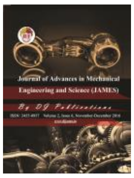
Journal of Advances in Mechanical Engineering and Science, Vol. 2(6) 2016, pp. 1-16



RESEARCH ARTICLE

Automated Fixture Assembly for a Shallow Water Jet Motor Assembly

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Received- 17 October 2016, Revised- 27 November 2016, Accepted- 20 December 2016, Published- 29 December 2016

ABSTRACT

A production unit could be claimed successful, only when it increases the likelihood of easy assembling and minimizes unit production cost. In order to undergo mass production methods, their orientation play a major role in enabling the ultimate operational time and cost. To cope up with such methods, the use of jigs and fixtures are facilitated. The paper encompasses the alternative solution for material handling flaws caused in the assembly process. The frequent reasons for the leakage are the improper positioning of the ceramic bushes in the impeller casing unit, owing to the downfall of the motor efficiency. The bushes are placed manually in general, leading to the improper positioning of the bushes, getting in contact with the rotor/impeller resulting in non-uniform wear, leading to water leakage. These defects could be overcome by introducing an assembly fixture for motor placement and using pneumatic cylinder actuation for the accurate bush placement. This indeed includes the reduction of idle lead time in the assembling process by automating the process of manual bush placement and the manufacturing of defect free products. This signifies the reduced lead time to increase the productivity factor and the efficiency of the motors. Lean study was conducted to reduce the lead time and Value Stream Map (VSM) is reported in this paper.

Keywords: Fixtures, Lean manufacturing, Six sigma, Pneumatics, Value stream mapping.

1. INTRODUCTION

The quality objective of a company is to satisfy the needs of the customers. The quality policy is pivoted on customer's perceptions of a product's design and the design, matching the original specifications. On observing the process of submersible motor and centrifugal pump manufacturing, the assembly section plays a vital role in assemblage of final motor and pump facet. Perhaps the assembly section leads to intermittent water leakage as a result of non-uniform wear of ceramic bush and it leads to the frequent replacement of ceramic bush placed in the impeller casing unit, thus affecting the motor quality. The ceramic bush was placed manually by blowing through a nylon hammer. This leads to inaccurate and improper positioning of bush. When the impeller in the casing rotates, the improperly placed bush gets into contact with the rotor/impeller and non-uniform wear occurs, leading to water leakage. This process reveals the assembly process by automating the process of manual bush placement and to manufacture defect free products. This has been done by introducing an assembly fixture for motor placement and by implementing pneumatic cylinder actuation for accurate bush placement, thereby optimizing the lead time.

[1] described the evolving intelligent fixtures which are enabled to identify the critical process conditions, error influences, minimization of defective parts. [2] succeeded in minimizing the defection of the work piece due to the dynamic machining forces and also introduced the adaptive machining fixtures with actively controlled clamping forces. [3] described the frequently used technologies for

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Double blind peer review under responsibility of DJ Publications

http://dx.doi.org/10.18831/james.in/2016061001

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automation system, including handling and feeding systems, vision, grippers and tool changers, as well as tooling and fixtures. [4] described the modular fixturing in computer integrated manufacturing. [5] introduced the six-axis alignment corrections and thereby improved the accuracy of the fixture, and the errors were made to determine and also to adapt the technology where it is feasible.

[6] introduced the fixturing mechanism with numerically controlled modules and designed on the idea of the minimum number of fingers needed to immobilize an object. [7] described the flexibility factor of the fixture assembly and its valued applications led to the reduction of the costs and formulated the design of flexible fixture and observed that the flexible fixture with the follow up has the high accuracy. [8] addressed the problem of rapidly synthesizing a realistic fixture that will guarantee stability and immobility of a specified polyhedral work-part by proposing the problem of automated fixture layout in two distinct stages. [9, 10] introduced a new system to recommend us about the number and order of the needed setups, and proposals on the appropriate fixture needed for the machining of a given work piece.

2. METHODOLOGY

2.1. Lean manufacturing

Lean Manufacturing is a method to provide the removal of waste from the value stream in the accounted manufacturing system. Lean methods are also able to cover up the waste created due to over loading and irregular distribution of work load. The waste includes cycle time, labour, materials and energy. The chief obstacle is that the defects are often hidden in normal sights and therefore the scientific methods and techniques of lean manufacturing like visual controls, visible management etc. are relied over to cover the drawbacks found in the value stream.

2.1.1. Elimination of waste

The waste could be eliminated from the value stream only through periodic inspection and surveys taken over the entire production unit with the mentality to reduce the operating cost. The operating cost could be eventually reduced with the concept of producing goods which possess high rates of sales and eliminating waste. Moreover, the prime objective of lean is to locate, identify and eliminate the waste and its related constituents.

2.1.2. Quality

The high rated sales are predicted only with the production of high quality products. The high quality is obtained with high precision handling and maintenance. The customer-producer chain could be held strong as long as the desired quality is achieved. The high quality products eliminate the work of reprocessing of defects, and storage of defective unit which could be accumulated as waste in critical cases.

2.1.3. Costing

Costing of units is the ability of the manufacturing system to determine the cost of a product after knowing the different expenses incurred in various departments. The most common elements of cost to be recorded are material, labuor and other charges which jointly complete the cost of the product. This method enables to find out the various jobs or processes that have cost but also what they should have cost. So in order to increase the sales and production, the best costs are decided based on the consumer demand and availability of resources.

2.1.4. Efficiency

The efficiency factor could be increased in several ways such as the output flow should be increased for the given input, for the given output the amount of the input would be reduced, and also with the fact that the minor changes in the input would give a major output changes profitably. Thus for attaining efficiency the position and handling components also contribute effectively.

2.1.5. Apparent and true efficiency

Apparent efficiency could be raised by improvising the production units for the observed labour-hours without regard for sales. To be more precise, it is mainly evaluated based on the count of production units. True efficiency on the other hand could be achieved by the producing salable products with minimum labour-hours required. It also encompasses the reduction in cost.

2.1.6. Total efficiency

The motive of ascending the company efficiency is elimination of waste. Each process involving the company has to be scrutinized, with this ultimate motive. The execution should be made as that all sectors are involved with the improved benefits of increasing efficiency. But it is hard to lay the improvements in efficiency with this type of systems approach.

2.2. Six sigma

Six sigma is a highly disciplined process that enables organizations to deliver nearly perfect products and services. It is a statistical concept that measures a process in terms of defects. In other words it can be stated as a methodology to measure the company's performance, practices and systems.

2.2.1. DMAIC

The word DMAIC stands for Define, Measure, Analyze, Improve, Control and this is a classic technique of six sigma to solve process problems. DMAIC resolves issues of defects or failure, deviation from a target, excess cost or time, and deterioration. The definition chart for DMAIC is highlighted in figure A1.

2.3. Automated fixture assembly

The 321 principle deals with the positioning of the locator, accuracy, tolerances, fool proof in, duplicate location and motion economy. This considers 12 degrees of freedom – 4 along each axis; 2 translational and 2 rotational. The translational degrees of freedom are X+, X-, Y+, Y-, Z+ and Z-. The rotational degrees of freedom are the clockwise and anticlockwise movement along the respective X, Y, Z axes.

