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Design of automated assembly system for globe valves

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ABSTRACT

Manual assembly of globe valves production generally demands more effort resulting in lowproductivity and high labor costs. Hence, implementation of new efficient automated assembly system is becoming increasingly necessary to speed up the assembly process. An automated system has been setup consisting of automated positioning systems with pick-and-place mechanisms, XY gantry systems, automated handling equipments with pneumatic gripper are positioned on transfer devices or rotary tables that move the assemblies from station to station. Each work-head is supplied with oriented parts either from a magazine or from an automatic feeding and orienting device, usually a step feeder, vibratory bowl feeder etc. Due to low-cost consideration, all the automatic assembly systems are pneumatically driven. The development of an automated assembly system involves the design, selection and integration of a number of different mechanical systems in order to develop an assembly system, which is capable of assembling a globe valve parts precisely. This paper examines each of the factors that should be considered when designing a generic automated assembly system and presents a novel low-cost automated assembly system design for globe valve.

KEY WORDS: Globe valve, Assembly automation, TransferSystems, ABC Analysis.

1. INTRODUCTION

Globe valve plays an important role in the oil, gas and chemical processing industries. Currently, the globe valve is being assembled manually at the rate of 100 valves per day. The assembly process of globe valve consists of time consuming, tedious tasks due to the high volume of products.

Figure.1. Globe Valve

Traditional assembly involves manual operations performed by fixing the body sub-assembly to the bonnet sub-assembly. Some of the operations are very critical and therefore pose difficulties to human assembly operators. A significant motivation of thisAcademic – Industry collaboration project is to streamline and automated the labor intensive, hazardous, high volume assembly of the Globe valve product. To reach higher production objectives along with worker protection, the increase of the degree of automation in the Globe valve assembly process is crucial (Bruno lotter, 1989).In the Globe valve production, a wide range of Globe valve types with varying performance characteristics are manufactured. Among various types, forged steel globe valve class-800 is considered for the design of assembly line. This paper demonstratesvarious prerequisite procedures such as product design, assembly sequence analysis, and production output calculation involved in assembly automation of a microswitch (Bruno lotter, 1982).With regard to the automated assembly, ABC assembly extended analysis, the product construction and the direction of joining, order of the assembly process, and functional analysis, were discussed (Bruno lotter, 1984).Geoffrey Boothroyd (2005), has presented enormous ideas in the field of assembly automation and product design. His work includes detailed discussions of design for assembly, and the subject of assembly automation is considered in parallel with that of product design. Also, this whole study is devoted to design of high speed automatic assembly, automated transfer devices, automatic feeding & orienting devices, and placement and escapement devices. John Parrish (1977), has suggested cylinder as a positioning device. Many production engineers appreciate the value of the pneumatic cylinder as a power device. But the double-acting cylinder also possesses unique positioning characteristics. Widdowson (1998), have designed a high speed linear motor driven gantry table.He describes the design optimization of a High speed, high accuracy, linear motor driven gantry table, for use in a semiconductor packaging machine and also focuses on various parameters involved in the design process of the gantry table. Among the discussions and to increase the production rate from 100 valves/shift to 500 valves /shift, fixed automation is preferable than flexible for yielding high productivity with less cost.

2. METHODOLOGY

Below figure 2 shows the various stages of methods carried out in deIt begins with identifying the problem in one of the valve manufacturing company.

