operation (group C components) is also considered easy for automation but the design of the handling devices involved in component transportation and positioning during assembly could prove rather complicated due to the low weight and easily deformable "collar" rim 2, conical diaphragm 4 and 8 (Figure 2). Vacuum grips could be used here but the applied adhesive or adhesive plastics could lead to unreliable automated operation cycles [9].

Assembly analysis chart

Legend:

yes +; no -; 9+10 sub-assembly of part items 9 and 10 or other part Nos.; Part numbers are as per Figure 2; The plane is the (X0Y) plane; LS – RSW401 loudspeaker

No	Designation		Description of the stage, operation, sub-stage or handling	Possible ways of performing			Tool, fixture, machine based on:	Time and location link with other assembly operations				Use of conveyor movement	Transport link-movement between work posts		Approx. duration sec.	Remarks and additional data
	operation	Substage		manual	automate	robot		before	simult.	after	workpost		from	to		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	I	**A1**	**The STAGE of assembling the 1drive unit 1,9,10,11,12 Gluing 9 and 10 (assembly)**													Group consisting of part Nos. 1,9,10,11,12 (sub-assys. 9+10 and 11+12)
1	I	01	Feeding 9 to fixture from the pallet	+	+	+	Fixture, plane and d_8	+	+	+	No3	-			4	Picking manually or by a handling device
2	I	02	Applying glue to 10 along the $d_8 – d_7$ plane	+	+	+	Fixture or applicator	+	+	+	No3	-			6	Sub-stage includes picking from Pallets
3	I	03	Positioning over 9 and pressing	+	+	+	I01 fixture, d_9 and the plane	+	+	+	No3	-			3	
4	I	04	Remove 9+10 and store in a pallet (or on conveyor)	+	+	+	Manually or by handler	+	+	+	No3	-			3	Time needed for the glue to set is not included in the duration time
	II	**A2**	**Assembling 11 and 12**													
5	II	01	Feeding 11 to the fixture from a pallet	+	+	+	Fixture, face and d_2	+	+	+	No3	-			4	
6	II	02	Picking 12 from pallet and positioning it on 11	+	+	+	Based on the support of 11 and d_1	+	+	+	No3	-			6	
7	II	03	Riveting through plastic deformation along face d_1	+	+	+	Press tool	+	+	+	No3	-			6	Manual or mechanically operated Press
8	II	04	Remove from press and put in a pallet	+	+	+	Manually or mech.handler	+	+	+	No3	-		No1	3	Possible to transfer it to No.1 with out pallet
	III.	**A3**	**Assembling 1 and 9+10 along the H6/r6 connection**													
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
9	III	01	Picking 9+10 from pallet (or conveyor) and position it in the press	+	+	+	Fixture based on d_9 and the plane			+ I	No2	-			4	
10	III	02	Picking 1 from pallet and position it on 9+10	+	+	+	Fixture based on H6/r6				No2	-			5	

11	III	03	Plastic deformation of 1 till H6/r6 is achieved; put in pallet	-	+	-	Press tool, hydr. Press		+	+	No2	-		No2	7	Mechanical or hydraulic press
	IV		STAGE D – Assembling the Terminal strip 20, 21, 22, 23							III						
12	IV	01	Picking from pallet and fastening 2off terminals 21 to 20	+	-	+	Tool, manually or with press	+	+	+	No2	-			12	Manual or mechanically operated press using el. motor, air, etc.
13	IV	02	Riveting strip 20 on the body 1 (1+9+10)	+	+	+	Tool, manually or with press	+	+	+	No2	-	No3		8	
14	IV	03	Soldering wires 5 to terminals 21 – 2off and 23	+	_	_	Soldering tool	+	+	+	No2	-	No1		10	
			STAGE B – Assembly of voice coil and support 1, 14, 16							I, III, IV						
	V		Assembly of diaphragm 14 and coil 16								No1					
15	V	01	Picking 16 from pallet and position it on work post	+	-	-	Fixture, d4 and face	+	+	+	No1	-			3	
16	V	02	Picking 14 from pallet and position it on work post	+	_	_	Fixture, d4 and face	+	+	+	No1	-			5	
17	V	03	Applying adhesive along contact rim surface (d4)	+	-	-	Fixture, brush and applicator	+	+	+	No1	-			6	
	VI		Assembling 14+16 and 1							I, III, IV, V						
18	VI	01	Picking 14+16 from pallet and position it on the work post	+	-	+	Fixture based on d3 and the plane	+	+	+	No1	-	No2		4	Operation I01 from para 1
19	VI	02	Position the "dolly" over 16	+	-	+	Fixture based on d3 and the plane	+	+	+	No1	-			8	Operation I02 from para 1
20	VI	03	Applying adhesive on 14 along d10	+	-	+	Fixture based on d3 and the plane	+	+	+	No1	-			5	Operation I03 from para 1
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
21	VI	04	Picking from pallet, inserting "dolly" in d5 and positioning on 14 + 16	+	-	+	Fixture based on d3 and the plane	+	+	+	No1	-			6	Operation I04 and II04, para 1
22	VI	05	"Dolly" removal along Z axis	-	+	+	Fixture, F01 and conveyor	+	+	+	No1	+		No2	4	Operation II03 from para 1
			STAGE C Assembly of cone and dust cover 4, 2, 8 and 1							I, III, IV, V, VI						

	VII		STAGE C Assembly of cone and dust cover 4, 2, 8 and 1													
23	VII	01	Picking 1 from pallet and positioning in work post	+	+	+	Fixture, oriented along the 102 sq.	+	+	+	No2	-	No1		3	
24	VII	02	Applying adhesive – d11	+	+	+	Fixture, brush or applicator	+	+	+	No2	-			6	
25	VII	03	Picking 4 from pallet, advancing towards 1 and threading wires 5 – 2off through holes in 4 Positioning on 1	+	+	+	Manually or with mechanical handler along d11	+	+	+	No2	-			7	
26	VII	04	Picking 2 from pallet, applying adhesive along d11 and positioning on 4	+	+	+	Fixture, brush or applicator	+	+	+	No2	-			6	
27	VII	05	Soldering wires 5 ends in position 6 – 2off and bending	+	_	_	Soldering tool	+	+	+	No2	-			10	
28	VII	06	Positioning in pallet	+	+	+		+	+	+	No2	-		No1	3	
		A4	STAGE A4 Additional assembly of 11+12 into the speaker 6 and control								No1		No2			
	VIII		Assembly of 11+12 into the speaker								No1					
29	VIII	01	Picking 11+12 from pallet and positioning on fixture	+	+	+	Fixture, based on d8 and radial fastening	+	+	+	No1	-			5	
30	VIII	02	Applying adhesive along face surface of 12	+	+	+	Fixture, brush or applicator	+	+	+	No1	-			4	
31	VIII	03	Picking speaker from pallet and positioning on 11+12	+	+	+	Fixture, based along d9	+	+	+	No1	-			5	
32	VIII	04	Insulation of 6, control and positioning in pallet	+	+	+		+	+	+	No1	-			5	

2.3.2 Recommendation for a suitable automation process for stage A (components group A)

2.3.2.1 Concept for a general diagram of the automated assembly process A (stage A)

Components are assembled (according to the example technique in Table 2) in 3 separate sub-stages; first parts 9 and 10 are glued together to form one unit and this is stage A1, then parts 11 and 12 are subsequently or in parallel with A1 riveted together and this is sub-stage A2; and finally, sub-assembly 9+10 is installed in the body 1 in the third sub-stage A3. Moreover, all three sub-stages are carried out in a single work post No.3 using three separate fixtures. Two auxiliary devices should be available at this workstation to provide for the riveting and adhesive-applying operations and intermediate operation time should also be allowed here for the glue to set. One final sub-stage is also carried out apart from sub-stages A1, A2 and A3, sub-stage A4. This provides final assembly of the drive unit. Due to the specific overall assembly operation sequence this sub-stage is actually carried out in a different work post No.1 and is therefore disregarded from our proposed automation scheme.

