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FEM Based Life Enhancement of Linear Motion Shaft Guide Way with Four Spindle Multi DC Nut Runner For Accurate Torque Output

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ABSTRACT:- The application of the linear guideways is very extensive, such as automation equipment, heavy-duty carry equipment, heavy-cut machining tool, CNC grinding machine, large-scale planning machine and machining centre with the demand of high rigidity and heavy load. This paper study work is proposed to carry out CAE analysis of linear motion guideway shafts failure used in Multi Nut Runner System used to deliver accurate torque on the product. The life of linear motion guideway shaft can be improved by carrying the necessary design changes to prevent infant mortality failure of guideway shaft. The proposed work is planned in following phases. The detailed study of present condition & investigation of type of failure. Root cause analysis of the Linear Motion Guideway shaft failure using engineering calculation & FE Analysis. To eliminate the root cause proposed design is prepared & FE analysis done of the proposed design with design modification. After successful design, the required modified bracket preparation, testing of bracket is carried out& then fitted on the said tool for guideway shaft condition observation & delivery of required torque in consistent manner.

Keyword:- Torque, Multi Spindle DC Tool, Pneumatic force, Linear Motion Guide rod, FE Analysis

I. INTRODUCTION

This paper is focus on the Multi Spindle DC Tool used in different manufacturing industry. The Multi Spindle DC Tool is used to apply torque on multiple bolts at a time with close accuracy. This is used for critical tightening joints. The Tool discussed in this paper is a four spindle DC Nut Runner. It consists of total four spindles used for tightening four engine head cover nuts at each cycle of operation. Each spindle is having one DC tool which is used to apply the torque on the bolt with predetermined torque value assigned to the tool. This tool is overhang type & for up-down motion of the tool, Linear Motion (LM) shaft is used. The torque accuracy & tool performance is directly depends on this LM shaft. The purpose of the paper is to eliminate the scoring mark on the guideway shaft. By eliminating this scoring our motive is to provide required torque on the product.

II. BASIC TOOL SETUP & WORKING DETAILS

The tool which is discussed here is an overhead hanging tool from overhead through overhead rail. The tool is mounted on overhead rail with help of trolley. This trolley allows to move the tool as per convenience of the operator working on assembly line. The tool has both horizontal as well as vertical up/down motion involved during actual working. The tool consisting of following parts:

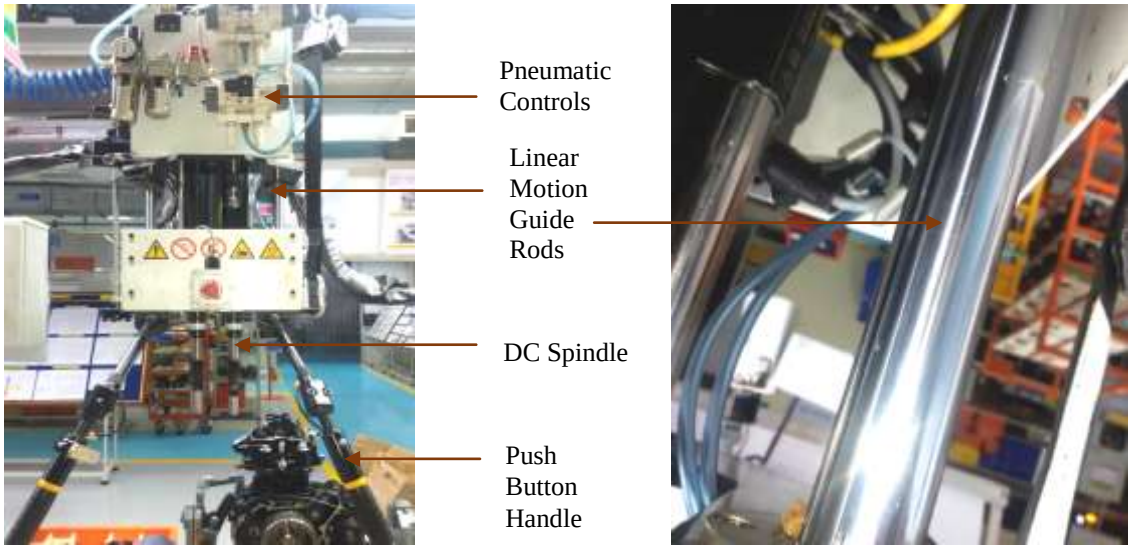


Fig 1. Multi Spindle Nut runner Tool Setup

It is used for precise torque application in Engine Cylinder head cover Dome nut bolt tightening. The equipment working is explained briefly.