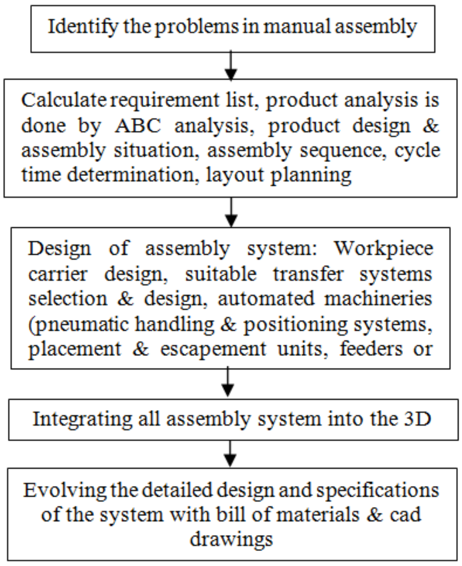


Figure.2. Methodology flowchart

In the planning procedure, planned production time and cycle time are calculated and product analysis is done by ABC extended analysis which is founded on seven fundamental questions aimed at discovering and reducing the total cost of a component, suitable assembly situation & assembly sequences are analyzed. Finally the suitable layout for the globe valve assembly line is identified. Assembly system is composed of work cell design, feeder design, transfer system design and workpiece carrier design. The work cell consists of pneumatically-driven handling units and other equipments. Using Festo product catalogue tool and design data calculations, drivers, grippers, sensors and other pneumatic components have been selected. In handling units, driver configuration and gripper design is done. Gripper selection is done based on the size, shape and weight of the component handled. Finally, integrating all the assembly machines on the periphery of the transfer systems and allocate enough space for maintenance.

Planning For Assembly Automation: The globe valve consists of 26 single parts (18 different parts such as 1.body, 2. Seat ring, 3. Gasket, 4. Stem, 5. Unique disc, 6. Regulating disc, 7. Bonnet,8. Gland, 9. Gland packing, 10. Gland bolt, 11. Rivet pin, 12. Gland flange, 13. Gland nut, 14. Thread bush, 15. Nameplate, 16. Handwheel, 17. Wheel nut, 18. Cap screw, 14. Thread bush) as illustrated in figure 3. For the sake of error- free assembly, above parts mentioned are meticulously analyzed and planned theassembly direction. Automated assembly is, however, necessary on account of the expected production volume.

Figure.3. Parts of Globe valve

Part No.	Name	No. per Product	Handling characteristics	Delivery condition	Quality requirements	Remarks
1	Body	1	◑	Packed positioned	◑	Holding difficulties
2	Seat ring	1	○	Loose material	◑	
3	Gasket	1	○	Loose material	◑	Careful handling, positioning
4	Stem	1	○	Packed positioned	○	-
5	Unique disc	1	○	Loose material	○	-
6	Regulating disc	1	○	Loose material	◑	Cleanliness
7	Bonnet	1	○	Packed positioned	◑	-
8	Gland	1	○	Loose material	○	-
9	Gland Packing	3	●	Loose material	●	Careful feeding
10	Gland bolt	2	●	Loose material	◑	Manual positioning, Manual assembly
11	Rivet pin	2	●	Loose material	◑	Manual positioning, manual assembly
12	Gland Flange	1	○	Loose material	◑	-
13	Gland nut	2	○	Loose material	◑	-
14	Thread bush	1	○	Loose material	◑	Cleanliness
15	Nameplate	1	○	Loose material	○	-
16	Hand wheel	1	○	Loose material	○	-
17	Wheel nut	1	○	Loose material	○	-
18	Cap screw	4	○	Loose material	◑	-

○ Suitable for automation
◑ Conditionally suitable for automation
● Not suitable for automatic handling

Figure.4. Assembly extended ABC analysis

Requirement List: The product sales volume forecast indicates that, following an introductory phase of approximately one to two years, the expected annual production is 1,55,500 valves. On account of the high number of valves required, the system is designed for 8-hour operation so that, in the event of high demand, two-shift operation can be introduced as necessary. At an annual production rate of 1, 55,500 valves over 8-hour working days, a planned production rate P_{pl} is calculated as follows:

$$P_{pl} = \frac{155500 \text{ valves}}{311 \text{ days} * 8 \text{ hours/day}} = \text{ } 62.5 \text{ valves/hour} \sim \text{ } 65 \text{ valves per hour}$$

Therefore, planned production rate of 65 valves per hour has been calculated.

Product Analysis: By reason of its specific requirements, every product has its own particular interrelationship in the product design and the resultant production methods.The greatest effort is achieved by the assembly oriented form in the draft design phase of a product. A finally designed product can only be altered at considerable cost during its production period. The assembly extended ABC analysis is one of the means for the assembly-oriented design of a product. This is derived from the generally known ABC analysis in the fields of company economics and value analysis. The product analysis is undertaken in accordance with the assembly – extended ABC analysis as shown below. The results of the analysis in relation to the supply condition, ease of handling, assembly direction and ease of assembly, assembly methods quality requirements and assembly costs of the individual part are summarized in figure 4.Based on the analysis, few alterations have been made on the product are necessary in order to create the conditions for automated assembly.