Essence of the idea for efficient automation

All components involved in the sub-assembly operations in sub-stages A1, A2 and A3 (sub-assemblies A1, A2 and A3) are rotational and simple in shape. Therefore, they can be fed to the specified location, the assembly fixture, and inserted into it automatically (without any manual actions) using two simple and conventional methods. One is to feed them along troughs positioned at a certain angle or horizontally by rolling or sliding them by gravity or using relatively simple pushing devices. Alternatively, them could be arranged in a column along the trough's length, one after the other. Examples of such "catcher" troughs are available at bearing manufacturers and spring feeding is similar or identical to bullet feeding in machine guns.

a) End actuator

The components being thus fed to the assembly fixtures should be inserted in regular small time intervals into the specified number of specific type (stage A1, A2 and A3) assembly fixtures moving underneath. These fixtures are then moved to the adhesive applicator or the fast-acting riveting press. Once sub-stages A1, A2 and A3 are completed the assembly fixtures can then be further transferred to feed their sub-assemblies into the next work post, WP 2 in this case. This is accomplished by means of releasing assembled, glued and riveted sub-assemblies 9+10 and 11+12 from their assembly fixtures in a location close to work post WP2 by means of a simple release mechanism. Parts 9+10 should have before that been released or fed to assembly fixture No.3 at work post WP1 in order for the sub-assembly A3 to be completed, assembling the body 1 and 9+10 (sub-assembly A1).

The role and functions of the operator at work post WP3

The function of the operator at this workstation will be to fill in the component input bins feeding the feed troughs from the pallets they are supplied in. Additionally, he will have to manually load assembly fixture No.3 for assembling the 9+10 sub-assembly into the body 1(or only monitor this operation), monitor the assembly operation and transfer movement and start and stop automatic fixtures and devices, machines (press) and auxiliary devices whenever considered necessary.

b) Involvement and function of the flat linear conveyor belt

The conveyor belt may in this case be only used for some additional auxiliary actions, such as to provide the transportation link between individual work posts in relation to their location along the conveyor and the assembly cell itself. From the analysis made in Table 1 we can conclude that the assembly cell area for a single type or model of loudspeaker products is obviously made up of three work posts (operator workstations) furnished with all necessary automated fixtures and means, which should be positioned close to each other. The conveyor belt could therefore be used to transport finished loudspeakers to the end of its length ready to be transferred into the finished products store. Alternatively, the conveyor belt could be used to drive auxiliary turntables rotating around one central axis and supporting specific assembly fixtures, or to actuate the fixtures (devices) themselves. A similar idea was discussed in p.1 above for the "dolly" removal device and this now proves sufficient or even particularly applicable to provide for the transportation link between work posts 3, 2 and 1 and back.

c) Feeding and storage of individual component parts

As we mentioned earlier, component parts are normally supplied in individual pallets in quantities sufficient to provide for feeding a specified duration of an operation cycle. Additionally, parts are arranged or fed into pallets or storage rack cells in the intermediate transfer course of the assembly process between stages A1, A2 and A3. The movement between work posts WP1, 2 and 3 is through an auxiliary transportation turntable providing automation to the whole process. Some manual transportation or movement of pallets with component parts is also possible here when small distances are concerned in large time intervals.

d) Possibilities to speed up assembly operations

Apart from the general assembly diagram discussed above and involving continuously or step-moving fixtures with nests or bases for performing the required assembly operations involved in sub-stages A1, A2 and A3, this concept also allows for another assembly arrangement involving multi-station fixtures for a single stage of each assembly operation. For example, if component parts 11 and 12 are arranged in one 1 to n-station fixture, the press having the same number of riveting positions will perform the riveting operation simultaneously on all of them thus saving a considerable amount of operation time.

The idea discussed in p.2.2 above could be illustrated as shown in Figure 6.

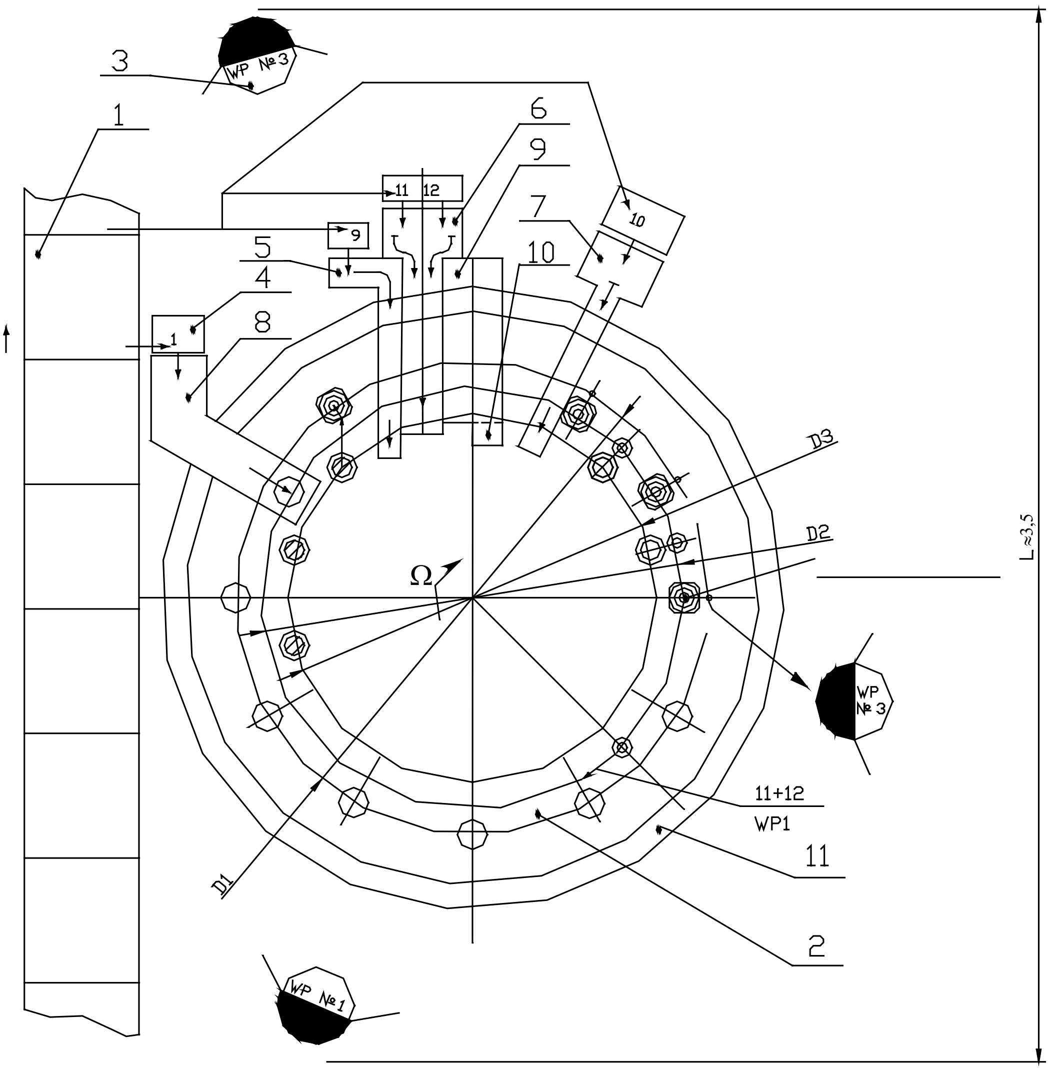

Figure 6: 1. Conveyor; 2. Turntable; 3. Work posts WP 1 thru 3; 4. Pallets filled with component parts 1, 9, 10, 11 and 12; 5. Feed-in bin and trough for part 9 towards D3; 6. Feed-in bins (2 off) and trough for parts 11 and 12 towards D2; 7. Feed-in bin and trough for part 10 towards D3; 8. Feed-in bin and trough for part 1 towards D; 9. Press (for D1 and D2); 10. Adhesive applicator (for D3); 11. Disc-shaped platform for transportation of pallets, component parts, tools, etc. or for the installation of F01 (fixture for "dolly").

Arrows indicate the directions of movement of component parts and transportation links. The operator at WP3 fills in the bins 5, 6, 7 and 8 from pallets 4 with component parts 9, 11, 12, 10 and 1 respectively (designations are according to Figure 2). Component part 9 moves along the feed trough of 5 and goes into the assembly fixtures positioned on D3 onto the turntable. Device 10 applies the adhesive and device 7 feeds in the other component part 10 in an identical or similar way. The movement of the turntable transfers assembled parts 9+10 to a location close to 8, where part 1 is fed in the same way (or manually) via the bin 8. The part 1 and bin 8 are positioned on D1 and sub-assembly 9+10 is taken from D3 and positioned into part 1. Further on, the punching press 9 performs operation III (Table 2) and sub-assembly 1+9+10 is then directed towards WP2.

2.4 Feeder design

Para 2 above describes the basic principal elements of feeder mechanisms. There are 5 types of feeding bins with troughs for transferring component parts to the locations where they are to be assembled. Therefore, we shall need to consider design ideas and details for each individual feeding device intended for each of these 5 different component parts. Axis Y is perpendicular to drawing plane [10].

