*Proceedings of the International Conference on Applied Mechanical Engineering Research (IC-AMER2019)*
*NIT Warangal, India – May 02-05, 2019*
*Paper No. XXX (The number assigned when the papaer is accepted )*

# Quality, Time and Cost Effective Brush Seal Manufacturing for Industrial Gas Turbines through a Reconfigurable Complete Fixture

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In the manufacturing, even though the machine centers have sophisticated machines for meeting the necessary quality of the job, the accuracy of the job setting, reduction of loading and unloading time, transfer of job to various machine centers without compromising the quality and functionality due to frequent resetting, On process inspection and rework on it if necessary are depends on the supporting equipments. The air machines which are operated either pneumatically or by means of steam or gas, need air sealing to prevent leakage of operating fuel. This research focuses on manufacturing of brush seal for gas turbines. The multiple loading and unloading of the same job at various machine centers produced some inaccuracies which lead the rejection or rework of brush seal jobs. Hence, as per manufacturing process demand, a complete fixture is designed to use universally for all manufacturing process at various machine centers and inspection also with a single setup of a job. The proposed complete fixture saves time and cost-effectively and assured quality and reliability of brush seal. The detailed study of problems and complete solution were discussed.

***Keywords*:** Brushseal; fixture; numerical study; Gas turbines

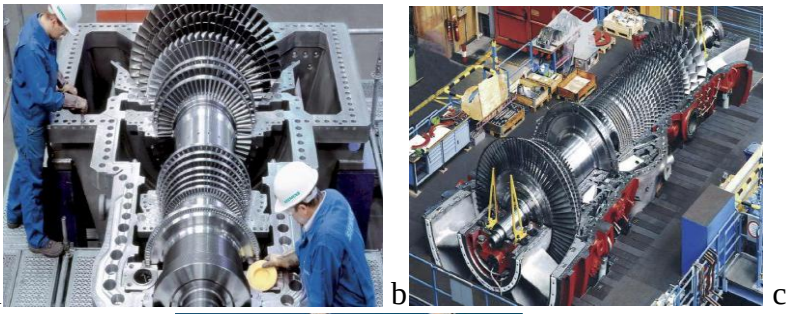
## 1. Introduction

The customized design of products, demand for shorten manufacturing lead time, proposals of rework and rejection eliminations etc arise the need for design the fixture to support the manufacturing processes.[2] discussed the need for paying attention on work holding devices and classified the fixtures as basic, for single component and for multi part (production and assembly). This research focuses the multi part type fixture. [4] developed Python-OCC-based platform to design the fixtures for specific application. this research used computer aided design to conceptualize, design, validation and weight reduction. The personalized fixture design often encountered for many manufacturing processes. one of such literature evident that [3] designed fixture for performing friction stir welding comfortably in a milling machine. [1] highlighted the importance of designing reconfigurable fixture to manage the product variants . That is use of single fixture for manufacturing of products which have the short lifecycles. [5] proposed the rapid fixture approach that is inclusion of agile provision and reconfiguration concepts in designing fixture for automation. this research made a such attempt in brush seal manufacturing.

## 2. Problem background

The gas and steam turbines are at operated in high pressure and the leakage sealing is still challenging one. It was estimated that the leakages in the gas or steam turbine through rotation (3%), tip leakage (22%), carryover (4%), nozzle profile (15%), bucket profile (15%), nozzle secondary (15%), bucket secondary (15%), root leakage (4%), and shaft packing leakage (7%). The Brush seals improved the leakage sealing than finned warren type (air-to-air labyrinth) air seals in

turbines. As it is contact type, it is to be adjusted towards efficient cooling and thereby avoiding the wear of bristle tips and their overheating. The figure 1a shows the Industrial Steam Turbine 50MW assembly, the Figure 1b shows the Industrial Gas Turbine 280MW assembly and the figure 1c illustrates the range of brush seal uses in the gas turbines.



a b c

Fig. 1. (a) 280MW Gas turbine Assembly; (b) 50MW Gas Turbine Assembly; (c) Various Size of Brush seal

This work is focuses on brush seal manufacturing in particularly fixture design for MIG welding and flowing up operations like milling drilling and finishing. That is design of special purpose machine having 5 axis individual simultaneous motions by integration of MIG welding and CNC machine to satisfy the manufacturing process of brush seal. The maximum capability of stroke length of 1.3 meters in both X and Y axis' .The Modeling of Special purpose machine is done by using CAD software and is optimized by finite element method by using CAE software to get robust design and to reduce unnecessary masses in structure. The Typical Geometric Values of Brush Seals furnished in the Table 1.