3. RESULTS

Assembly Sequence Analysis:

Product Design and Assembly Situation: The overall design of the product can be subdivided into the assemblies of body and bonnet and also in terms of the complete assembly is shown in figure 5. All the assembly operations for this unit can be performed vertically.

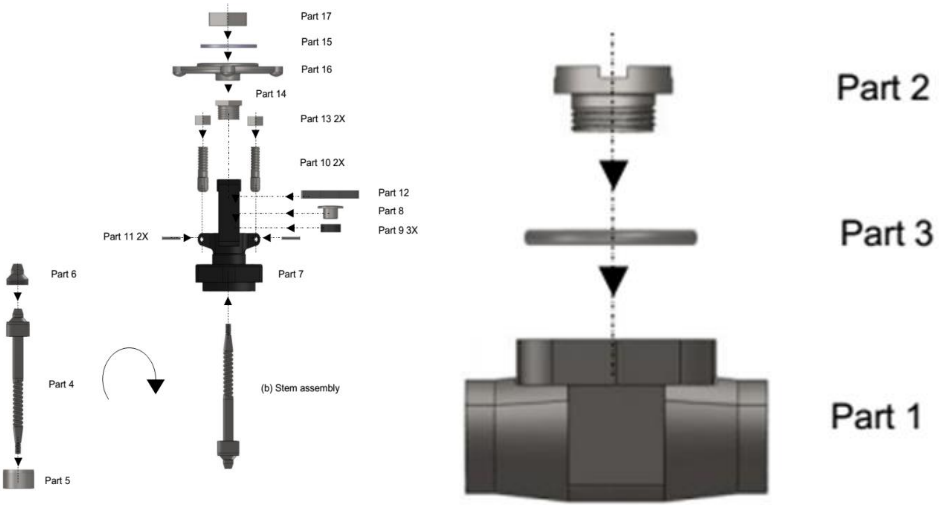


Figure.5.Assembly Situation

Assembly Sequence: As assembly sequence of the globe valve assembly shown in figure 6, six assembly processes are necessary for the assembly of the body unit.Since part 1(the body), is not only the base part for the body assembly but, as a complete assembly is also the base part for final assembly, the assembly of the body and the final assembly could be undertaken on one machine. All necessary preassembly operations and the assembly of the bonnet must, however, be undertaken on subassembly assembly machines.

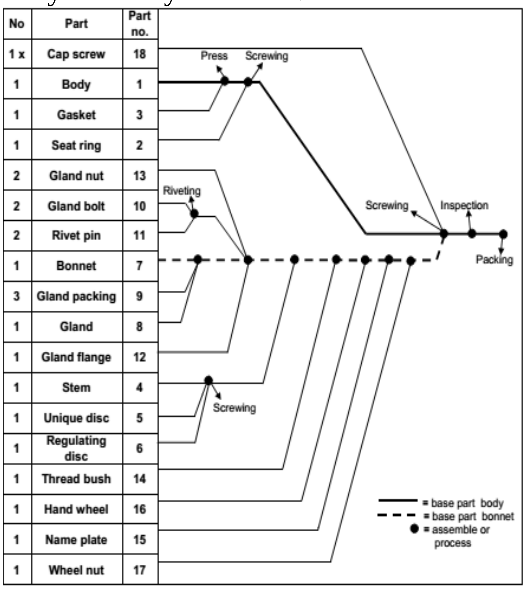


Figure.6.Assembly sequence diagram

Work piece Carrier Design: The product design and assembly order determined the design form of the workpiece carrier, planned output rate, number of parts of a product to be assembled and the number of workpiece carriers in an assembly system. Workpiece carriers whose main function is in the arranged transport of the object to be assembled. The product design of the globe valve requires different Workpiece carriers. So, three workcarriers are designed for assembling parts 1,2,3,4,5,6,7,8,9,10,11&12.The design of workpiece carriers is not considered in this work due to time constraint. Design solutions are illustrated belowin figure 7 (a, b & c) on three examples of workpiece carriers which are permanently attached to the transfer equipment.Figure 7a shows a workpiece carrier for the operations for assembling parts 1, 2 & 3. Figure.7b shows a Workpiece carrier for the operations for assembling parts 4, 5 & 6.Figure 7c shows a Workpiece carrier for the operations for assembling parts 7, 8, 9, 10, 11 & 12.