The DC tool unit is getting up/down during each time nut tightening work on the assembly line. For this automatic up /down movement, one pneumatic cylinder is used. The up/down movement of this heavy unit is guided through two numbers of guide rod with linear bearing. For the actuation of Pneumatic cylinder, one pneumatic circuit is designed. It is equipped with Filter Regulator Lubricator (FRL) unit, pneumatic solenoid valve, flow control valves, pneumatic hoses etc. The Pneumatic cylinder which is used of Double acting type. The pneumatic cylinder movement is controlled through an electric switch. After actuation of this switch, 24 V DC current is supplied to Pneumatic valve solenoid & solenoid gets operated. Hence Valve spool gets operated & air is supplied to the cylinder.

After air coming to the cylinder, piston rod moves & lifts or downs the Nut runner unit.

For moving the whole unit in précised way to get the proper torque at proper place, linear guides are used. Linear Bushing model is a linear motion system used in a combination with a cylindrical LM shaft to perform infinite state motion. The balls in the loaded area of the nut are in point contact with the LM shaft. This allows straight motion with minimal friction resistance and achieves highly accurate and smooth motion despite the small permissible load. So, the performance of this Multi Nut Runner depends on the condition of LM Guide ways.

III. EXISTING PROBLEM & FAILURE TYPE

The LM Shaft of the linear bushing needs to be manufactured with much consideration of hardness, surface roughness and dimensional accuracy of the shaft since ball rolls directly on it. The surface hardness of an LM shaft affects the service life of Linear Bushing system most significantly. The heat treatment by tempering assures LM Shaft uniform hardness in both radial & axial directions, developing a hardness layer.

The recommended surface hardness is of 58 HRC or higher. The depth of the hardened layer is determined by the linear bushing. To achieve smooth motion, the surface should be preferably be finished to 04.40a or less.

The installation date of Tool is in the month of February 2015. But the failure of guide rod starts from the month of June 2015. After replacement of guide rods in the month of June 2015, same failure reoccurred in the month of September 2015. So, before proceeding further we should understand the type of failure. According to the failure we will go further for analyze of failure.

Reliability specialists often describe the lifetime of a population of products using a graphical representation called the bathtub curve. The bathtub curve consists of three periods: an infant mortality period with a decreasing failure rate followed by a normal life period (also known as "useful life") with a low, relatively constant failure rate and concluding with a wear-out period that exhibits an increasing failure.