Table 1. Typical Geometric Values of Brush Seals

| **Description** | **Range of values** |
|---|---|
| Bristle length | ~15-20 mm |
| Bristle diameter | ~0.125-0.2 mm |
| Backing plate gap | 1.5-2mm |
| Number of bristles | ~100-200 Nos |
| Lay angle | ~$35^{O}$-$45^{O}$ |

## 3. Materials and Methods

In the conventional method of manufacturing brush seal includes the cut the 5 mm thick steel plate to required arc length and profile by means of wire cut EDM. Then winding of 0.025mm thick seal wire at $30^{o}$ lap angle without gap by means of automatic wire winding machine. After winding the wire to the fixture, hold the bristles in both sides of the fixture by using magnetic holder. Then insert the seal fixture in the universal fixture which will fix in both the machines. By using CNC programming cut the back side of the fixture of 3mm from reference edge of the seal fixture. Please take care about the clamping of bristle pack in cutting. Now the major role of the machine will take place after the wire cutting operation transfer the whole fixture to the special purpose machine. Here the operation is MIG welding of the fixture plate is very typical task. Initially fix the whole fixture in between of rotary tables which will rotate the fixture in a programmable angle of position on as well as rotation. Load the program which we want weld the seal as per length of the seal set all the parameters as per design. Here the material is to weld is mild steel to steel. So set all the parameters regarding this material combination. Initially set the depth of penetration and fusion area under the torch by trial and error method. Then finalize the results for further use for optimized welding. After completion of MIG welding operation check the quality of the welding if it ok without any misalignments of bristles then move to next operation. After completion of MIG welding, the job is moved to EDM wire cut for further process. Here the cutting of 0.5 till 1mm for

finishing of welding penetration in the seal and for better finishing on surface. After that check the quality of the finishing if it is ok go to the other process .if it is not again cut the material as per required finishing till 2mm. After that transfer the whole fixture on to the SPM then perform the finishing operation of brush seal. Like buffing polishing by doing live milling attachment on the SPM. The proposed fixture avoids the unloading and loading of job till it complete all operations and quality checks. Hence the setup time can be reduced significantly and the accuracy can be ensured due to single loading and unloading of job.

### 3.1 Complete Fixture

The feasibility study includes the computer aided design and analysis of universal fixture. The design and modelling were done by using Uni-graphics NX 7.5 and the Finite Element Analyses like simulating and static analysis were carried out in ANSYS 13 CAE software.