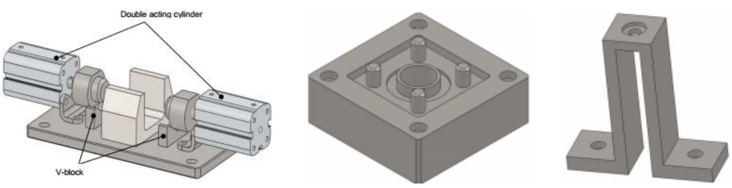


Figure.7.Workpiece carriers (a, b & c)

Determination of Cycle Time: The determination of the planned output in accordance with – indicated 62.5 globe valves per hour, so when rounded off to 65 valves per hour, the cycle time can be calculated as:

$$t_c = \frac{3600 * A_{STA} \ \text{[seconds/hour]}}{\text{PO [parts/hour]}}$$

So if planned output = 65 parts / hour and static availability (A_{STA})= 0.8,

$$t_c = \frac{3600 \text{ s/hour x } 0.8}{65 \text{ parts/hour}} = 44.3 \text{ s} \sim 44 \text{ s}$$

The weak point in this calculation is in the assumption of a static availability (A_{STA}). This must be obtained in detail and, on account of risks, not set too high. Typical values fall between 0.8 and 0.85.With this respect, stacking and arranging parts in the magazine requires more time, it would affect the cycle time to increase.

Layout Planning: The object of layout planning is to achieve an optimum arrangement of an assembly system with regard to work piece flow and material provision in relation to the space available. At the same time personnel requirements must be considered.

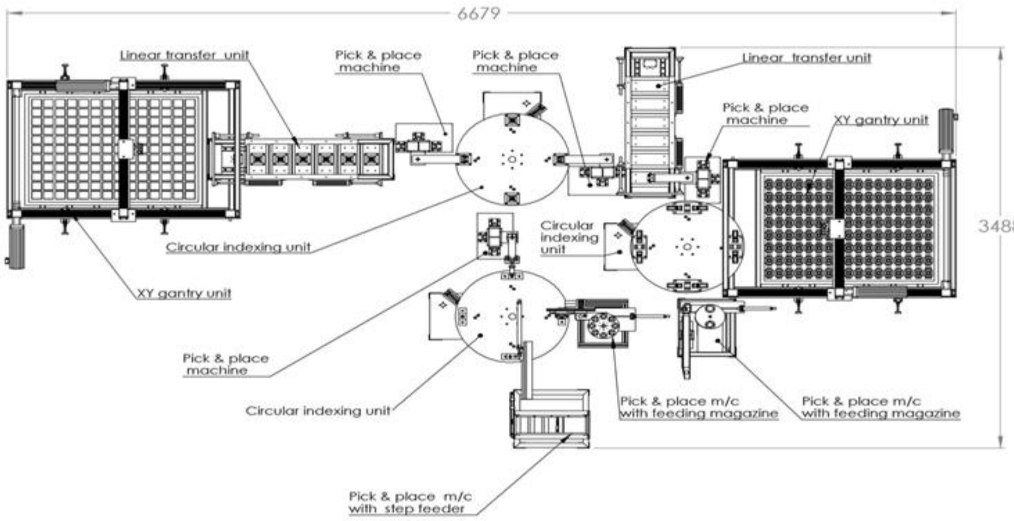


Figure.8. Layout design of an automated system for globe valve assembly

Layout planning is based on the data obtained from previous planning stages, in particular relating to the assembly sequence, cycle time determination and the space available. Figure 8 shows the layout planning of an automated assembly line consisting of pick & place machines, feeding and handling units, gantry systems interconnected with three pneumatically driven circular cyclic units and two linear transfer units for the assembly of the globe valve. The planned space in this case measures 6679 x 3488 mm. But this space level may be changed in the future due to the inclusion of remaining assembly equipment.