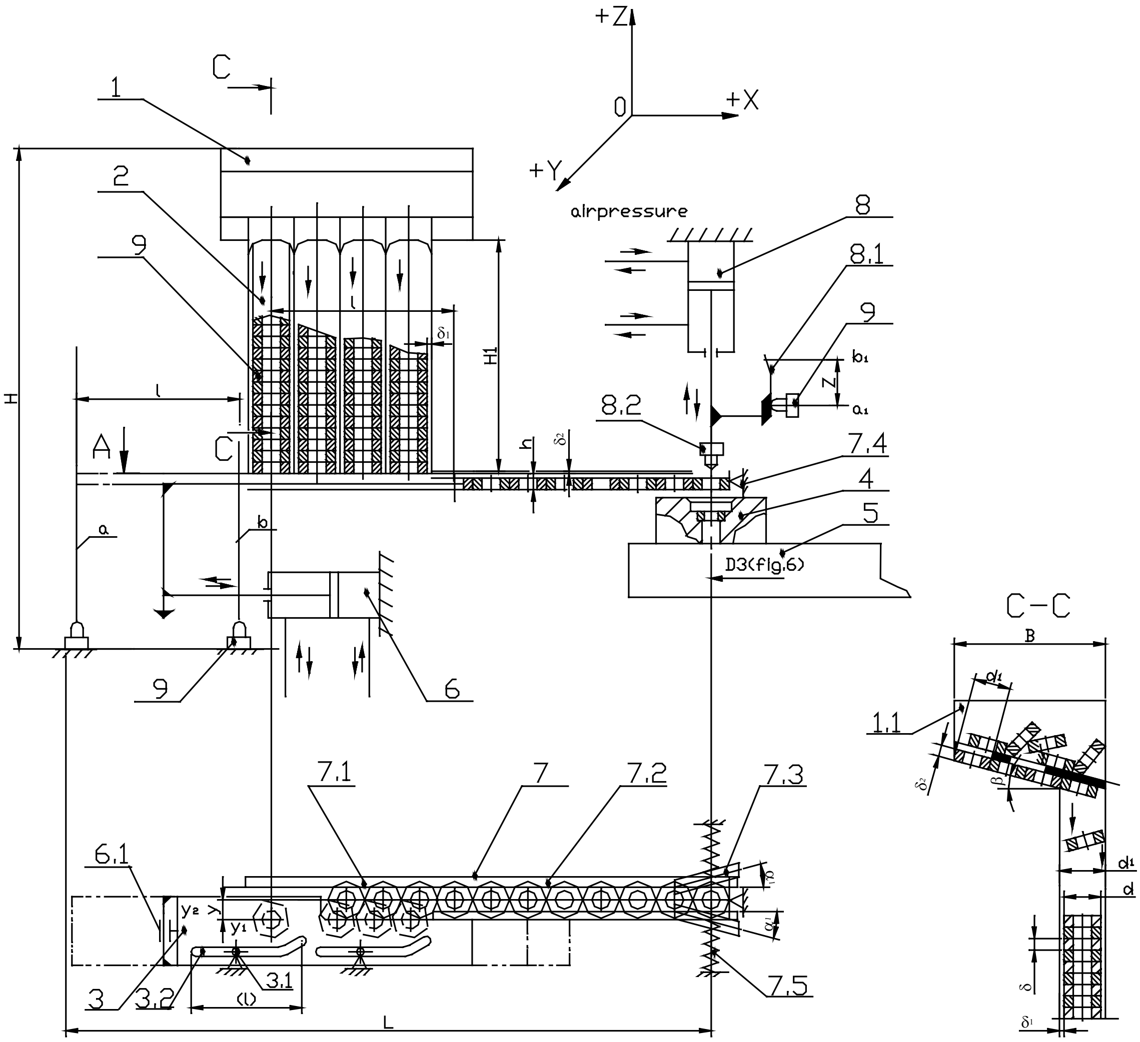

Figure 7: Direction of the arrows shows: – direction of movement of component parts; – direction of movement of mechanisms; – compressed air fed to the pneumatic cylinders.

Component part 9 "Magnet system top plate (washer)" is the most convenient and suitable part to be used in the described method of feeding into the assembly fixture and subsequent assembling performed on the turntable. Figure 7 shows the design idea of such type of feeding mechanism.

SPECIFICATION

for Figure 7

No.	Item No.	Description	Qu-ty	Notes
1	1	Bin for component parts (part 9)	1	
2	1.1	Slope partition	1	Bottom with openings
3	1.2	Vertical partition	5	
4	2	Column	4	d_1 dia tubes
5	3	Pusher	1	
6	3.1	Reel, guide	2	
7	3.2	Profile groove	2	
8	4	Assembly fixture	12	On 5
9	5	Work table	1	Turntable
10	6	Cylinder, horizontal	1	Along X-axis, pneumatic
11	6.1	Slide	1	Along ±y axis
12	7	Trough	1	
13	7.1	Guide, top	1	
14	7.2	Guide, bottom	2	
15	7.3	End plate	2	
16	7.4	End support	1	Stop along X
17	7.5	Spring	2	
18	8	Cylinder, vertical	1	Along Z axis, pneumatic
19	8.1	Switch	1	Flat cam
20	8.2	Assembly punch	1	
21	9	Electrical circuit breaker	3	

A, b, a_1 b_1 – end positions of 6 and 8. Z is the movement of 8.

2.4.1 Description of Figure 7

The movement of part No.9 (Figure 2) is shown in Figure 8 underneath:

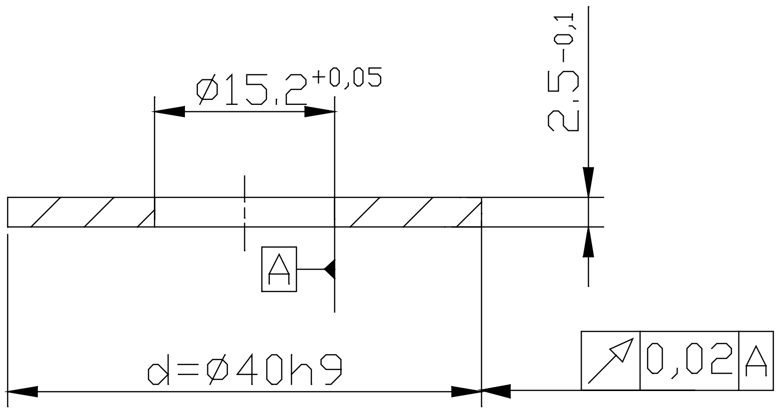

Figure 8: Washer (top plate); Material: Steel

A feed mechanism provides for the movement of component parts from the parts feeder bin 1 towards the assembly fixture 4, which performs the assembly with part 10 (Fig.2). A hopper bin for component parts 1 is located on 4 (up to *n*-number) vertical columns, d_1 inner diameter tubes and the hopper bin bottom is positioned at an angle of β. A second bin bottom with openings d_1 provided on it in several rows located horizontally (to the β angle) is positioned at a distance $\delta_2 \approx \delta + 0.5$mm. The axis of the second bottom plate coincides with the axis of columns 2. A knife-shaped pusher 3 is positioned horizontally in the lower section of the columns 2, underneath them.

The pusher 3 is connected and moved in the horizontal direction ± x by means of the power cylinder 6. The columns 2 are supported above the guide trough 7 transferring component parts towards the axis of the fixture 4. Component parts are located in position into the trough by guides 7.2 underneath and by end plate 7.3 (2 off) in the assembly fixture position. The assembly punch 8.2 is located along the axis of 4 and above the part, which is currently positioned for assembly and its movement is ensured by the cylinder 8 having control elements 8.1 and 9. Longitudinal profile grooves 3.2 are provided along the x axis of 3 and guide reels 3.1 are positioned into these grooves their datum surface being the structure of columns 2 (and the entire unit). Cylinder 6 is connected to 3 by means of the slide 6.1, which also provides movement along the y-axis.

2.4.2 Operation, Figure 7

Component parts 9 are filled into the bin 1 from a pallet positioned and located independently. When stirred by hand (or automatically) some of them enter the d_1 openings provided in the slope partitions, the bottom 1.1, the diameter of the openings being slightly larger. The parts are then arranged one after the other along the slanted grooves with the vertical walls 1.2 acting as side stops (along the y-axis). Then they slide down the slanted bottom by gravity (angle β) until they enter one of the columns 2 piling and locating with their plat surface, the X0Y plane, in the columns until columns are full to the top. The horizontal pusher 3 with cam grooves 3.2 guided by the reels 3.1 moves along +x at a distance of l in the bottom section of the columns 2 in accordance with the cycle of feeding component parts to 4. First, it pushes four parts between $y_1 - y_2$ in the – y direction to a y distance and then it pushes the entire row (4 parts) into the trough 7.