2.3.1. Vertical fixture

The motor needs to be fixed vertically or horizontally in such a way that the bush placement must be done accurately. Comparing the possibilities of developing different types of fixtures with respect to load, degrees of freedom and automation, vertical fixture is enabled. The advantage of this type of fixture is the force due to center of gravity is automatically balanced as it acts downwards and it also provides more flexibility in implementing automation. The motor at the assembly stage of bush placement has two ends in which, one is an open end impeller casing unit where the bush needs to be placed and one closed circular end. The fixture is developed for the closed circular end with respect to the diameter of the end. The fixture is developed as a sectional part within the base structure which holds the closed end firmly by arresting all the stated degrees of freedom in fixture design strategy.

2.3.2. Basic structure development

The base structure is developed for maximum safety, durability and reliability. The fixture is drawn or cut within the base structure so that the motor can be placed in line with the vertical axis of the cylinder. The cylinder and cylinder housing are located in the base structure in such a way that the vertical central axis of cylinder runs in line with the vertical central axis of the fixture. Thus this arrangement provides accurate placement of motor in the fixture. The material chosen for base structure is ASTM A 106 GRADE B due to its excellent mechanical properties and availability. This material has also been chosen for that fact that it absorbs small vibrations. The two dimensional design of base structure with circular fixture cut is displayed in figure A2. The cylinder housing for chosen cylinder also comes within the base structure development.

2.3.3. Cylinder selection

The process of manual bush placement is automated through an assembly fixture with the help of pneumatic cylinder. So the appropriate cylinder selection is an important step in implementing automation. The operating pressure of all the pneumatic circuits in the assembly lines of the industry is 5.5 kg/cm^2 to 6.5 kg/cm^2. While considering the pressure range, diameter of the ceramic bush and the diameter of the motor open end, a double acting cylinder having a bore of 50 mm and stroke of 250 mm is chosen whose two dimensional view is highlighted in figure A3. It is mounted vertically, so that the cylinder actuation makes the piston rod to travel vertically and induce the necessary force needed to place the bush perfectly in the impeller casing. The 2D layout of piston rod is showcased in figure A4. The cylinder is provided with proper housing so that it is not damaged in any cases.

2.3.4. Parts of the assembly fixture

An outer bush of diameter greater than the ceramic bush diameter is placed in the ceramic bush placement process, in addition to the double acting cylinder. Resulting in a chuck like structure with tension springs. The chuck structure covers up two parts, one attached to the thread of the piston rod and to the tension springs, other to the tension springs alone. Lastly a rod which has a diameter equal to the diameter of the rubber bush is employed. This specific arrangement for bush operation is unique, and certain steps are followed in designing the arrangement. All the fasteners used in the assembly fixture unit are of metric grade 8.8. The steps in specific arrangement are as follows

- **Step 1:** A rod which has inner diameter equal to the outer diameter of the piston rod is selected so that both rods are threaded and coupled.
- **Step 2:** The rod is selected in such a way that it has outer diameter and thickness equal to that of rubber bush and an inner small rod coupled inside having diameter and thickness equal to that of the ceramic bush.
- **Step 3:** A tension spring is selected based on the load that the cylinder piston rod generates for an operating pressure of 6.5 kg/cm^2 and according to the self-weight of the newly introduced rod (Lower chuck part). The spatial arrangement of upper and lower chuck parts is exhibited in figure A5 and figure A6 respectively.
- **Step 4:** The two separate chuck structures are united with the springs using a flat plate by welding and using fasteners.

2.3.5. Pneumatic circuit

The pneumatic circuit, for actuating the double acting cylinder for automatic and accurate bush placement through hand lever operated 5/2 direction control valve is designed and simulation is carried out in software. The circuit consists an air compressor, FRL Unit, 5/2 DCV, flow control valve and double acting cylinder. The 2D design of pneumatic circuit used for assembly fixture unit is displayed in figure A7.

2.3.6. Model of the parts

All the 2D drawings of the assembly fixture unit were developed as a 3D model and its respective views are shown in figure 1 and 2. Also the isometric outlook of the modelled assembly fixture is shown in figure 3.

Figure 1.CAD model of upper and lower chuck part

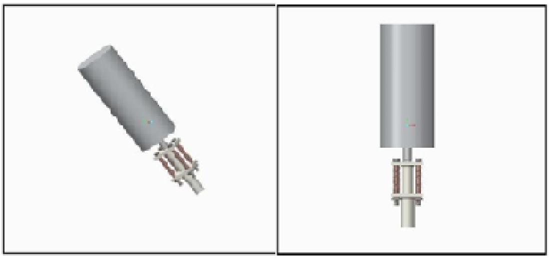

Figure 2.Isometric and front view of cylinder along with chuck and springs

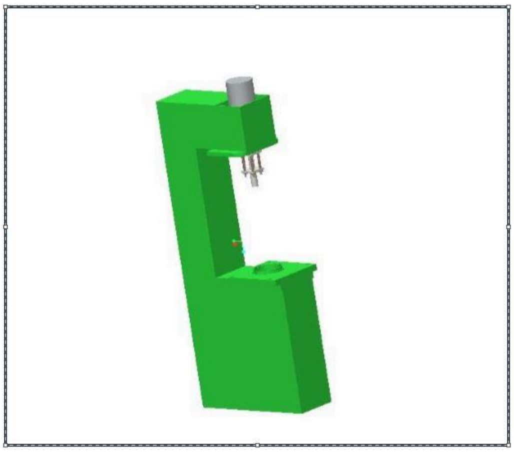

Figure 3.Isometric outlook of model of assembly fixture

2.4. Analysis of base structure

2.4.1. Finite element analysis

The base structure is fixed to the ground and is subjected to various static loads. It holds the motor in the fixture. The pneumatic operation exerts load in the motor which is transferred to the base structure. When the cylinder is extending and it is prevented from full extension of its stroke, a reaction load will act in the part that is preventing the extension. This is how the bush is provided a force to settle in the impeller casing. The concept is that the stress acting on the piston rod will be transferred to the ceramic bush if it is prevented from its full extension. Hence it is necessary to carry out the finite element analysis of the base structure to find its safety factor under maximal load conditions. Also it is necessary to observe the stress distribution in the base structure, so that the fixture part in it is not affected. FEA is carried out in software. The element used for FEA is tetrahedral and the proximity and curvature options are enabled in the software to find accurate results in the curves and edges. The parameters used for computations are displayed in table 1 and table 2.

Table 1.Specifications used for calculations

Specifications	Value
Pressure acting through the cylinder	6.5 kg/cm^2
Diameter of the piston rod	50 mm
Stress due to pneumatic actuation on the inner end of the piston rod	32480 N/m^2
Diameter of the ceramic bush	30 mm
Cross sectional area	0.0007065 m^2
Load acting on the ceramic bush	22.94 N

Table 2.Particulars used for maximum load computation

Particulars	Value
Weight of the motor	70 N
Load due to pneumatic actuation on base structure	22.94 N
Maximum static load on base structure	22.94 + 70=92.94 N
Factor of safety	3
Maximum load taken for FEA	279 N

The results of the finite element analysis of base structure are shown below in figure 4 and figure 5.