Detailed Planning Of Assembly System

Design of Transfer Systems: In accordance with the following considerations like number of assembly or machining direction, number of stations and space, this automated system required three pneumatically driven circular indexing units and two cycled plate longitudinal transfer system with permanently fixed work carriers. With regard to cost, transfer systems were fully pneumatic driven.

Pneumatically-driven circular indexing unit: Nowadays, indexing units with mechanisms such as Ratchet drive, Maltese-cross drive, Geneva and cam drive are available in the market. Although, they are well précised, but often ends in failure due to noisy operation, less efficiency and high cost. Hence, cam clutch was used to precisely give intermittent motion with the aid of double acting cylinder.Cam clutches comes with varying indexing speed and indexing angle. An indexing plate (A) mounted on the axis of rotation of a drive shaft, is indexed by the engagement and disengagement of a cam clutch MI-300K (B) by the action of a double acting cylinder (C) via a connecting lever (D).

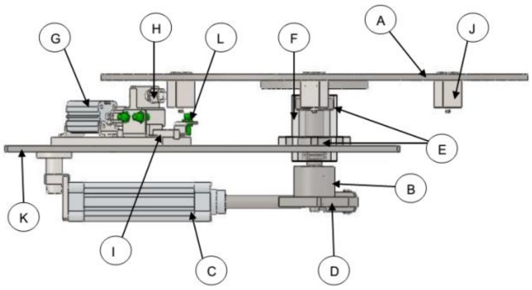


Figure.9. Pneumatically-driven circular indexing unit

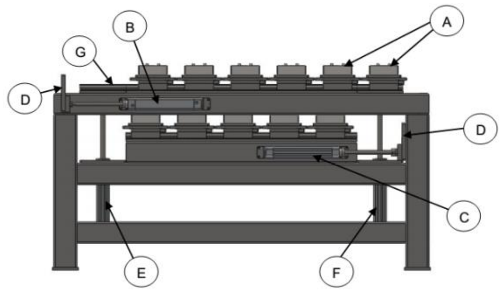


Figure.10. Pneumatically-driven linear indexing unit

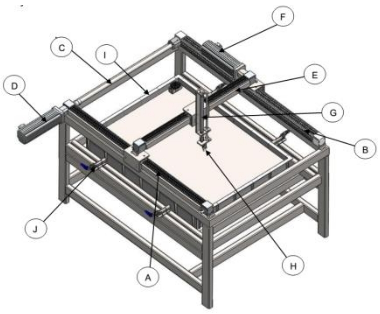
Bearing housing (F) is fixed with table plate, which carries the cushioning system. The compact cylinder (G) is placed over the plate at certain angle. The mounting plate is fixed to the cylinder piston rod and it holds the adjustable hydraulic shock absorber (H) with hexagonal stop element. The shock absorber is clamped over the movable linear motion system (I) (comprising LB block & LM rail).For precise indexing at specific station, four rectangular stopper plates (J) are attached underneath the indexing plate at an angle of 90^0 between the plates, will be get stopped by the stop element. Cushioning system is provided to dampen the impact load generated, when the moving indexing plate having stopper plate hits the stop element. When the stopper plate comes within the sensor sensing range; the sensor sends the signal to activate the cylinder piston rod to move forward to stop the indexing plate from rotating. After the assembly operation is finished, the piston rod will move backwards to release the stopper plate. The piston rod motion is monitored by two proximity sensors attached adjacent to the cylinder. Suitable assembly based work piece carriers have been accommodated over the indexing plate.

Pneumatically-driven linear indexing unit: Figure 10 shows the linear indexing table for transferring bonnet sub-assembly & final assembly of the globe valve. This type of unit is called as plate longitudinal transfer system.