Under this action the parts cannot lift up and go back to 2 once they move to the distance –y held there by the side guide 7.1. The parts are further guided along the trough by its side walls, supported on the bottom side by the guides 7.2 horizontal surfaces, slide along the trough and stop in the assembly location of 4. When the cylinder 8 actuates it presses down part 9 by means of the punch 8.2. The moving sections 7.3, "end plates" then open thus causing the springs 7.5 to compress to an angle of α_1 ($2 \times \alpha_1$) and the component part thus descends into the – Z direction entering the seat provided for it in 4. The diameter of the seat is slightly larger than d to provide for 0.02 A (Figure 8). Additionally, part face is slightly above the datum surface for part 10, for example: +0.5+0.2. The cylinder 8 actuates as the worktable 5 rotates in a position where the axis of 4 is coincident with the axes of the punch 8.2 and the cylinder 8. Circuit breakers 9 and the cam of 6, the switch 8.1 of 8 provide the controls for the forward and backward movement of the cylinders. The circuit breakers control respective electromagnetic control pneumatic and hydraulic valves depending on the operation fluid selected.

2.4.3 Basic dimensions (Figure 7)

Dimensions are determined by the necessary number of component parts (part 9) held into the columns 2; by the stroke and size of power cylinders 6 and 8 and other parts and mechanisms involved in their operation; the length of the trough 7 and the distance between the outer diameter D of the turntable and $D_3 = (D - D_3) \times ½$. Due to the fact that component part 9 has small relative size, Figure 8, the height H_1 of loading necessary number of parts into the columns for continuous 8 hour operation (single shift) will be:

1) $H^{min} = \delta . n$, where $\delta = 2.1 - 0.1$; n is ¼ of necessary parts for 8-hour operation.

It can be seen from Table 2 that the overall time T_A necessary for operations I, II and III from the A stage to be carried out on work post No.3 (WP3) is the sum of times in column 16, i.e. ≈ 51 sec. The time necessary for sub-stage A4, operation VIII01 … 04 should not be added here because this is performed in another work post, work post No.1 where the final assembly and test of the loudspeaker is performed.

From all said above,

2) $n = T_{op.}/(T_{A1} + T_{A1} + T_{A1}) = 8.\ 3600/51$
$n = 566$ parts
[$T_{op.}$ is the operation time fund for 8-hours operation (single shift)]

For column 1, Item 2 $n_1 = 566/4 = 141.5 \approx 142$ parts No.9 and $\delta = 2.5$mm.

Therefore, $H_1^{min} \geq 142.\ 2{,}5 = 355$ mm

The overall height H of the feeder (Figure 7) will result if we added the height of the feed bin 1 ≈ 200 mm and the cylinder unit 6 ≈ 200 to H_1^{min} for design purposes, so

3) $H_1^{min} \geq 355 + 200 + 200 = 755$ mm

The size along the X length, L is defined as ≈ 4.d.4

4) $L_1^{min} \geq 4.4.40 = 640$ mm

The size B across the width is defined in the design as: $B^{min} \geq 180$ mm.

The dimensions thus defined are valid for the particular loudspeaker discussed. Specified dimensions will differ within tight limits for the other 14 variants or types of speakers (to make up to 15 as required in the assignment) if we assumed that this same conveyor will be used for assembling loudspeaker versions close in size and similar in design to the initial one [10].

2.4.4 Storage capacity (Figure 7)

The parts storage capacity is determined by the design dimensions adopted and mainly by H and B, para 3.3. above. The bin 1 is capable of holding almost twice the number of component parts of the specified dimensions held in the columns 2 and the trough 7 and therefore the actual possible minimum set quantity of part 9 will be:

5) $N_{stor.} \geq 2.n - 1132$ parts – from (2) above we have n – 566,

Where, Nstor. is the storage capacity (number of parts).

This quantity is sufficient to provide 16 hours continuous conveyor operation.

2.4.5 Cycle time T_c

6) $T_c = T_A / m$

$T_c = 51/12 = 4.25$ sec, where

T_A is the time necessary to perform Stage A or ≈ operation I 01;
m is the number of positions provided on the turntable 5 (Fig. 7)

2.4.5.1 Cycle time for the power cylinder 6 – T_{c6}

7) $T_{c6} = n_c . T_c$
$T_{c6} = 4. 4{,}25 = 17$ sec., where n_c is the number of columns 2 (Figure 7).

2.4.5.2 Cycle time for power cylinder 8 – T_{c8}

8) $T_{c8} = T_c = 4.25$ sec

2.4.6 Method of re-filling

2.4.6.1 Time for re-filling

Re-filling is performed every 16 hours of continuous conveyor operation or once in every 2 shifts and this necessitates some additional time of around 2 minutes. This time could be on the expense of short coffee breaks (of 10 to 15 minutes) allowed for operators within the 8-hour working time or before conveyor operation has started. Time for re-filling is in this sense per every 15 hours and 58 minutes when there are still some parts in the unit [11].

2.4.6.2 Re-filling technique (Figure 7)

Re-filling is performed by gradually filling 1132 component parts into the bin 1 (parts 9, Figure 2). To facilitate entrance to the openings 1.1 and the columns 2 parts are stirred in by hand when filled into the hopper bin. Additional stir in is applied 4 or 5 times throughout the shift to provide uniform column feed.

2.4.7 Feeder of component part 10 (Figure 2) to the fixture Item No.4, Figure 7

Once component part 9 has been fed to the fixture 4 further rotation of the worktable moves it underneath the fixture, which assembles part 10 over it. Prior to this stage, the glue applicator unit Item 10 in Figure 6 has applied glue to the upper surface of part 9 (not shown in Figure 7).

2.4.7.1 Design

Part No. 10 (Figure 2) – "Permanent ring-shaped magnet", Figure 9 is similar in shape to part 9 (Fig.2). Therefore, the part feeder device for parts 10 will be identical to the device shown and described in para 3 thru 3.3 above. There will be some differences in the sizes and storage capacity, as well as the time for re-filling, which is due to the larger size of part 10 compared to that of part 9.

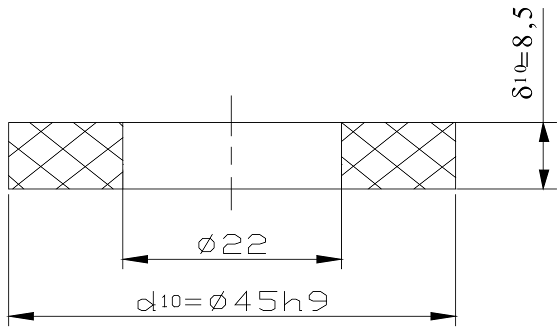

Figure 9

Intrinsic part magnetism could cause certain problems so the bin 1 (Figure 7) and the columns should be manufactured of some non-magnetic material, such as laminated fabric, plastics, Al, etc. It is also possible for the entire storage and feeder unit to be manufactured of such materials with the only exception of the feeder cylinders 6 and 8. For the punch 8.2 and the fixture 4 itself it is mandatory to avoid sticking to the part 10 for magnetic reasons.

2.4.7.2 Dimensions

If we assume that parts 10 will be filled once for every work shift, then the number of component parts filled into the unit will be:

9) $N_{stor.10} = N_{stor.} / 2$, where $N_{stor.} = 1132$ form (5)
$N_{stor.10} = 566$ parts

As part 10 is slightly larger in size: $\delta_{10} = 8.5$mm, the size for the height H_{10} will be:

10) $H_{10}^{min} \geq H^{min}.\ \delta_{10}/\delta_{.}\ ½$,
where $\delta = 2.5$ mm and $H^{min} = 755$ mm from (3)
$H_{10}^{min} \geq 755.\ 8{,}5/2{,}5.\ ½ = 1283.5$ mm

The size along the length L_{10} is:

11) $L_{10}^{min} \geq 16.\ d_{10}$,
where $d_{10} = 45h9$ (from Fig.7) and 16 from (4)
$L_{10}^{min} \geq 16.\ 45 = 720$ mm

The size across the width B_{10} is:

12) $B_{10}^{min} \geq B^{min}.1/2.\ d_{10}/d$, where
$B^{min} = 640$ (from (4); and $d = 40$
$B_{10}^{min} \geq 640.\ ½.\ 45/40 = 360$ mm.