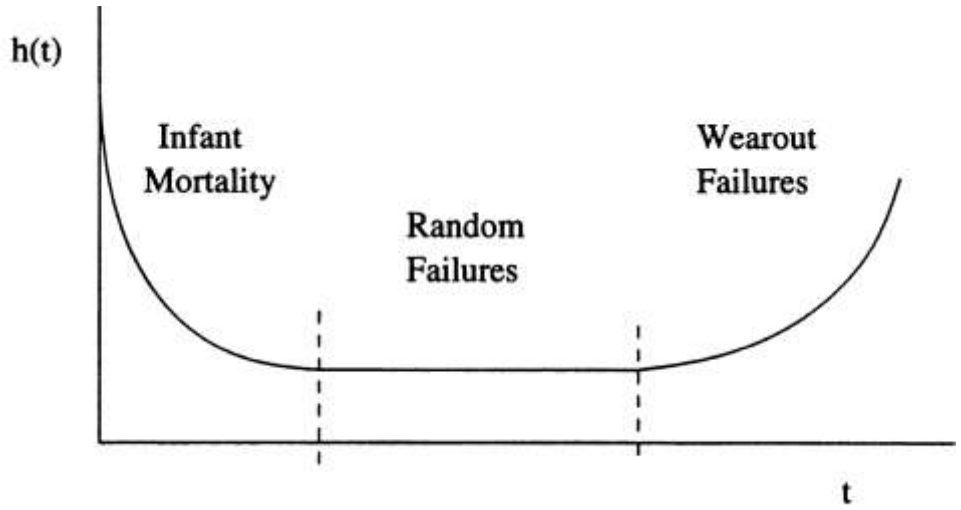


Fig 2. Bathtub Curve

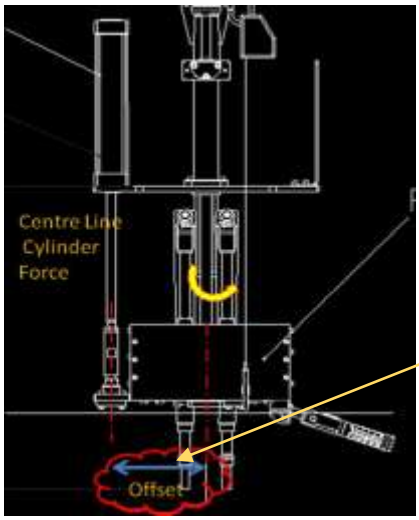
From this Fig.2 the failure type is stated as Infant Mortality because the product fails before its normal life.
The steps to diagnosis of Infant Mortality failure analysis are–

1. The first approach, eliminating root causes, is generally the best approach and can significantly reduce infant mortalities. It is usually most cost-effective to run 100% stress screens only for early production, then reduce the screen to an audit (or entirely eliminate it) as root causes are identified, the process/design is corrected and significant problems are removed.
2. The failures should be investigated for material defect. Such an approach can help to eliminate material defects that would otherwise show up with product failures in the field.
3. The failure should be investigated in view of design of product. Approach should be there to remove design weakness.

In the above points, Point 1 & 2 are not relevant according to the discussed phenomena. So Point 3 needs to be considered.

IV. FAILURE ANALYSIS

To understand the failure analysis, detailed study of the equipment present condition carried out. After details study the problem which is mentioned above due to weak design. After analysis it is found that the pneumatic cylinder actuating force is acting on the base structure of the tool. This load is directly transferring to the guide rods while tool up/down movement. There is long offset distance between cylinder actuating center line & guide rod center line. This offset distance creating torque. Due to this one tensional force is developing, this force in turn affecting the guide rods can be shown in Fig.3.



The Offset distance is creating torsional force on the guide rods

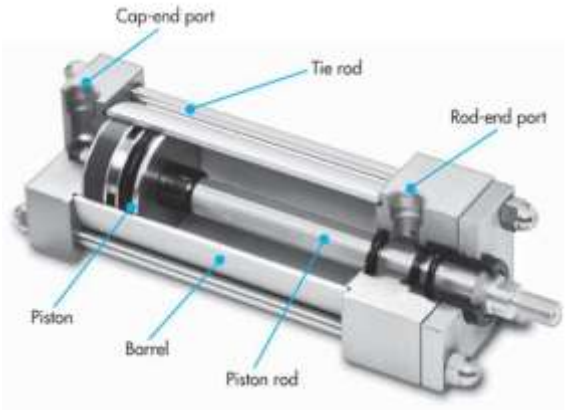


Fig 3. Offset Distance & Torque Development

Fig 4. Cross sectional view of Pneumatic Cylinder

A. Engineering Analysis

To do the engineering calculation, basic data like Cylinder Technical details, working pressure of pneumatic cylinder collected. The amount of force applied by the cylinder & the torque which is developing due to the offset distance between centre line of cylinder & centre line of linear motion guide rods, engineering calculation is being carried out. To calculate the force by cylinder all the dimensions of the cylinder are taken.

Cylinder bore (d): 63 mm

Cylinder stroke (L): 200 mm.

Pneumatic pressure is (P) = 5 bar

Area of Pneumatic Cylinder force acting is (A) = (π/4)*d2 = (π/4)*632

The force applied by the cylinder on the base of the tool is: Pneumatic Pressure X Area

=PXA = 1330 N= 135 Kgf

Presently the offset distance as shown in Fig 3 is 0.210 m.

So, Torsional force is = Force applied by the cylinder X Offset distance

= 135*0.210=27.93 Kgfm

This amount of torque applying stress on the linear bearing area, which is then transferred to the guide rods. This creates scoring marks on guide rods. This can be clear through following figure.