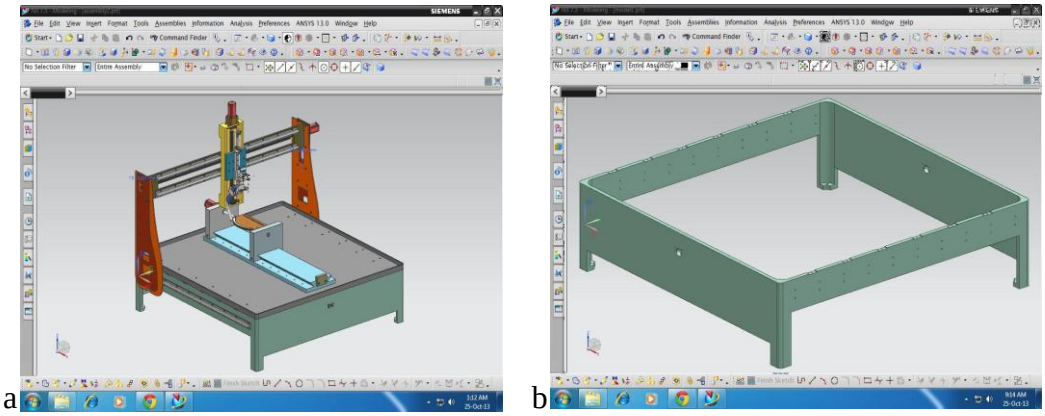


Fig. 1. Conceptual Design of (a) Universal Fixture (b) Base

Fig. 2 (a) Bed (b) Side Columns (c) Machine Head (d) Ball Screw

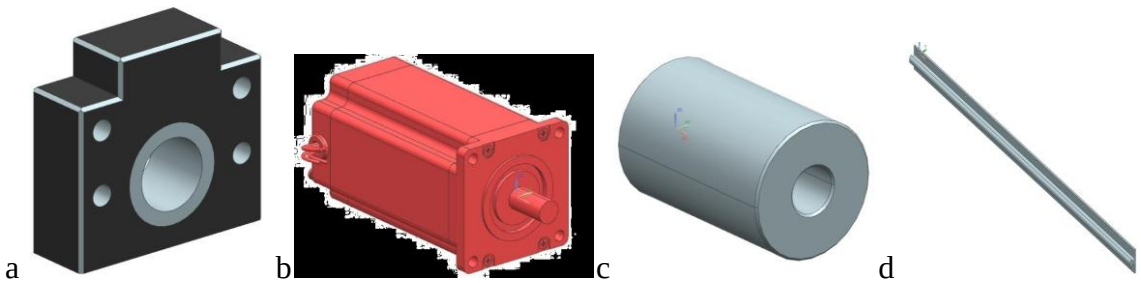


Fig. 3 (a) Bearing Housing (b) Side Columns (c) Machine Head (d) Guide ways

The requirements of universal fixture are:

- The fixture must support the manufacturing of range of brush seals
- The design includes components of fixtures like the machine structure, ball screw, nut, locknut, bearing, coupling, guide ways, fasteners, etc,.
- The design should compatible with rotary table for holding the job in angular position and rotating for perform welding and other operations comfortably.

- The Welding torch must rotate in multi degree freedom with torch holder.
- The complete setup to be fixed in Z axis.
- To proposed design of universal fixture must avoid the misalignment and increase the position accuracy at various operations.
- The proposed design of universal fixture must be cost and time effective in manufacturing of brush seals and must have minimum self weight to transfer one machine to another.

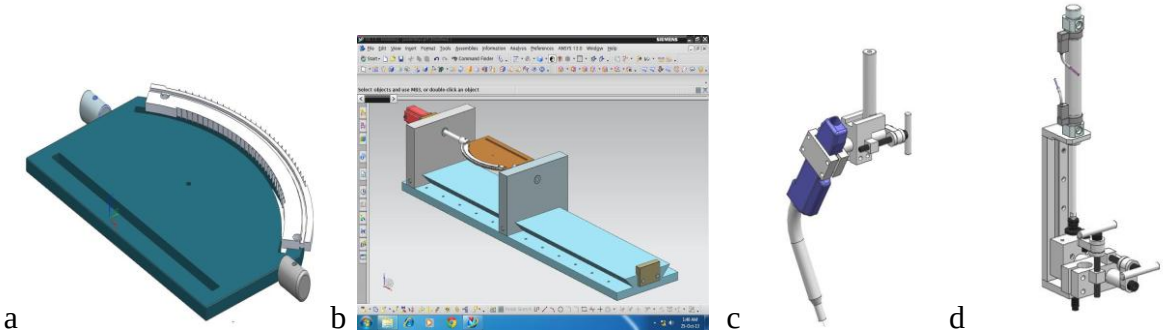



Fig. 4. (a) Rotary table; (b) Universal fixture; (c) Welding torch; (d) Drive system for torch

The conceptual view of proposed fixture, its base, bed, columns, machine head, ball screw, X and Y axis movement provisions, bearing housing, servo motor, coupling, guide ways, Rotary table, universal fixture, welding torch and drive system for welding torch shown in the Figure 1, Figure 2, Figure 3 and Figure 4 respectively. from the top left to bottom right respectively. The range of brush seal were finalized by their arc lengths for fixture design. The components which support to hold the range of brush seal jobs like (Machine structure, Ball screw 3 numbers for XYZ axes movements, Bearings, Bearing Mountings, Couplings, Linear Motion Guide ways, Locknuts, Screws, Nuts, Bolts, Side Supports, etc.,), Rotary Table, Universal Fixture, and Welding torch were designed by using NX 7.5 CAD software.