In this arrangement, the plates are moved, inline, by one plate length, on guide rails. The work- piece carriers (A) are mounted on the plates and upon reaching the end of the installation, are moved transversely in the same manner on to a return track. The mechanism is as follows. When the Cylinder is activated, the piston rod extends and pushes those work-carriers that move on the linear rail to the next station. In this case, permanent magnet is rigidly attached to the fixed plate beneath the moving work-carrier to ensure the accurate positioning with the work-head. The two double acting cylinders (B & C) have been attached face to face with the sides of the forward and reverse track and its piston rod is connected to the vertical plates (D), which are rigidly fastened to the forward track (E) and reverse track (F). When the cylinder (G) is activated, it pushes the vertical plate forward and it makes the work-carriers to move. The same arrangement is also made in the reverse track to reverse the flow. Furthermore, two more double acting cylinders (H & I) are placed vertically facing upwards and it is connected to the start and end plate for lifting-up and lifting-down the workcarriers. Cylinder (H) is used to place the empty work-carrier by lifting up from the reverse track to forward track. Cylinder (I) is used to the escape empty work-carrier by lifting down from the forward track to reverse track. For fine motion, linear motion rails (J) have been attached to the fixed plates and it supports the movable plate. Finally, this whole arrangement has been supported over the rigid structure.

Design of Individual Assembly Machines:

XY-gantry system: Figure 11 illustrates the typical design of XY gantry unit consists of toothed belt axis, pneumatic cylinder, parallel gripper with suitable finger for handling parts, and a tray for storing the body & bonnet part of the globe valve.



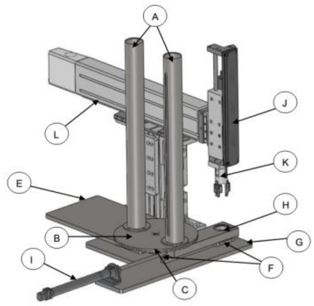


Figure.11. XY-gantry system with tray **Figure.12. Gasket feeding and positioning machine**

Two electromechanical axes DGE-ZR model (A & B) with toothed belt drive is connected parallel at a distance of 1100mm and it is guided by re-circulating ball bearing .A guide rod (C) is connected in between the axis via coupling unit. These axes are controlled by the servomotor (D), which is fixed to the right side corner of the guide rod via coupling unit. Electro mechanical axis (E) is mounted on the axes (A & B) perpendicularly. The axis (E) is also driven by a servomotor (F), which is fixed to its end. The axes (A & B) move in y direction and axis (C) moves in x direction. In addition, linear Z-travel is performed by a double acting cylinder (G), which has a parallel gripper (H) attached vertically for grasping parts like body & bonnet. A suitable finger for grasping body/bonnet has been designed and employed. All the movements are precisely controlled by a servo controller. The axes setup is supported by a table of dimensions 1629 X 1200 mm.A rectangular tray (I) is placed under the axes for storing the arranged body/bonnet parts. Toggle clamps (J) are used to accurately locate the tray with respect to the gantry system. The axes will move over the tray to pick the part and place it to assembly position.

Gasket feeding and positioning machine: The Gasket feeding and positioning machine consists of a feeding unit with magazine and a pick and place unit. In feeding unit, only a simple magazine is required for stacking and arranging the gaskets as illustrated in figure 12.Magazining section comprises of two cylindrical chutes (A) with internal ø42 mm is mounted vertically over the circular plate (B). The chutes have been designed to hold 320 gaskets. Slot provision is made at their sides to monitor the levels of gaskets.

Under the chutes, through holes are made on the circular plate (B) to pass the gasket. A circular stationary plate (C) having same size is placed beneath the top circular plate (B). Plate (B) is rotatable and is driven by a semi-rotary device (D) via flanged shaft. Semi-rotary drive also called as swivel module can rotate up to 180^0. Stationary plate (C) is rigidly mounted on the plate 350 mm x 150 mm (E) with the aid of two cylindrical mounting kits. In the stationary plate, a single ø42 mm through hole is made. Both holes are made with accurate circularity. A LM guide-way (consists of LM block l and LM rail, length 250 mm) (F) is fastened on the plate (G) underneath the stationary plate (D). Agasket carrier (H) having cavity of ø42mm, 13 mm depth is mounted on the LM block .A compact double acting cylinder (I) is connected to the gasket carrier via piston rod. The cavity in the gasket carrier has been positioned with the hole in the stationary plate (C) with accurate circularity. A linear module (J) having stroke length of 100 mm is positioned vertically above the gasket carrier cavity. A three-point gripper (K) is attached with the linear module via adapter kit .A suitable gripper fingers have been designed and attached to the gripper jaws for grasping the gasket from gasket carrier. Linear module is connected perpendicularly by its sides with another linear module (L), which is supported by aluminium profiles. Next, linear module will be activated for picking the gasket with the help of gripper. After picking, linear module travels a length of 200 mm to reach the assembly position to accurately place the gasket on the body part. If the gaskets in the chutes become empty, rotary drive will be activated to rotate the circular plate (B) to positioning the next chute to serve the gasket.