2.5. Implementation of lean

The ultimate motive of this paper is to eliminate the lead time in the assembly section of the shallow water jet assembly. The unrelated activities or time would be readily removed by applying lean manufacturing principles, thereby eliminating the waste. Finally the cycle time must be reduced with improved efficiency. The value stream mapping is formulated for the current and future scenario and the improvisation method of the process are identified. An assembly fixture was successfully developed to reduce the wastes. The process of automation implemented through the assembly fixture is taken into account for lean study. Accordingly, the wastes which get reduced/eliminated are

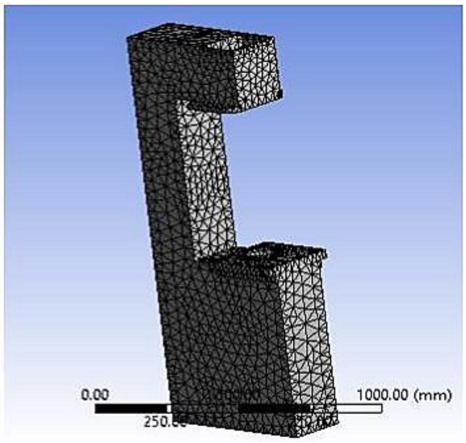

Figure 4.Mesh generated for base structure

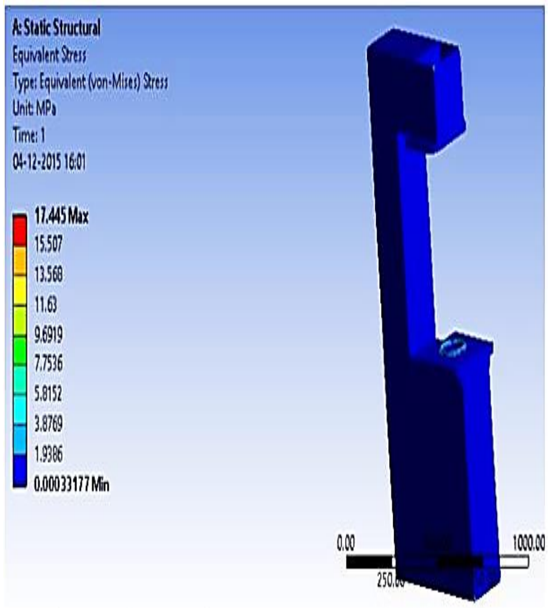

Figure 5.Equivalent stress distributed in base structure

(i) Correction – ceramic bush placement through assembly fixture
(ii) Inventory – process automation reduces parts in process
(iii) Conveyance – effort for transport of materials, parts

Thus by eliminating correction (accurate bush placement), the quality of the product motor is improved. In line with Deming's Quality Chain (DQC), as the quality gets improved the productivity must increase.

Hence it is clear that the apparent efficiency of motor must be increased and overall cost of the product must be reduced. The major and minor processes in the assembly of shallow water jet motor are shown as a process flow diagram in figure A8 and A9.

2.5.1. Value Stream Mapping

Value Stream Mapping (VSM) is a Lean-Management (LM) technique to analyze the current state and develop a future state comprising of events that it take a product from its starting stage to the product form. Value Stream Mapping (VSM) is involved in order to build to the standard form. The list of the activities, where the replacements or repairs are to be made are sorted and isolated within the mapping.

Table 3.Time study before lean/assembly fixture (for 30 motors)

PROCESS	PROCESSING TIME(minutes)
Stud placement	14:31
Bearing placement in motor	4:21
Stator placement	10:27
Water deflector	2:15
Thinner coating on rotor	3:50
Cover placement for wire connection	6:01
Tight fit cover using pneumatics	4:45
Nut placement hand tight	6:06
Capacitor placement	7:27
Capacitor wire connection	23:02
Finishing process	30:35
Pump assembly	54:39
Total processing time	**2 hour 39 min 03 sec**

2.5.2. Current state value stream mapping

With the relevant information about the process, the value stream for the current scenario is formulated with the processing time for all the process observed as highlighted in table 3 and table 4. The observation is done for 30 motors. The relevant information including the processing time, inventory storage, inspections, rework loops, number of workers and operational hours per day were collected. Total processing time for the assembly of 30 motors before implementing lean/assembly fixture is 2 hours 39 minutes and 03 seconds. The current state map has been showcased in figure A10.

Table 4.Time study for finishing processes (for 30 motors) before lean

PROCESS	PROCESSING TIME(minutes)
Nut tight	4.28
Motor check	2.58
Cooling fan	9.46
Gasket	3.46
Ceramic bushing & seal	4.19
Impeller	7.01

Table 5.Time study after lean/assembly fixture (for 30 motors)

PROCESS	PROCESSING TIME(minutes)
Stud placement	14:31
Bearing placement in motor	4:21
Stator placement	10:27
Water deflector	2:15
Thinner coating on rotor	3:50
Cover placement for wire connection	6:01
Tight fit cover using pneumatics	4:45
Nut placement hand tight	6:06
Capacitor placement	7:27
Capacitor wire connection	23:02
Finishing process	26.17
Pump assembly	54:39
Total processing time	**2 hour 34 min 45 sec**

2.5.3. Future state value stream mapping

After implementing assembly fixture unit in assembly line of shallow water jet motor, time study was performed for thirty motor assembly at a single stretch to construct the future state value stream map and table 5 and table 6 summarizes the overall activities associated with the motor assembly along with their processing time. Eventually, the value stream map for the future state is constructed. The lead time is reduced and apparent efficiency is increased. The diagrammatic representation of future state map is depicted in figure A11.

Table 6.Time study for finishing processes (for 30 motors) after lean

PROCESS	PROCESSING TIME(minutes)
Nut tight	4.28
Motor check	2.58
Cooling fan	9.46
Gasket	3.46
Ceramic bushing & seal	2.35
Impeller	5.23

Table 7.Apparent efficiency calculations

Specifications	Value
Total lead time for assembly of shallow water jet motor before lean/assembly fixture (30 motors)	159.03 minutes
Total lead time for assembly of shallow water jet motor after lean assembly fixture (30 motors)	154.45 minutes
Total lead time reduced for assembly of 30 motors	4.18 minutes
No. of motors produced per day (multiple shifts) before lean	250
Total lead time reduced for assembly of 250 motors	34.6 minutes
No. of motors produced per day (multiple shifts) after lean	268
Production of motor increased per day (in numbers)	18
Increase in apparent efficiency	7.2%

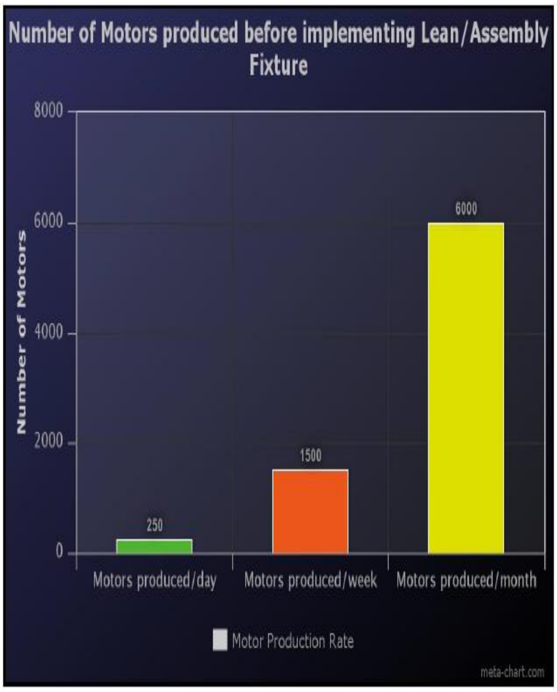

Figure 6.Motor production rate before lean/assembly fixture

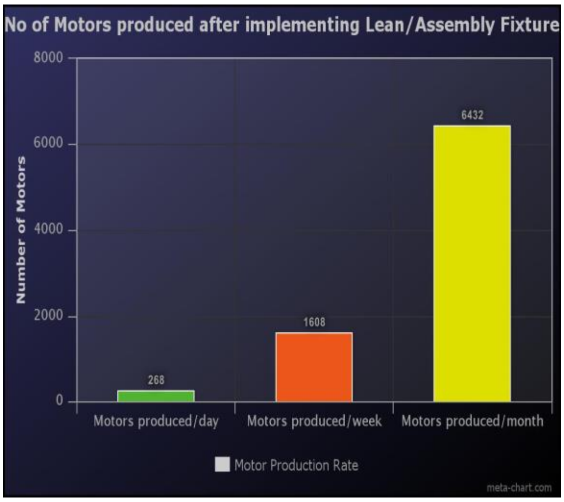

Figure 7.Motor production rate after lean/assembly fixture

Table 7 highlights the specifications used for computing apparent performance. Total processing time for the assembly of 30 motors after implementing lean/assembly fixture is 2 hours 34 minutes and 45 seconds. Hence after implementing lean/assembly fixture, a reduction of 4 minutes and 18 seconds in total lead time is achieved. Thus there will be a considerable increase in apparent efficiency and production rate.Figure 6 and 7 shows the motor production rate before and after lean/assembly fixture. Figure 8 shows the fabricated assembly fixture.