### 3.2 Weight Reduction Analysis

The each and every component carefully designed with safe consideration of materials, shape and dimensions to meet the requirements properly. As the proposed fixture to be changed from one machine to another machine, the weight is to be reduced considerably without affecting the function, safety and reliability. In the above discussed components the weight reduction can be considerably done on the base only. Hence base is considered here for weight reduction analysis. The dimensions of the base, material properties (gray cast-iron). The initial volume was 2.9576e-002 m³ and the Mass of 212.95 kg. The meshed model of initial machine base design is shown in the Figure 5(a). The Figure 5, Figure 6 and Figure 7 demonstrate the results in the order of the deformation maximum value obtained was 0.0000243750 mm. the Von mises Strain and the maximum obtained is 0.0000243640. Von mises stress the maximum obtained is 2.61 Mpa, the

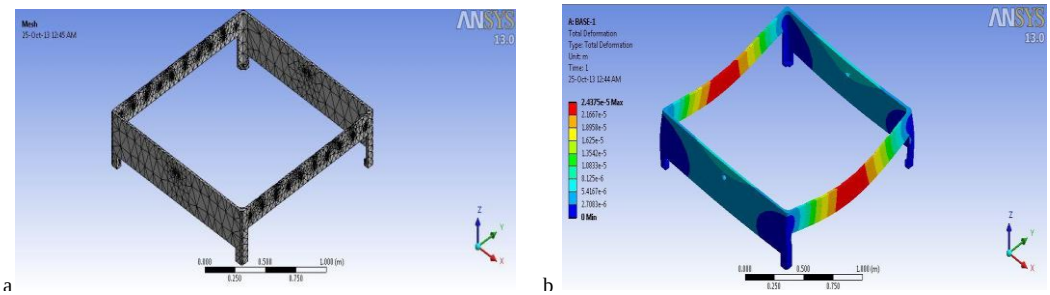



Fig. 5. Initial Machine Base Design (a) Meshed Model (b) Total Deformation

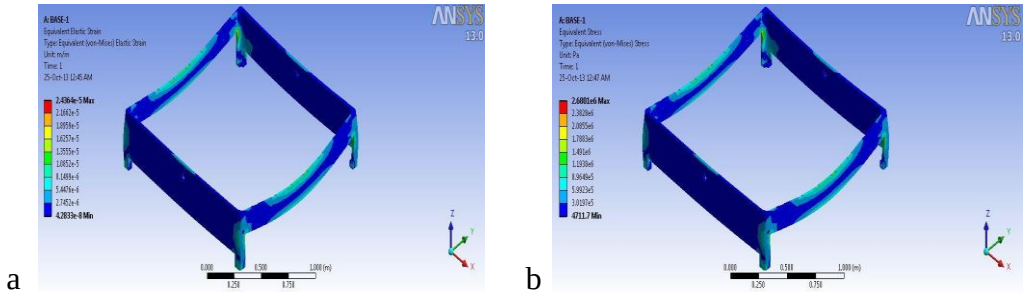


Fig. 6. Initial Machine Base Design (a) Von mises strain of (b) Von mises stress

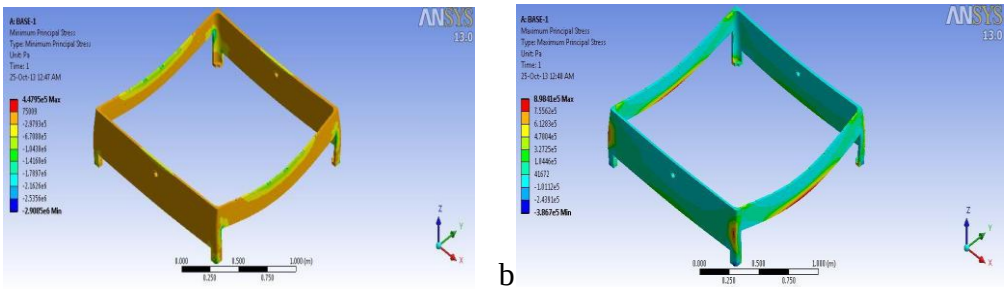


Fig. 7. Initial Machine Base Design (a) Min. Principal stress (b) Max. Principal stress

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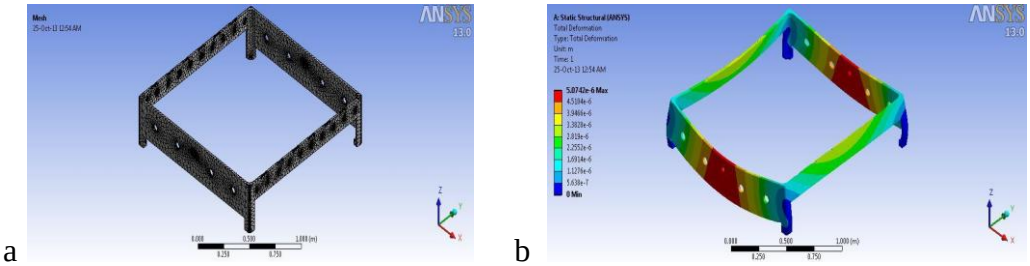