Stem sub-assembly pick and place machine: The mechanism is same as in swivel pick & place machine as shown in figure 13. The main difference with this unit is extra swivel motor (A) required to orient the stem sub-assembly. Here, pneumatic cylinder (B) guided by a linear motion bushing with guide rod (C) is connected vertically downwards to the swivel arm (D) end.

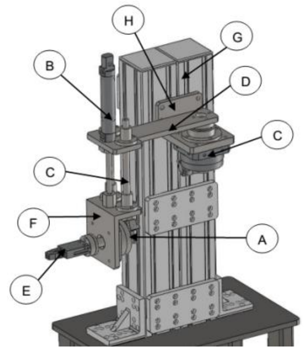


Figure.13.Stem sub-assembly pick and place machine

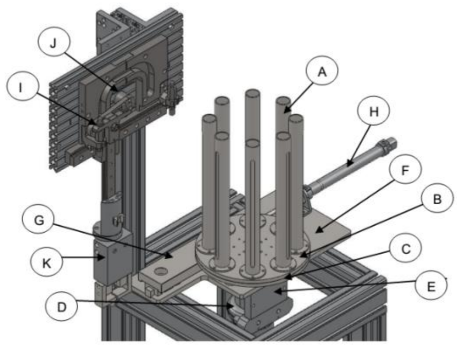


Figure.14.Unique-disc feeding and positioning machine

Another swivel motor consisting of parallel gripper (E) & flange shaft is fixed horizontally to the L-bracket (F), which is attached to the double acting cylinder (B).The swivel motor used here is capable to rotate 180^0, so it can orient the stem and place it over the assembly position. For accurate stem positioning, the motor is moved up & down by a double acting cylinder.The mode of operation is as follows. When the pneumatic cylinder (B) is activated, the gripping unit (E) will move downwards to grasp the stem sub-assembly from the fixture and it will travel upwards.After grasping, the swivel motor (F) is activated to turn the swivel arm through 180^0.In accordance with the assembly direction; the swivel motor (A) turns the stem sub-assembly through 180^0. Next, the cylinder (B) is activated to drop the sub-assembly on the assembly fixture. This entire unit is fixed to the aluminium profile (G) via L-bracket (H). Precise sensing &cushioning devices are inbuilt in the rotary modules for accurate handling.

Unique disc feeding and positioning machine: Same as in gasket feeding system, a simple magazine is required for stacking and arranging the unique disc. Magazining section comprises of eight cylindrical chutes (A) having same internal ø24mm is mounted vertically over the circular plate (B). The chutes have been designed to hold 280 unique discs. Slot provision is made at their sides to monitor the levels of discs. Under the chutes, through holes are made on the circular plate (B) to pass the gasket. A circular stationary plate (C) having same size is placed beneath the top circular plate (B). Plate (C) is rotatable and is driven by a semi-rotary device (D) via flanged shaft. Semi-rotary drive is also called as swivel module can rotate upto 180^0.So, freewheel unit (E) is coupled with the rotary drive to make full rotation. Stationary plate (C) is rigidly mounted on the plate (F) with the aid of two cylindrical mounting kits having ball catchers attached. In the stationary plate, a single ø42 mm through hole is made. Both holes are made with accurate circularity.