Note: It is possible to increase B_{10}^{min} in order to make it identical to B^{min} on the expense of reducing dimensions H_{10}^{min} to provide for the storage capacity of 566 part 10 if this is considered appropriate during the design process.

2.4.7.3 Storage capacity

As defined above, the storage capacity is 566 parts

13) $N_{stor.10}$= 566 parts

2.4.7.4 Cycle time – T_{c10}

Cycle time T_{c10} is identical to that defined for part 9 due to the fact that one component of each type should be fed simultaneously for assembly.

$$T_{c10} = T_c = 4.25 \text{ sec}$$

Cycle times for power cylinder 6 and power cylinder 8 are the same as in (7) and (8), para 3.5.1 and 3.5.2 above:

$$T_{c6/10} = 17 \text{ sec; } T_{c8/10} = 4.25 \text{ sec.}$$

2.4.7.5 Method of re-filling

This is the same as in * 3.6 above for every 8 hour operation.

2.4.8 Feeder for part No. 11 (Figure 2)

2.4.8.1 Design and operation

Part No.11 "Central pin" (magnet core system) is shown on Figure 10.

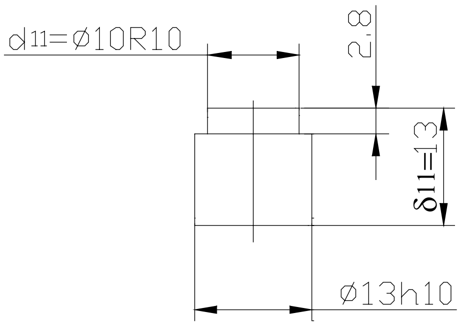

Figure 10: Feeder; Material: Steel

This component part could be fed in way similar to that described for part 9 and 10 earlier. One basic difference is the method of feeding the component into the tubes, columns 2 (Figure 7), where 11 should enter with its 10R10 dia pointing upwards (=Z), as shown in Figure 10. Therefore, parts filled into the tray above 1.1 (Fig. 7) should be arranged exactly the same way and in 1 row (1 level) heights – Figure 11 (designations are according to Figure 7).

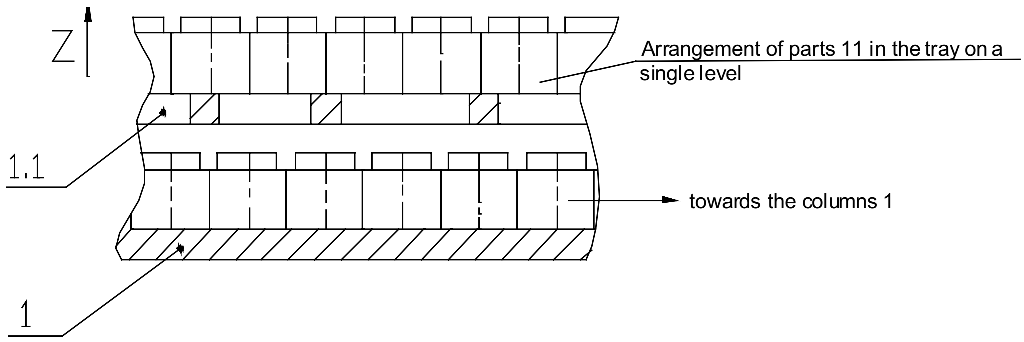

Figure 11

2.4.8.2 Basic dimensions

The basic dimensions here are identical to the dimensions of the part 9 device.

14) Height $H_{11}^{min} = H^{min} = 755$ mm; from (3) H = 755 mm
15) Length $L_{11}^{min} = L^{min} = 640$ mm; from (4) $L^{min} = 640$ mm
16) Width $B_{11}^{min} \geq B^{min} = 180$ mm; $B^{min} = 180$ mm

2.4.7.3 Storage capacity $N_{stor.11}$

This should be identical to the quantity of parts 9 in order to guarantee simultaneous filling of hopper bins:

$N_{stor.11} = N_{stor.} = 1132$ parts; $N_{stor.} = 1132$ parts from (5)

2.4.7.4 Cycle time T_{c11}

This is again identical to cycle time for parts 9 and 10

$T_{c11} = T_c = 4.25$ sec; $T_c = 4.25$ sec from (6)

2.4.7.5 Method of re-filling

Re-filling should be done every 16 hours of continuous conveyor operation, T_f, which is the time needed to arrange the parts in the bin 1 tray (Figure 7). This is ≈ 15 min. In other words, re-filling is performed every 15 hours and 45 minutes. This is done by manually filling component parts 11 from a pallet into the bin 1 and arranging them with the 10h10 dia pointing up (the +Z direction).

2.4.9 Feeder of component part 12 (Item 12 in Figure 2)

The feeder bin item 6, Figure 6 for component part 12 is identical to the one shown in Figure 7 because all external (datum) dimensions and the shape of component 12 are identical to those of part 9. All other process parameters, such as cycle time, storage capacity and method of re-filling are also identical to those for component part 9.

2.4.10 Feeder of component part 1 (item 1 in Figure 2)

Used for performing assembly operations III 01…04 as in Table 2.

2.4.10.1Design description and operation (according to Figure 7 and others)

Component part 1, "Body", is the most complex in shape and as a manufacturing technique part of the loudspeaker. It is made of 1mm thick steel sheets punched and stamped into a complicated shape. Therefore, the feeder mechanism cannot use the same bin 1 and columns 2 (Fig. 7), where component parts are filled in and almost automatically (semi-automatically) arranged in the required positions for further handling and fed into the respective assembly fixture (12 off) located around the diameter D1 of the turntable (item 2, Figure 6 and item 5 in Figure 7).

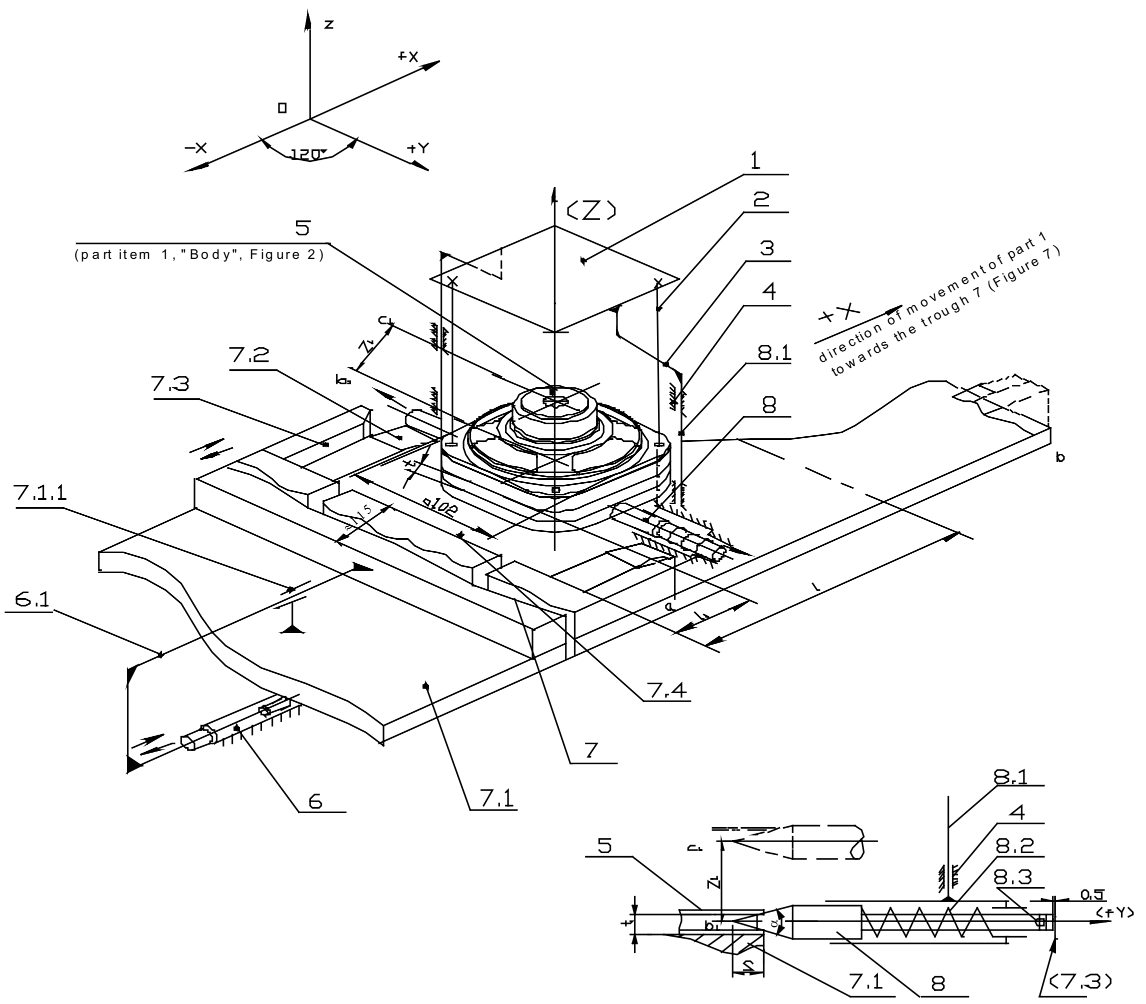

Figure 12

The design of part 1 is similar to that for part 9, except for 1 and 2 (Figure 7), which are not included. One column of "Body" parts is provided instead of 2 and the parts are stacked one on top of the other not in the feeder device but in a special removable cartridge "a magazine", which is removed when empty and replace by a re-filled one during operation. The feeder mechanism 6 and part items 3 and 9 are also present in this design solution but have a different operation, mechanics and design shape.