3. RESULTS

After implementing the assembly fixture, the lead time of the shallow water jet motor assembly is reduced to 4.18 minutes for the assembly of 30 motors and 34.6 minutes for assembly of 250 motors. Finally, the productivity is increased from 250 motors per day (multiple shifts) to 268 motors per day and apparent efficiency is increased by 7.2%. A bar chart illustrating the increase in annual productivity of shallow water jet motor (before and after implementing lean) is given in figure 9.

Figure 8.Fabricated assembly fixture

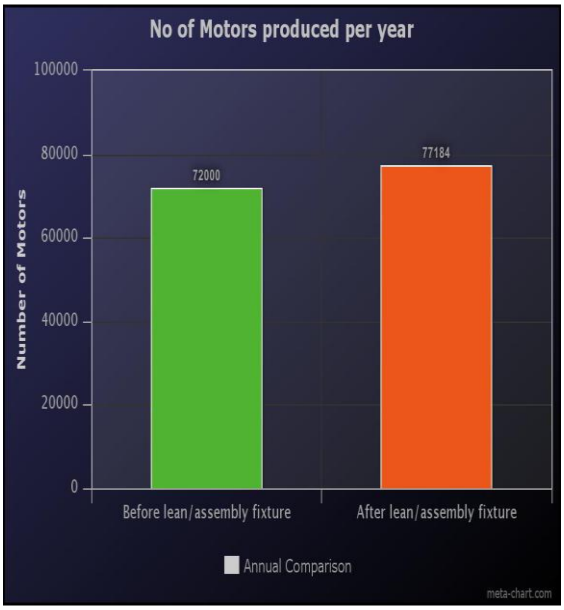

Figure 9.Annual Motor Production Comparison Chart

4. CONCLUSION

The problem task took from the assembly line of shallow water motor in the production department of the industry is understood, analyzed and a solution has been found. The ultimate aim is to reduce the lead time and increase productivity. The solution is the assembly fixture automation of the ceramic bush placement in the shallow water jet motor assembly. The assembly fixture is successfully developed and implemented for bush placement with automation and an evident future state map is successfully generated. Thus, the task to rectify the product defect with reduced lead time and increased productivity is successfully achieved.