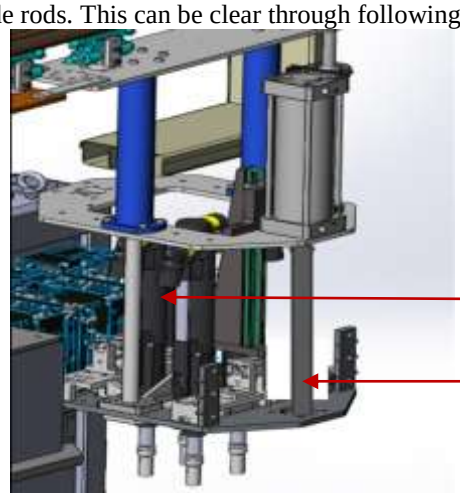


Fig 5. Pneumatic Cylinder Mounting Details

B. Finite Element Analysis

Since last decade advent of powerful finite element analysis (FEA) packages have proven good tool to accurately analyse them. FEM enables to find critical locations and quantitative analysis of the stress distribution and deformed shapes under loads. However detailed modelling and specialized knowledge of FEM theory are indispensable to perform these analyses with high accuracy.

For doing FEA analysis, the basic model of the existing system is prepared in CATIA software. Fig. 6 shows the basic structure of the tool in CATIA model. For doing FE Analysis, the software used is Hypermesh. By the help of the software detailed analysis is done. In this software all the boundary condition provided as per the existing system of tool. After providing the basic boundary condition FE Analysis is carried out to obtain the values like displacement, strain stress etc.

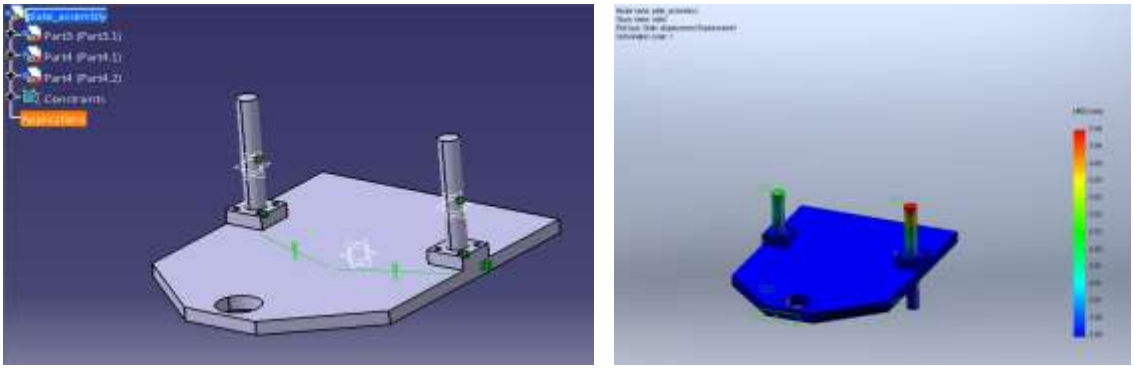


Fig 6&7. Existing Tool base structure and Displacement plot

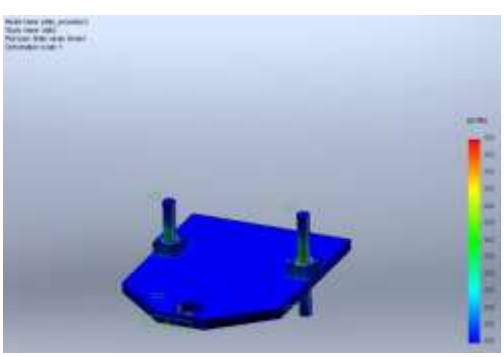
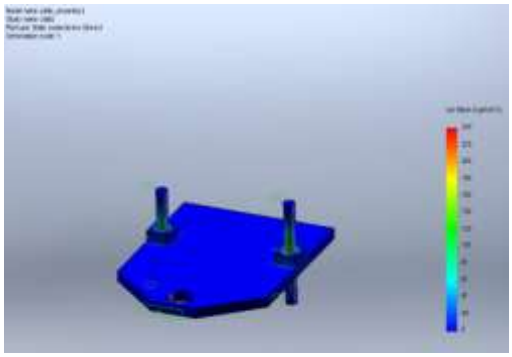