The feeder mechanism operated on a single cycle, i.e. it feeds 1 component part towards 4 (Figure 7) for every cycle of the turntable (which we estimated at 4.25 sec.)

Figure 12 shows the principal design diagram for this type of feeder mechanism.

SPECIFICATION

for Figure 12

No.	Item No.	Description	Qu-ty	Notes
1	1	Cartridge for component parts	1	120 parts (part 1, Fig.2)
2	2	Pin	2	Guide for part 1
3	3	Stand	2	Fixed to part 1
4	4	Guide	4	Sliding hinge on 8
5	5	"Body" part	180	
6	6	Power cylinder	1	Pneumatic or hydraulic
7	6.1	Guide	1	Towards push bar of 6
8	7	Pusher	1	
9	7.1	Base plate	1	
10	7.1.1	Bracket	1	With sliding support for 6.1
11	7.2	Inclined plane	2	Part of 7, angle towards X0Y
12	7.3	Vertical plane	2	Part of 7, parallel to X0Z
13	7.4	Face wall	1	Part of 7, parallel to X0Y
14	8	Positioning lock, lifting	2	Axis parallel to y
15	8.1	Sleeve for positioning lock, with guide	2	
16	8.2	Spring	2	
17	8.3	Split pin	2	

Note: 7.2; 7.3 and 7.4 are elements of part 7 "Body".

Parts are stacked one on top of the other as shown in Figure 12, with their tapered section pointing towards cartridge 1 bottom and are positioned in place (around the Z axis) by mean of pins 2 fixed to the cartridge. If the cartridge has been manufactured to have the shape of a deep square-shaped pallet it is possible for parts to be located and fixed in the required position by the four wall s of 1 instead of using the pins 2. The cartridge 1 is rotated at 180° around the axis, which is parallel to x or y during transportation, such that component parts (part 1 in Fig. 1) are prevented from falling off. Located in the bottom section of 1 at a distance of t/2 from its end are 2 positioning locks 8, Figure 12, which are being held against the centre of the (pallet) cartridge 1 by means of the spring 8.2 and their travel distance is limited by the split pin 8.3. The positioning lock 8 sleeve is moving in the +Z direction from its initial position as shown in the figure to a travel distance of Z_1 (between positions b_1 and c_1), which is slightly longer than the full height of 1 – 1off "Body" part. The cartridge 1 is secured to the base plate 7.1 of the device, which is also the bottom plane of the profile groove (pos.7 from fig. 7) in a manner that should allow for dismantling.

Operation

When the cartridge 1 is positioned at 180° over 7, the topmost component part contained in it is forced by the weight of all the other parts to overcome the spring force of the positioning lock 8 thus dropping under the lock's axis, its flat section abutting the plate 7.1. When the hydraulic cylinder 6 is actuated in the +x direction it moves the pusher 7, which slides along 7.1 guided by the bracket 7.1.1 (or some other guides in the ±x direction). The travel distance of 7 along the +x direction includes the travel l_1 and the 102 dimension of the component part: $e = l_1 + 102$. While travelling the distance l_1, initially 7 contacts the sleeves 8.1 of the positioning locks (2off) via the inclined planes 7.2 thus lifting them up to a distance of Z_1. As the positioning locks lift they cause the whole stack of component parts above them to lift as well, such that only one (the bottom-most one) is left, which is pushed 102 mm towards the trough (7 in Figure 2). The piston rod of the cylinder 6 then moves backwards, which causes the pusher 7 to retract to position a, which repeats the whole cycle.

2.4.10.2 Dimensions

17) Length L_1 $L_1^{min} = 640$ mm;
18) Width B_1 $B_1^{min} = 250$ mm;
19) Height H_1 $H_1^{min} = 560$ mm;

Cartridge height is ≈ 380 mm; cartridge cross-sectional area is ≈ 125 mm.

2.4.10.3Storage capacity

$N_{stor.1} \geq 120$ parts

2.4.10.4Cycle time

T_{c1} $T_{c1} = 4.25$ sec

2.4.10.5Method of re-filling

The cartridges 1 come from the storage area filled and arranged and the operator only has to remove the empty cartridge and replace it with a new one. Cartridges have to be replaced every 8.5 minutes of continuous feeder operation, in other words every 2 hours of continuous operation of the assembly unit (work posts No.1, No.2 and No.3).

2.5 Evaluation of the assembly unit

Based on the analysis of individual assembly operations described earlier and the "Assembly analysis chart", Table 2 prepared, we were able to define [12]:

- Individual assembly operations and transition stages of various types, sequence of performance, duration and interrelation.
- The number of basic equipment involved and its position within the assembly unit, interrelation between individual devices and work posts. This has been based on the assumption of having one operator servicing one work post [13].
- The overall fund of required operation time T_{op} necessary for the assembly of one loudspeaker of the selected example type.
- The type, quantity and direction of movement of component parts (semi-finished units required for the assembly operation), sub-assemblies (assembled sections comprising more that one individual component part) as well as the finished product ready for packaging [11].
- The role of the currently available conveyor in relation to the assembly units configuration thus formed
- Possibilities for mechanisation and automation of operations from the A stage aimed at increasing production capacity and reaching the required level of parameters; loudspeakers/month. The cost of mechanisation investment resources [14].
- Work posts and assembly operations suitable for the use of robots.

2.5.1 Structure and functioning of the assembly operation unit

Three work posts have been defined all serviced by a single operator each: WP No.1, WP No.2 and WP No.3. These are positioned around the auxiliary turning worktable, which is located on the sideways next to the linear flat conveyor with work posts No.3 and No.1 closer to the linear conveyor. (A layout arrangement is shown in Figure 6).

2.5.1.1 Operations to be carried out (part numbers are as in Figure 2)

- Assembly operations for the drive unit, stage A are carried out in work post WP No.3. These include the assembly of component parts 1, 9, 10, 11 and 12 involving operations I 01 … 04, II 01 … 04 and III 01 … 03.
- Assembly operations for the terminal strip are carried out in work post WPNo.2.
  - Stage D includes the assembly of component parts 20, 21, 22, 23, 5 and 1. Involved assembly operations and transition sub-stages are IV 01, 02 and 03.
  - Stage C includes the assembly of the cone and dust cover. Component parts 4, 2, 8 and 1 are assembled here. Involved assembly operations and transition sub-stages are VII 01 … 07.
- Assembly operations for the voice coil and suspension, stage B are carried out in work post WP No.1. These include the assembly of component parts 1, 14, and 16 involving operations V 01, 02 and 03; VI 01 … 05.
- Additional assembly (final) of the loudspeaker
  - Stage A4, component parts: 1 with the parts already assembled to it 11+12; 6 and control [15].

4.5.1.2 Duration of operations performed in the individual work posts – T_{WP} (Table 2)

Duration is defined as the sum of individual duration of all assembly operations and transitional sub-stages in the relevant work posts.

20) $T_{WP1} = 60$ sec; $T_{WP2} = 60$ sec; $T_{WP3} = 51$ sec.