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APPENDIX

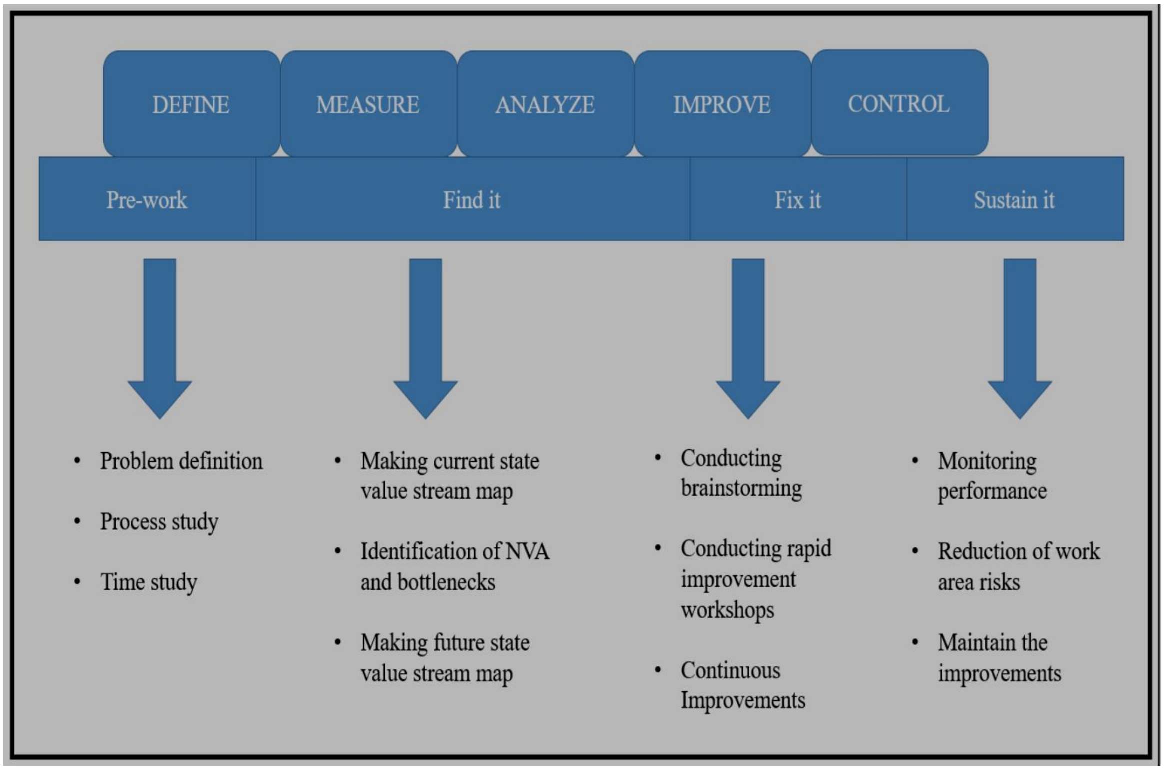

Figure A1.DMAIC – definition chart

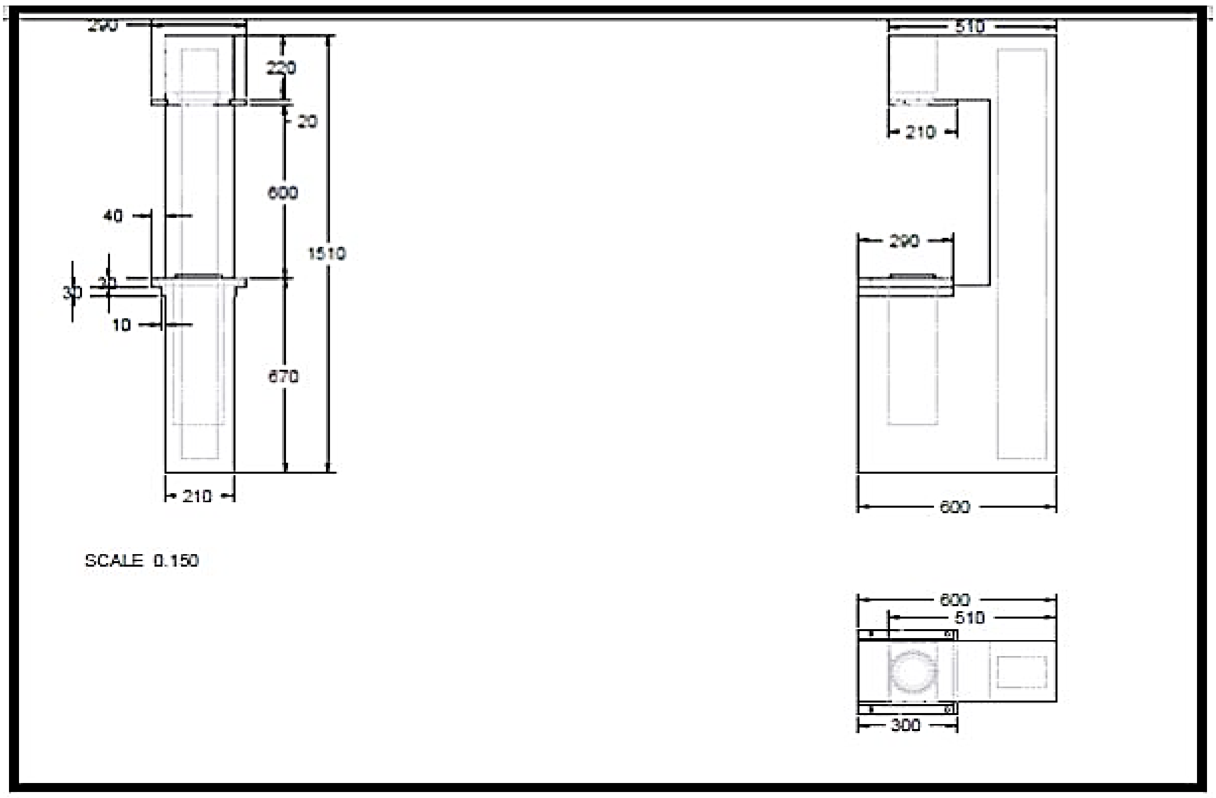

Figure A2.2D design of base structure with circular fixture cut