Fig 8 & 9. CAE analysis with Strain & Stress Values

From the above Fig. 7 we are able to understand the displacement patterns during working of Linear Motion Guideways. In Fig. 8 & Fig. 9 the strain value & stress values developed during working can be understand easily. The maximum Von Mises stress value is shown at the CAE analysis is at the contact surface is 243 kg/cm2. So this contact stress on the Linear Motion Guideway shaft is creating scoring marks. To overcome the failure of scoring marks on Linear Guideways the stress value needs to be reduced. The whole force of pneumatic cylinder is acting through the mounting hole of base plate. This creates one eccentric force on mounting hole of the base plate. This eccentric force is creating torque on the guide rods of the structure as shown. Due to this high load, all the stress transfers on the guide rod. Due to this stress, the scoring mark is developing on the guide rods.

V. CORRECTIVE ACTION & DESIGN CHANGE

To reduce he stress on the LM guideways, we have to reduce the torque developed.
Torque= Force X distance= Pneumatic force X Offset distance (As per present topic)
Either Force to be reduced or distance (i.e. offset distance) needs to be reduced. As the cylinder is fixed size the force cannot be altered, so the offset distance to be reduced.
To reduce the offset distance, new design idea explored. One bracket designed so that it should accommodate the cylinder mounting as well as reduce the offset distance.

A. Design Change by Addition of New Brackets

To reduce the offset value, one bracket has been designed. This bracket is do designed that it can be fitted on the existing tool considering minimum modification work on the base plate.

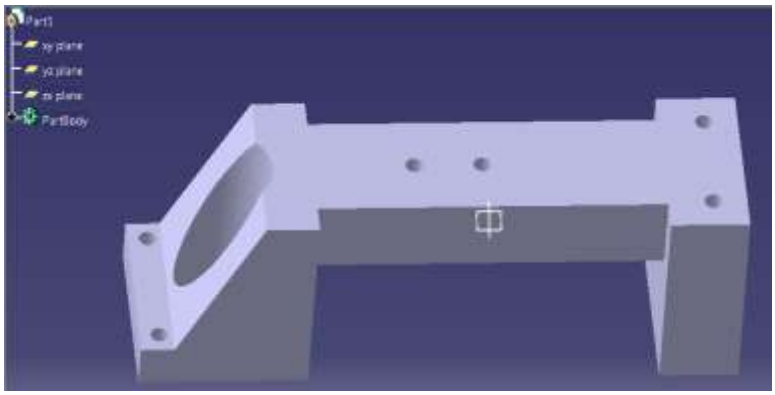


Fig 10. Bracket design view

The Fig. 10 shows the Bracket design made. This is so made that minimum rework to be done on the base plate of the tool to fit this. The base structure with the tool will be fitted as shown in Fig. 11.

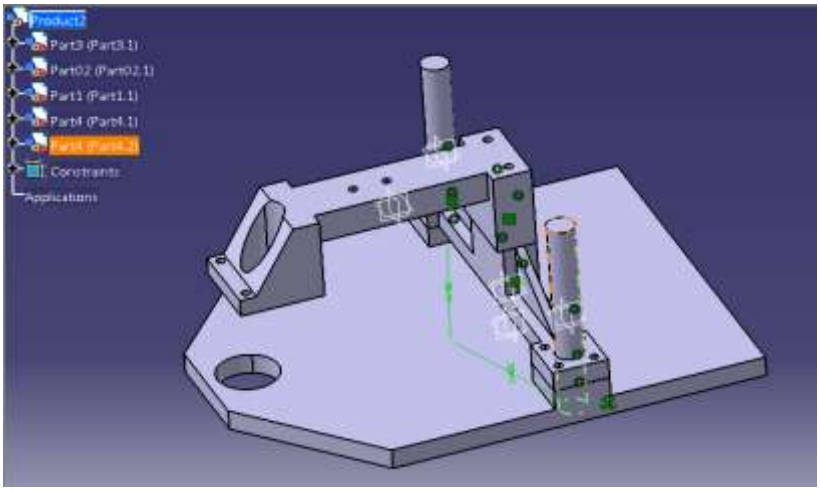


Fig 11. Tool with Modified Bracket

The comparison can be easily done between old base structures & modified base structure from Fig. 5 and Fig. 10 respectively. Due to addition of this bracket, the offset distance is being reduced. This in turn will reduce the torque value which is creating scoring marks on the LM guideways.