2.5.2 Transportation of component parts and sub-assemblies, Figure 13

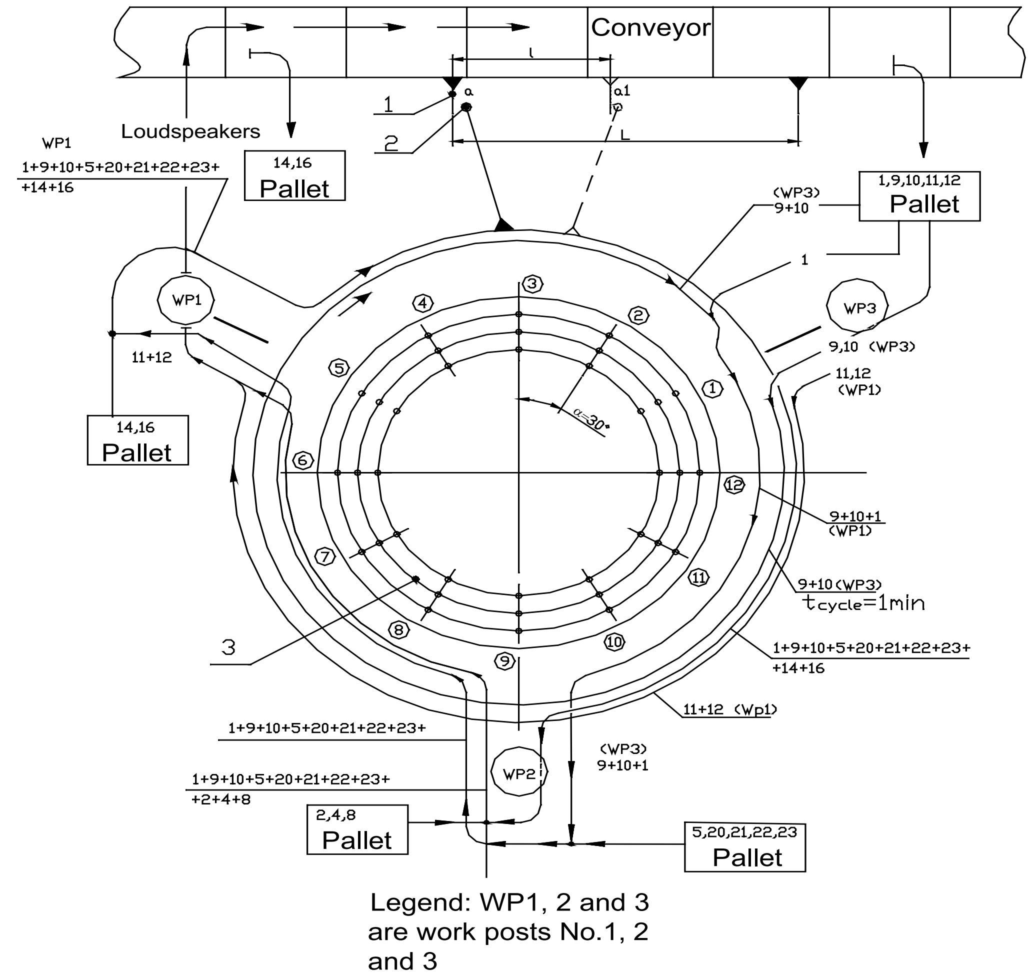

Figure 13

Figure 13 shows the transportation flow for individual components and sub-assembles. Parts 1, 9, 10, 11 and 12 are fed to WP3 from pallets. Parts 5, 20, 21, 22 and 23 as well as 2, 4 and 8 are fed to WP2 from pallets. Component parts 14 and 16 are fed to WP1, respectively. The pallets with component parts required for the continuous operation of individual work posts and conveyor are transported from the store to the corresponding work post by means of the conveyor and in between individual work posts WP1, 2 and 3 – by means of the turntable 3. One complete turn of 3 takes 1 minute and the cycle duration between all 12 individual working positions located around the table (1 thru 12) is 5 sec. The rotation of 3 is interrupted and alternated by idle time necessary for the assembly operations of the machine to be carried out in every working position. For example, the time required for riveting part 11 and 12. The rotation of 3 around the axis O is synchronised with the conveyor movement with the driving click 2 (a mechanism similar to a Geneva wheel) travelling the distance l between positions a and a_1 thus moving the reel on the arm 2 (of the table 3) for as much time as is required to rotate 3 at an angle of 30°, which is < 5 seconds.

2.5.3 Arrangement layout of assembly operation units along the conveyor, Fig. 14

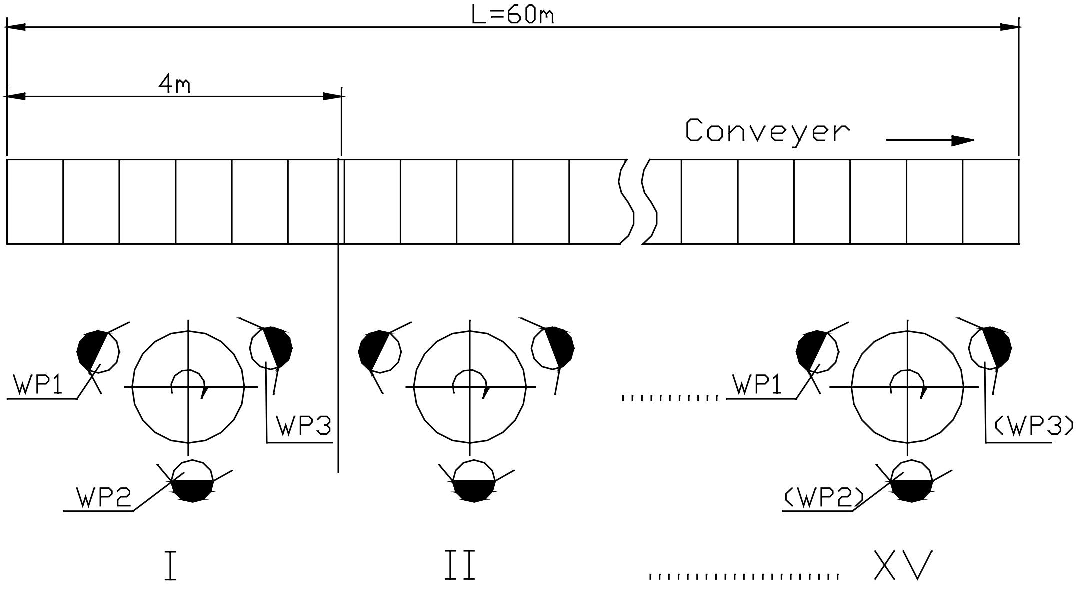

Figure 14

Figure 14 shows an example of a layout diagram for operation units from I to XV along the conveyor. Each operation unit produces (finally assembles) 1 particular type of loudspeaker. One pre-condition is that all 15 types should not differ considerably in overall size. From 4.1.2 above it can be seen that when WP1, WP2 and WP3 operate simultaneously in each assembly unit, the time required to assemble one loudspeaker of a particular size and type (or model with only slight design differences), $T_{ass.sp.}$ is:

21) $$T_{ass.sp} = \frac{\sum_{i=1}^{n} Twp_i}{N}$$

$$T_{ass.sp} = \frac{Twp1 + Twp2 + Twp3}{N}$$

$$T_{ass.sp} = \frac{60 + 60 + 51}{3} = 57[s]$$

Where: $T_{ass.sp}$ is the time required to assemble one loudspeaker;
T_{WPi} is the time required for work post i, and

N is the number of working positions included in the assembly unit.

The rotation cycle for the work table (time per 1 turn) is T_{tt} = 57 sec. For ease and convenience to operators we could assume that $T_{ass.sp} \approx$ 1 min. In other words, the operation unit, which comprises WP1, 2 and 3 and a turntable will produce one loudspeaker on every 1 minute not involving the automation in WP3.

2.5.3 Production capacity of the assembly line

The production capacity of the assembly line thus comprising operation units I … XV and the conveyor will be Q:

22) $Q = Q_{ass.un} \,.\, N \,.\, T$
$Q_{ass.un}$ = 60 parts/hour
N = 15
T = 50 . 4 = 200 hours
Q = 60 . 15 . 200 = 180000 units/month, where:
$Q_{ass.un}$ is the production capacity of the assembly unit;
Q is the production capacity of the line per month
N is the number of assembly units
T is the working time fund within 1 month.

2.5.3.1 Production capacity of the assembly unit following the automation of assembly operations involved in WP3 – Q_{WP3}

If the mechanisation and automation techniques suggested in para 2 and 3 earlier are adopted, the time required to carry out all assembly operations in this particular work post will then be $q_{WP3=}$= 5 secK This is implied by the necessity of keeping the cycle time required for the rotation of the worktable to 1 minute because of manually operated WP2 and WP3. It is not impossible to include all operations involved in the A stage on WP3 within this time of T_{WP3} = 5 sec because they are performed by all 5 automatic part feeders in parallel (Figure 6).