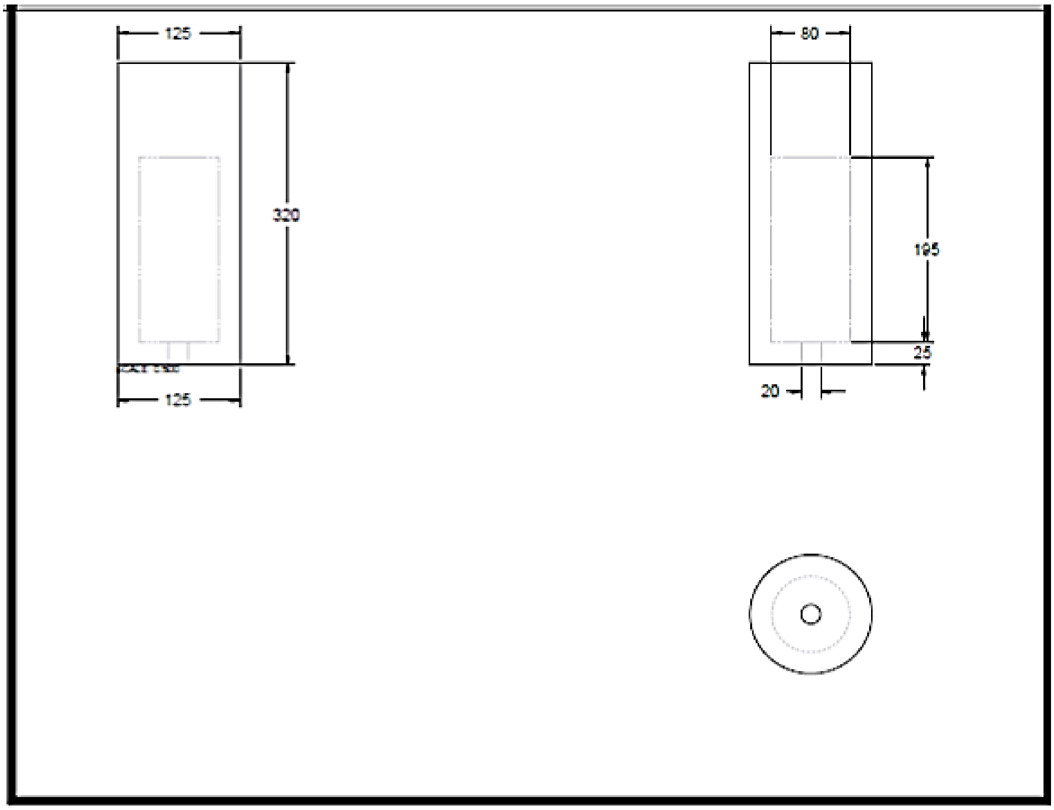

Figure A3. 2D drawing of cylinder

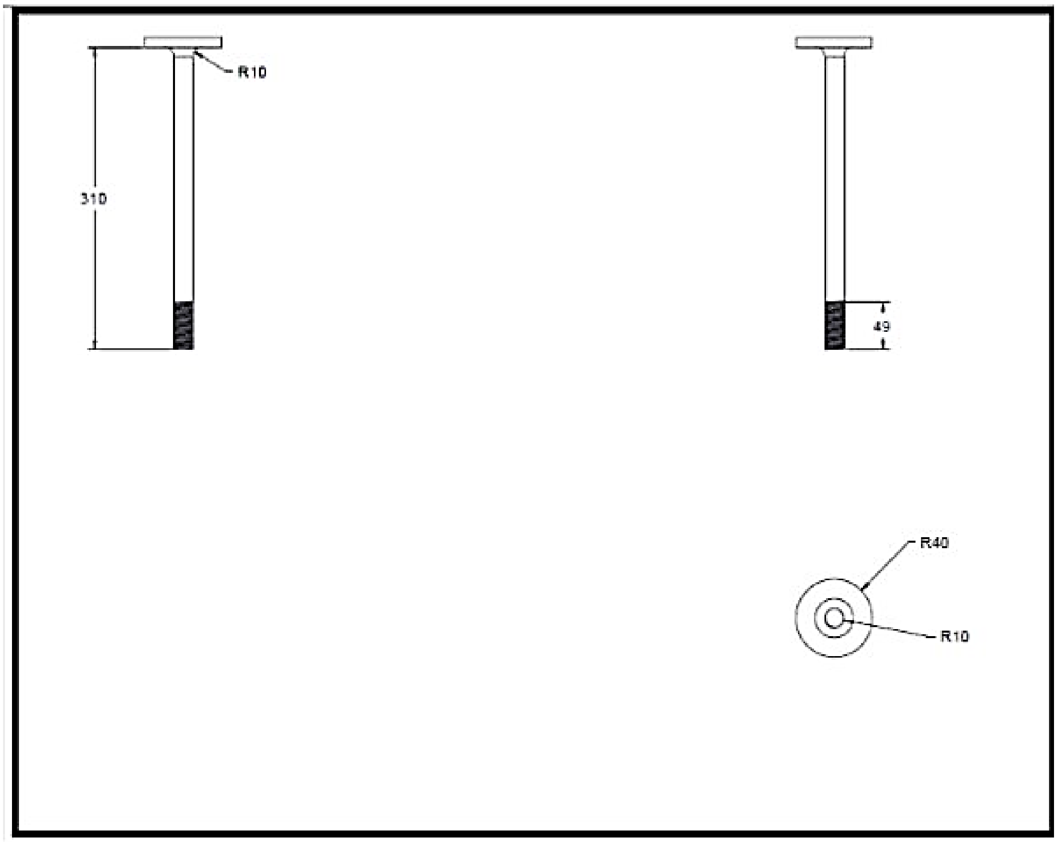

Figure A4. 2D layout of piston rod

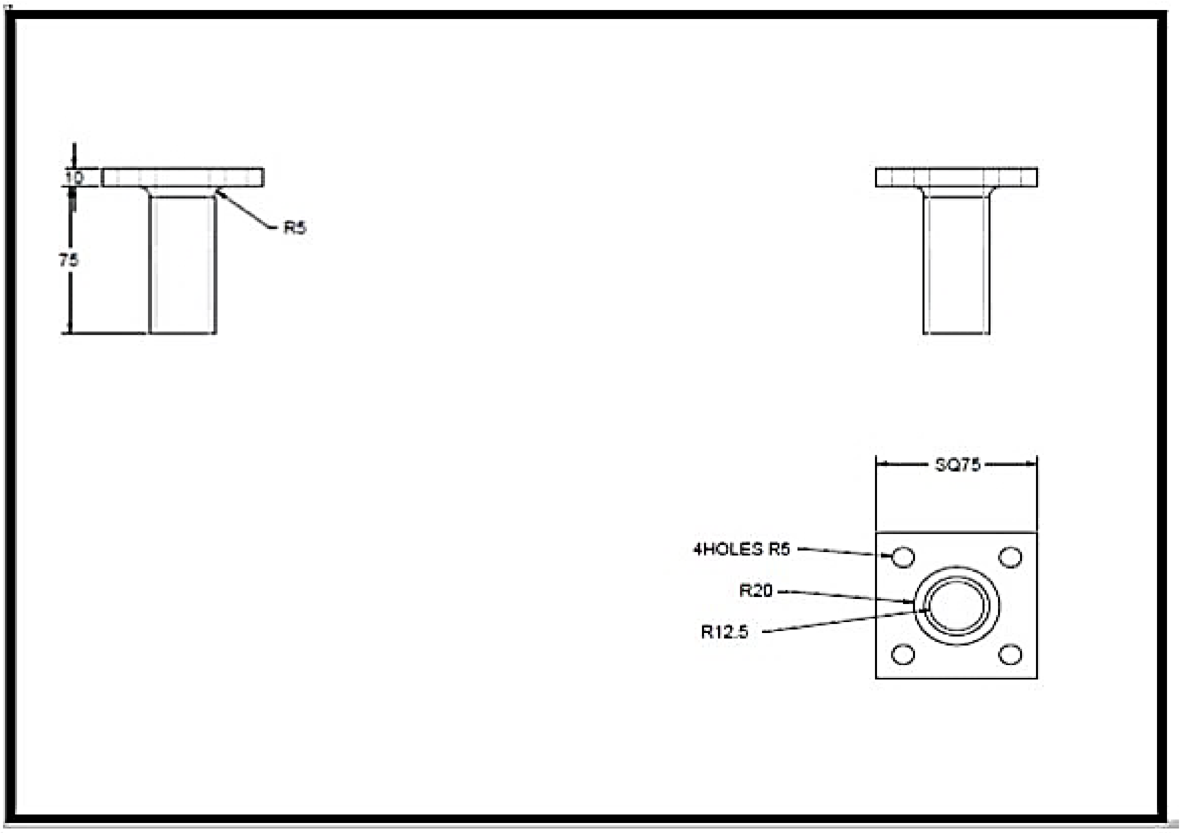

Figure A5.Spatial arrangement of upper chuck part