B. Engineering Calculation after Design Change

After Design change as explained above, the offset distance is reduced. From the Fig.11 it can be shown that the offset distance is reduced as shown by arrow mark. By this design modification, the offset distance is reduced to 0.120m which was previously 0.210m.

Now with help of the Engineering Calculation, torque value can be obtained as below:

Cylinder bore (d): 63 mm

Cylinder stroke (L): 200 mm.

Pneumatic pressure is (P) = 5 bar

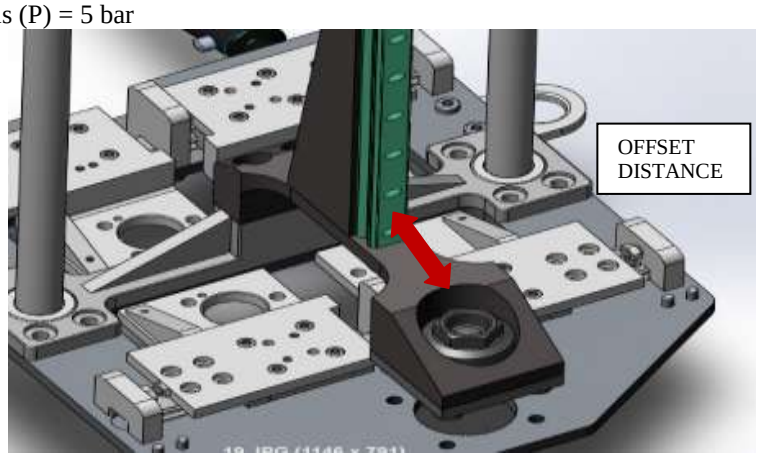


Fig 12. Offset Distance after Design Change

Area of Pneumatic Cylinder force acting is (A) = (π/4)*d2 = (π/4)*632

The force applied by the cylinder on the base of the tool is: Pneumatic Pressure X Area

=PXA

= 1330 N= 135 Kgf

This is same as before.

After design modification the offset distance as shown in Fig.12 is 0.120 m.

So, Torsional force is = Force applied by the cylinder X Offset distance

= 135*0.120=15.96 Kgfm

By this engineering calculation, it is easily comparable that the torque value before modification was 27.93 Kgfm & after design change the torque value is 15.96 kgfm.

VI. CONCLUSION & POTENTIAL FOR FUTURE SCOPE

This chapter comprises a summary of the presented achievements and results and provides an outlook for subsequent future scope.

A. Conclusion

In order to cope with today's challenges in the development process of highly complex automated assembly systems OEMs and PMs have collaboratively established virtual validation procedures utilizing methods and tools of the Digital Factory. As fundamental background a simplified structure of automated assembly systems and virtual validation procedures currently applied in the automotive industry were introduced in this paper, motivating the physics based modeling.

The comparison is shown in the Fig. 13. The offset distance is reduced, thus the torque value is also reduced.