From all said above we could conclude that WP3 will operate for only a small relative part of the working time for each shift to feed the sub-assemblies produced in it to the other manual work posts WP2 and WP1. Thus, we will have a large reserve available for increasing the production capacity of the line, or:

Q_{WP3} = 720 units/hour (= 12.60)

Meanwhile, 480 sets of sub-assemblies produced in WP3 are required per shift to feed WP2 and WP1. Therefore, work post WP3 will only have to operate for 40 minutes per shift to produce this number when automation is adopted (the is due to its production capacity, which increases 12 times as a result of the automation).

(12.40 min. = 480 min = 8 hours)

From what we have said above we could conclude that automation could be adopted for 15/12 = 1.25 WP3 work posts from all the 15 assembly units discussed above (we could round this to 2 WP3 work posts). These 2 automated WP3 will be sufficient to feed all assembly units in the assembly line, from I to XV with sub-assemblies produced in this particular work post provided that Q = 180000 units/month. This will also result in reduction of 13 basic operators throughout the line. Two operators will work on each of the assembly units III thru XV as these will only involve WP 2 and WP1 [16].

2.5.4 Investment required to achieve Q = 180000 units/month

23) I = M . N +AS

I = 3500 . 15 + 25000 = 77500 £, where

I is the investment required (in £);
M is the funds needed to equip the assembly unit (automation of WP3 is not included here) (in £);
N is the number of operation units;
AS is additional expense involved in the assembly line (in £)
I assume M = 5500 £ per one turntable (one table for each assembly unit);

25000 £ is the expense involved in the conveyor, organisation of transportation and training of operators.

$$I = 77500 < 100000£$$

100000£ have been initially calculated for a capacity of Q = 180000 units/month

2.5.4.1 WP3 automation investment – I_{aut}

WP3 will require larger investment if built according to Figure 6. For example, ≈ 4000 £ will be required for all 5 feeder devices or totally 15 × 4000 = 60000 £ for all 15 operation units [16].

$$I_{aut} = I + 60000 = 135500 £$$

2.5.5 Operation sequence using assembly robots "Fanuc" or "Pragma"

From all said above it can be seen that a suitable assembly section to involve assembly robots is the "drive unit" Stage A. On the other hand, it would be hard for the robot to reach the set requirement with the other mechanised attachments involved in WP3 due to the exceptionally short time = 5 sec required to feed component parts 1, 9, 10, 11 and 12 in all 5 working positions. Nevertheless, the operator in WP3 could be replaced by one assembly robot. In this case the time required to perform the operations involved in Stage A will increase to 30 sec, or in average, 6 sec for each part [16].

The robot could carry out the following handling operations [17]:

- Picking component parts 1, 9, 10, 11 and 12 from a pallet or parts storage rack and position them in sequence into the assembly fixtures with the grip (robot arm) being identical for parts 9 and 12; magnetic grip for part 10 and a combined (more complex) grip for part 1.
- Moving the punching press and the glue applicator
- Put finished sub-assemblies back into the pallets or storage racks ready to be assembled in the next work post positions
- Unload pallets containing parts for WP3 from the conveyor and transporting sub-assemblies to working positions in WP2 and WP3.

If assembly robots are selected to be used this could avoid the use of turntables thus producing a **linear work post arrangement** diagram.

2.5.5.1 Linear arrangement of work posts, Figure 15

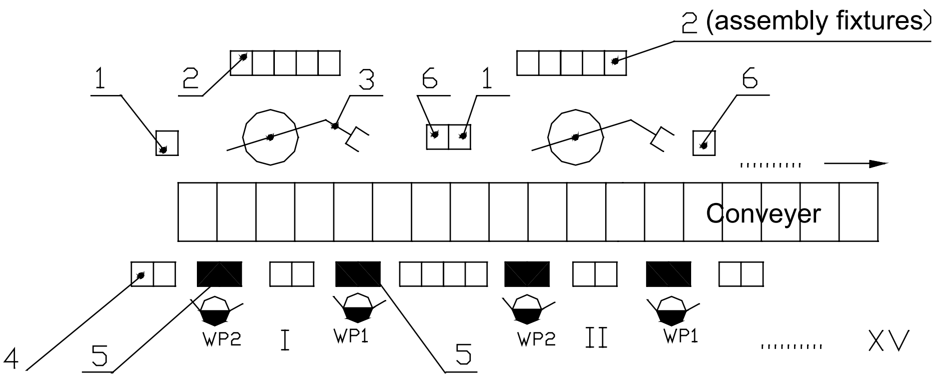

Figure 15: 1. Pallets containing parts for WP3 (robot complex)
2. Work table with assembly fixtures for parts 9+10, 11+12 and 1+9+10
3. Assembly robot, "Fanuc" or "Pragma" type with double grip arm
4. Pallets containing parts for WP2
5. Work table for WP2 (WP1), etc. Up to assembly unit XV
6. Pallets (storage racks, cartridges) containing finished or drying subassemblies.

2.5.5.2 Production capacity $Q_{aut.ass.un}$ of automated WP3

from (22) above $Q_{aut.ass.un} = 2 \cdot Q_{ass.un} = 120$ parts/hour

2.5.5.3 Assembly line production capacity Q_{aut}

$Q_{ass.un} \geq 180000$ units/month. This is due to the fact that the production capacity of WP3 is twice higher.

Saving around 30 sec at WP3 would allow us to reduce the number of required assembly robots by two (the number of working positions in WP3). Such reduction will require one assembly robot to assemble parts 1, 9, 10, 11 and 12 for two types and sizes of loudspeakers and servicing two neighbouring assembly units [comprising 2 × (WP2 + WP3)]

2.5.5.4 Required investment for an assembly line comprising 15 assembly robots and 30 operators (15 assembly units × 2 operators each)

$I_{aut} = P_{aut} . N + AS_1$

$I_{aut} = 4500 . 15 + 4000 = 107500$ £, where:

I_{aut} is the required investment (in £);

N is the number of assembly units;

AS_1 is additional expense involved (in £).

References

1. Angeles, J., *Fundamentals of Robotic Mechanical Systems: Theory, Methods, and Algorithms*. TWER 681.3*I29 / ANGE 1997.
2. Asada, H. and Slotine, J.-J.E., *Robot analysis and control*. TCPW 681.3*I29/0011 TELE 681.51:007.52/ASAD 19.
3. Ball, Robert S., *Theory of screws: a study in the dynamics of a rigid body*, Hodges, Foster and Co., 1876. TWER 514 / BALL 1988.
4. Bar-Shalom, Yaakov and Li, Xiao-Rong. *Estimation and Tracking, Principles, Techniques, and Software*. TWER 681.5.01/BAR 1993.
5. Brady, J.M, *Robot motion planning: planning and control*. TELE 007.52/ROBO 1982.
6. Brand, Louis, *Vector and tensor analysis*, Wiley, 1948. TWER 512/BRAN 1948.
7. Canudas de Wit, C., Siciliano, B. and Bastin, Georges, (Eds.), *Theory of Robot Control*. TWER 681.3*I29 / THEO 1996.
8. Craig, J.J, *Introduction to Robotics: mechanics and control*. TWER 681.3*I29/CRAI 1986.
9. Crane, C.D. III and Duffy, J, *Kinematic Analysis of Robot Manipulators*. TWER 681.3*I29.
10. Ginsberg, M, *Essentials of Artificial Intelligence*. TWER 681.3*I20/GINS 1993.
11. Duffy, J, *Statics and Kinematics with Applications to Robotics*. TWER 531.8 / DUFF 1996.
12. Kanal, L.N. and Lemmer, J.F., (Eds), *Uncertainty in Artificial Intelligence*. TCPW 681.3*I23/0045.
13. Latombe, Jean Claude. *Robot motion planning*. TWER 681.3*I29/ROB 096.
14. Alain Hertz, Yves Mottet, Yves Rochat, On a scheduling problem in a robotized analytical system. *Discrete Applied Mathematics, Volume 65, Issues 1–3, 7 March 1996, Pages 285–318.*
15. Advances in manufacturing. *Computers in Industry, Volume 6, Issue 4, August 1985, Pages 288–295.*

16. M.C. Gupta, C. Judt, Y.P. Gupta, S. Balakrishnann, Expert scheduling system for a prototype flexible manufacturing cell: a framework. *Computers & Operations Research, Volume 16, Issue 4, 1989, Pages 363–378.*
17. Mark R. Cutkosky, Paul S. Fussell, Robert Milligan Jr., The design of a flexible machining cell for small batch production. *Journal of Manufacturing Systems, Volume 3, Issue 1, 1984, Pages 39–59.*