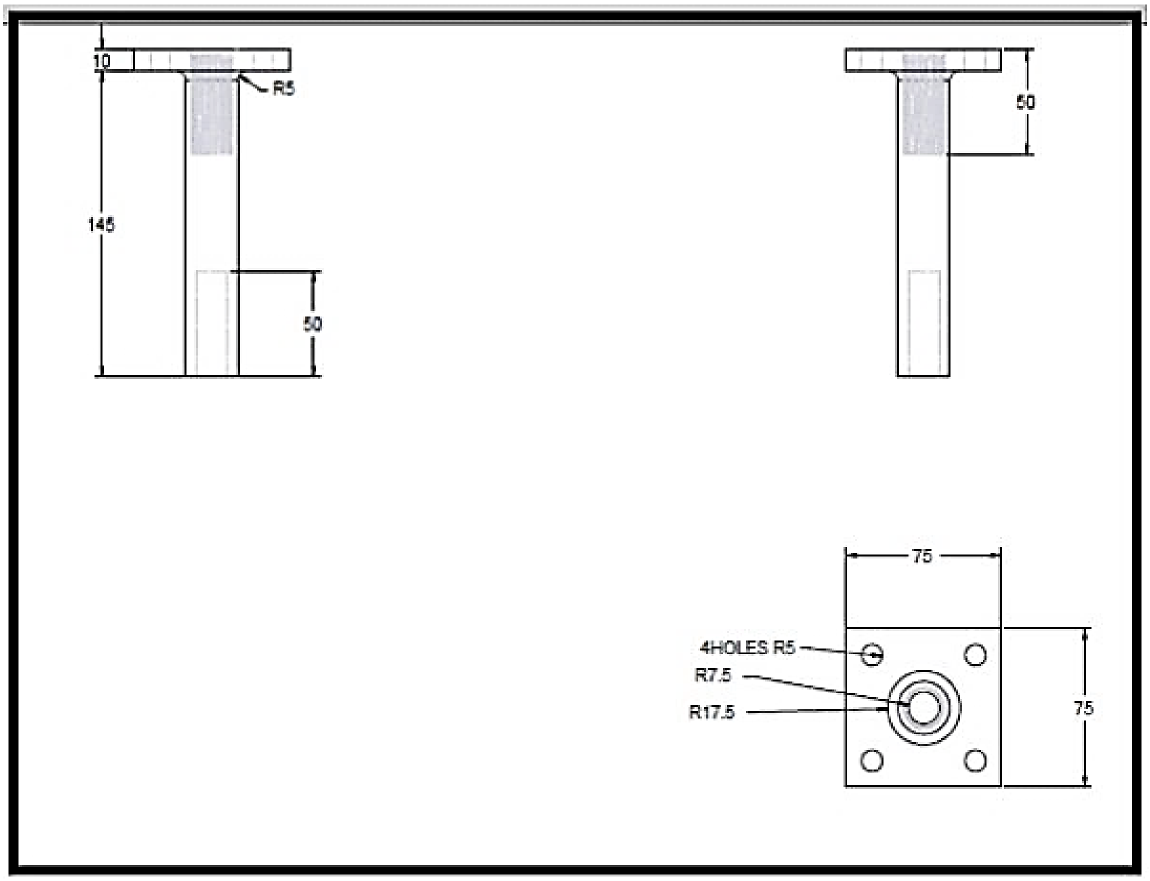

Figure A6.Spatial arrangement of lower chuck part

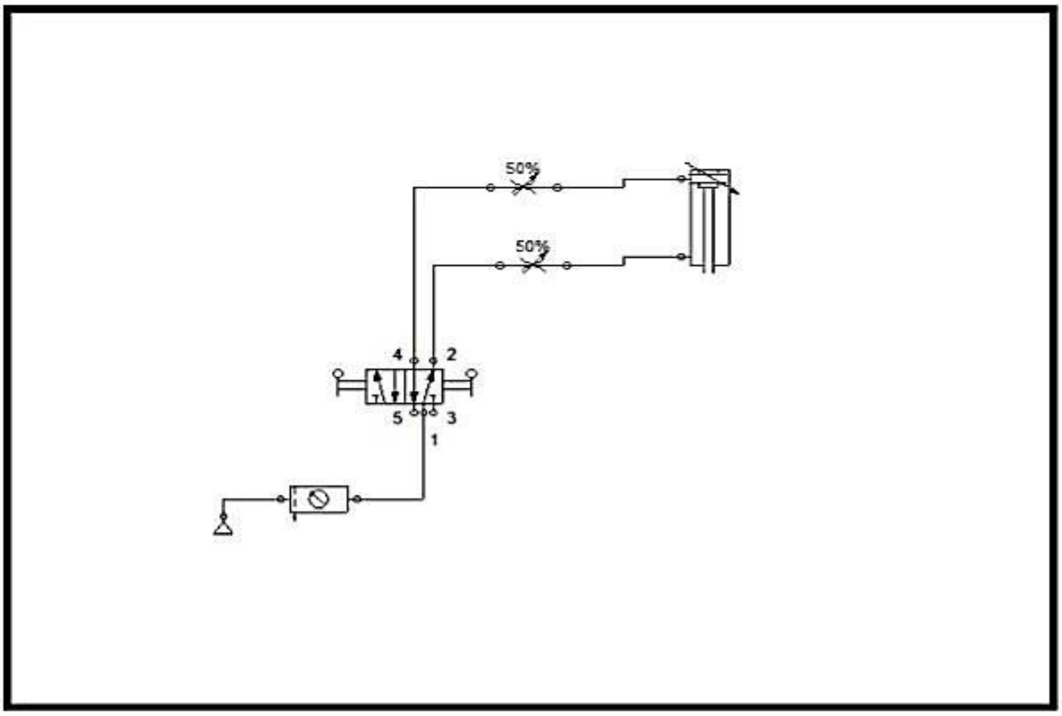

Figure A7.Pneumatic circuit of double acting cylinder in the assembly fixture unit