A LM guide-way (consisting of LM blockand LM rail, length 250 mm) is fastened on the plate (F) underneath the stationary plate (C).A gasket carrier (G)having cavity of ø42mm is mounted on the LM block .A compact double acting cylinder(H) is connected to the unique disc carrier via piston rod. The cavity in the unique disc carrier has been positioned with the hole in the stationary plate (C) with accurate circularity. A pick and place unit HSP model (I) is brought from Festo & Co. This pick & place unit has a stroke length of 170mm is positioned vertically above the gasket carrier cavity. This pick and place unit is driven by a swivel motor (J) fixed behind the aluminum profile.

A parallel gripper (K) serves better gripping force to handle the unique disc. A suitable gripper fingers have been designed and attached to the gripper jaws for grasping the disc from disc carrier. Pick & place unit has a stoke length of 200 mm, so it can easily reach the assembly position accurately. Due to gravity, all the discs stacked in the magazine fall one by one into the disc carrier. After the disc reaches the carrier, double acting cylinder will be activated to transfer the disc to the picking area. Next, pick & place unit will be activated for picking the disc with the help of gripper. After picking, gripper travels a length of 200 mm to reach the assembly position to accurately place the disc on the stem. If the discs in the chutes become empty, rotary drive will be activated to rotate the circular plate (B) to positioning the next chute to serve the unique disc.

Stem feeding & positioning machine: This system shown in figure 15 (a&b) is designed with integral storage, feed track and control ensuring an accurate interface of the relative modules and ease of installation. Movement of the stems from the random storage area (A) is by reciprocating plates (B) picking up and feeding parts on the leading edge of one plate and transferring to the leading edge of the next etc. until the desired discharge height is reached for presentation to the orientation tooling.

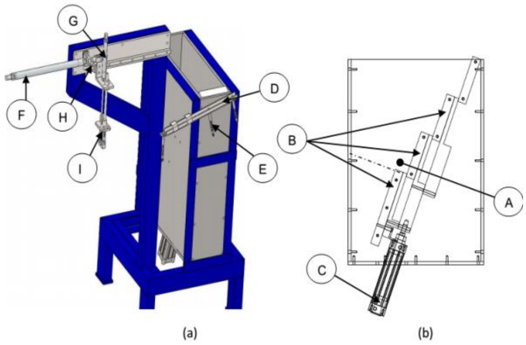


Figure.15. a) Stem feeding & positioning machine
b) Interior view of the step feeder box

The reciprocating plates are connected diagonally with the pneumatic double acting cylinder (C). The length of the stem is equal to the width of the plate for accurate orienting. The smooth reciprocating action of the stepper plates will ensure a positive, quiet and gentle movement of the components. Wear is negligible in the absence of a constant churning and tumbling action. The orientation is performed by a track (D), which is attached adjacent to the top stepper plate for picking up the stem (E). Orientation track is accurately designed and positioned at an angle of 38^{o} to finely orient the stem. So, the stem travels in the track due to gravity without any difficulties. Two double acting cylinders are mounted perpendicular to each other on the linear motion guide-way system. Cylinder (F) is mounted horizontally to the front end of the LM block (G), cylinder (H) is mounted vertically on the LM block and it carries the parallel gripper (I). After stem part reaches the end track, cylinder is activated to push the LM block, which carries the gripping system. Next, stem part is picked by a parallel gripper and it travels back to drop the stem over the assembly fixture.

4. CONCLUSION

To meet high market demand in the globe valve assembly line, a new efficient and economic assembly process has to be setup. This can only be achieved with an automated assembly system. The following work has been done in this project,

- Step by step planning procedures involves ABC assembly extended analysis, layout planning and cycle time calculation have been conducted prior to assembly automation.
- Fourteen automated assembly units out of twenty stations interconnected with three pneumatically driven circular cyclic devices and two linear indexing devices have been designed using appropriate design calculations & tools.
- Suitable work piece carriers are designed for individual assembly stages.
- Detailed drawing and bill of materials of each assembly unit have been developed.

Scope of Future Work: The remaining stations will be designed and integrated into the automated assembly layout in the future. In addition, accessories like valves, tubes, fittings will have to be incorporated.PLC devices are to be used in the assembly system for synchronizing the assembly sequence and automatic control. All the pneumatic components and sensing devices will be integrated with the programmable logic controllers. Finally, this automated system can achieve the demand rate of the globe valve assembly line.

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