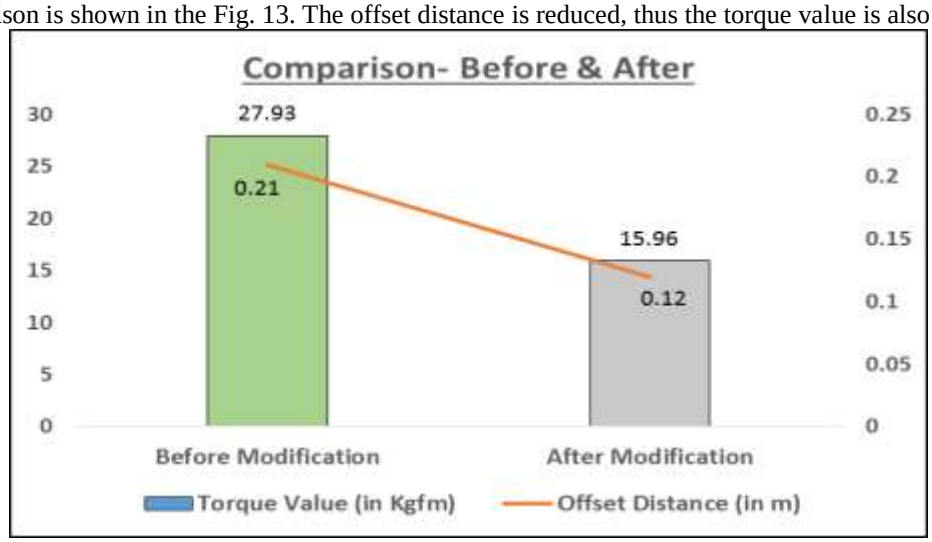


Fig 13. Comparison of Torque Value

So, less torsional force will be applied on the cylinder. So, lesser load on the Linear Guideway shaft. This will increase the life of Linear Guide way Shaft. The scoring mark elimination due to lesser load on the shaft.

The structural difference of the Four Spindle DC Nut Runner before & after modification can be easily understood by the following Fig.14.

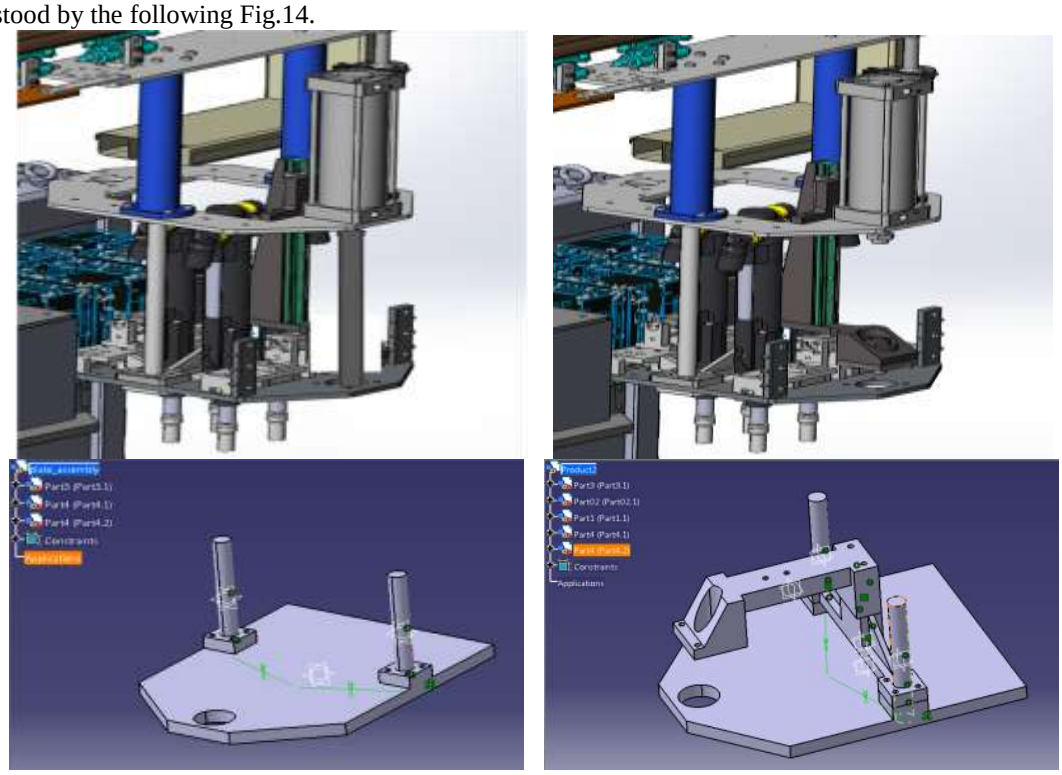


Figure 14. Comparison of Before & After Structure

The objective of the paper is to eliminate scratch on the LM Guide Shaft for best toque application by the four spindle DC multi nut runner is achieved through the design change & optimized life of LM shaft ensured.

B. Future Scope

The future scope of this paper can be given as, changing in Pneumatic Cylinder positioning. As the cylinder position is at one side, eccentric force is acting. For more accurate result, the pneumatic cylinder should be so designed so that it should be positioned at the middle of the tool base. Also the pneumatic cylinder to be used should have inbuilt guide rods which is advanced pneumatic technology in order to cope with today's challenges in the development process of highly complex automated assembly systems OEMs.

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