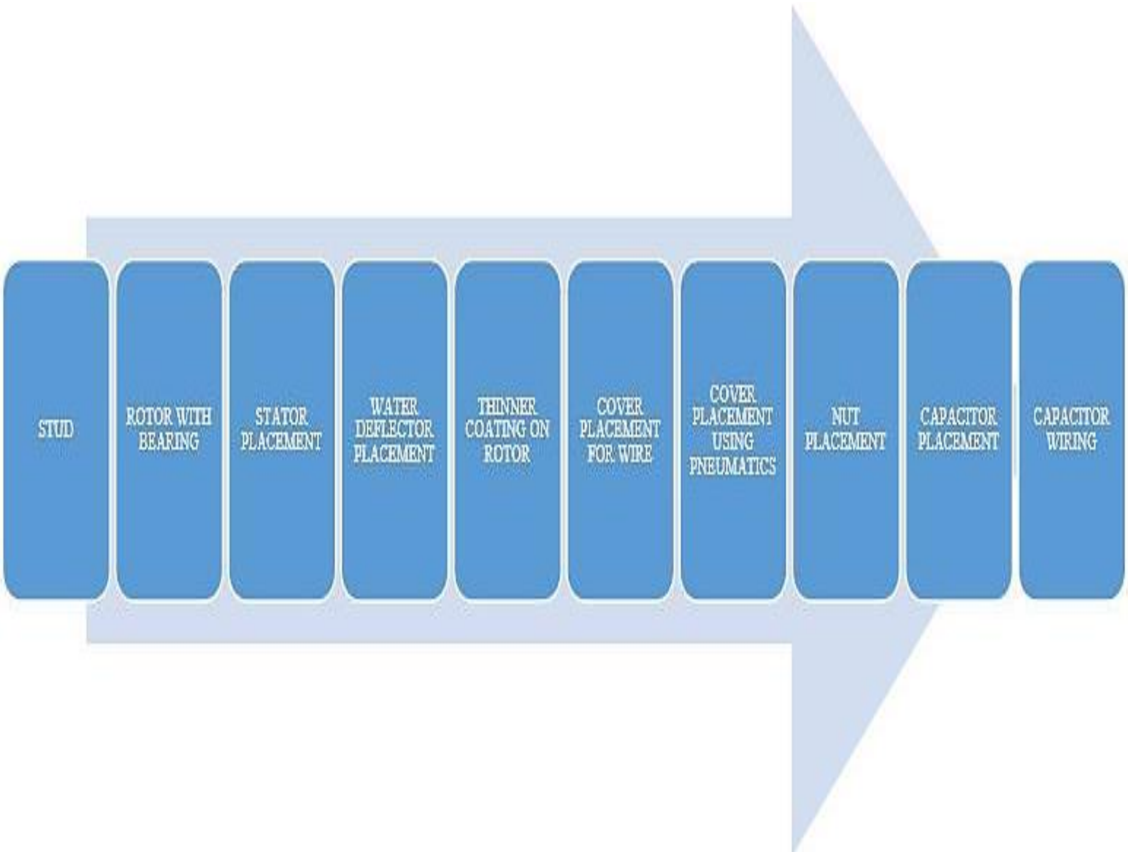

Figure A8.Major process in shallow water jet motor assembly

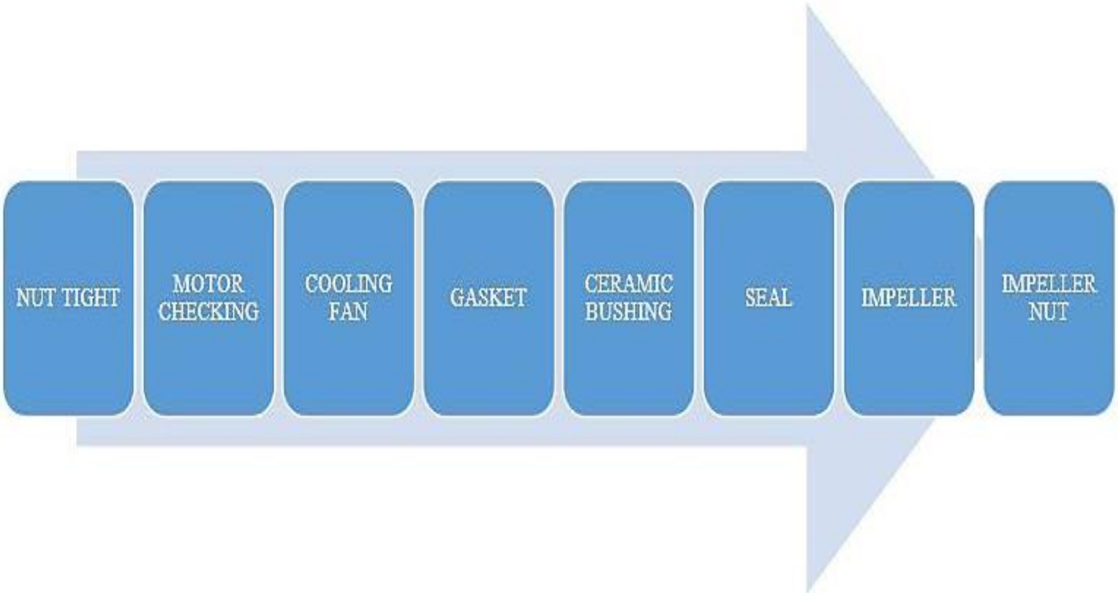

Figure A9.Minor concluding process in shallow water jet motor assembly

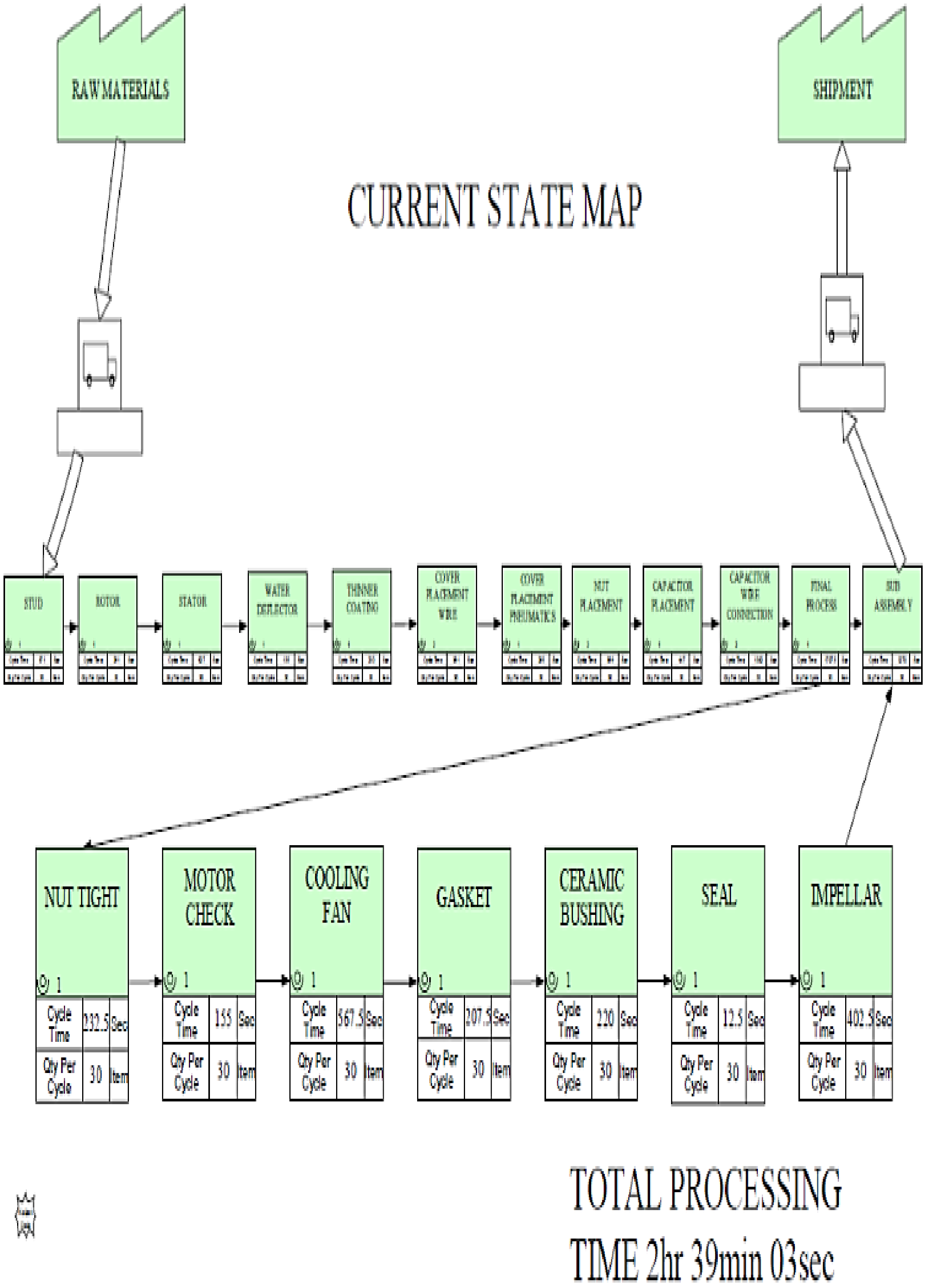

Figure A10.Current state value stream map

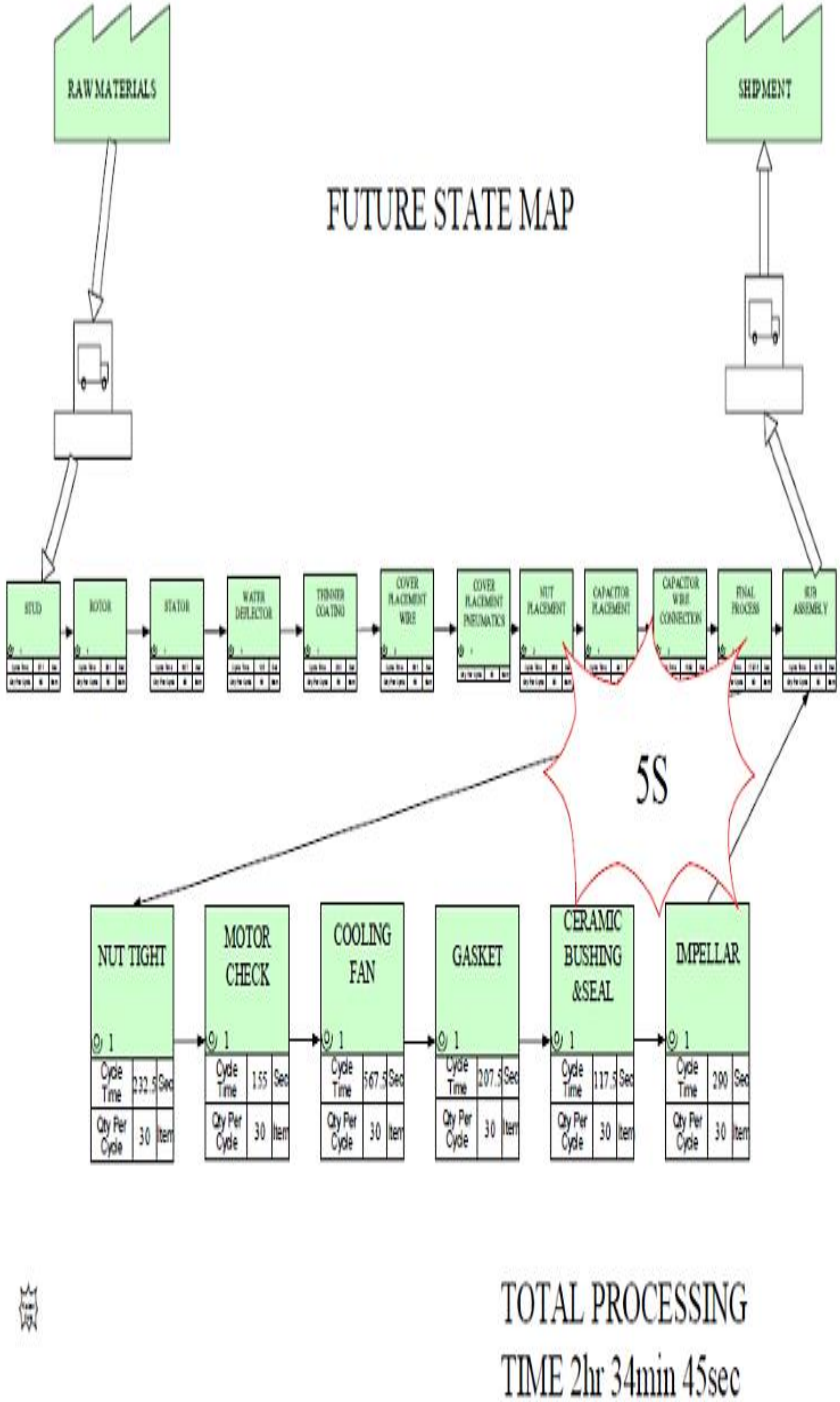

Figure A11.Future state value stream map