Fig. 8. Improved Machine Base Design (a) Meshed Model (b) Total Deformation

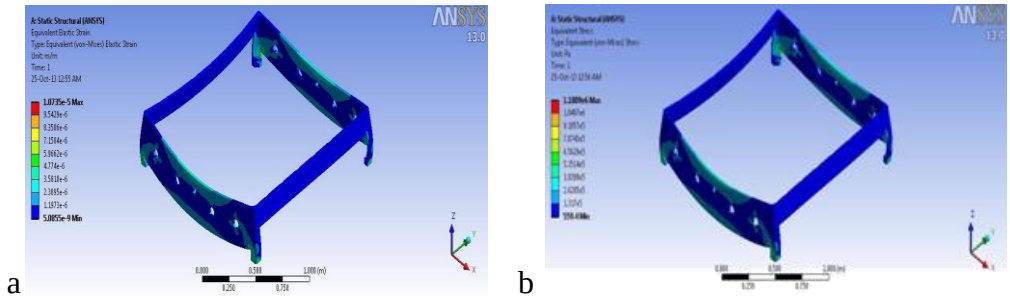

Fig. 9. Improved Base Design (a) Von mises strain of (b) Von mises stress

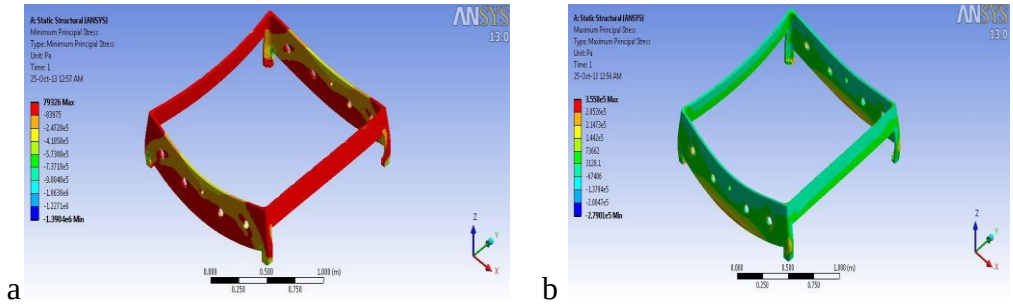

Fig. 10. Improved Base Design (a) Min. Principal stress (b) Max. Principal stress

minimum principal stress of machine base and the maximum value obtained is 0.448 Mpa. The maximum principal stress of machine base and the maximum obtained is 0.898 Mpa. The numerical analysis iterated with holes of different diameters and finally optimized the weight with safe strength and presented here the improved design. the meshed model of the improved base design is shown in the Figure 8(a). The finally reduced volume of the base is 2.9124e-002 $m^3$ and its mass 209.69 kg. The Figure 8, Figure 9 and Figure 10 demonstrate the results in the order of the total deformation of modified machine base and the maximum obtained is 0.00000507420. The von mises strain of modified machine base and the maximum obtained is 0.0000107350. The von mises stress of modified machine base and the maximum obtained is 1.18 Mpa. The minimum principal stress of modified machine base and the maximum obtained is 0.0793 Mpa. The von mises stress of machine base and the maximum obtained is 2.61 Mpa.

## 4. Results and Discussion

The frequent settings including loading and unloading of brush seal jobs for processing, inspection and for rework were eliminated by proposed universal fixture. the conceptual designs were presented part wise as well as assembled view. The numerical investigation on base for weight reduction, are consolidated in the Table 2. The allowable value for the cast iron G15 Tensile strength is 130 $N/mm^2$ and the ultimate strength is 200 $N/mm^2$ for the thickness of 20 mm which has been used in casting the machine base. The comparative results are presented in Table 2. The figure 11 illustrates the results in graphical form.

Table 2. The comparative results Initial and improved machine base design

| Description | Initial Machine Base Design | Improved Machine Base Design |
|---|---|---|
| Total Deformation in mm | 0.000024375 | 5.0742E-06 |
| VON MISES Strain | 0.000024364 | 0.000010735 |
| VON MISES Stress in Mpa | 2.61 | 1.18 |
| Minimum Principal Stress in Mpa | 0.448 | 0.0793 |
| Maximum Principal Stress in Mpa | 0.898 | 0.356 |
| Weight in kg | 212.95 | 209.69 |

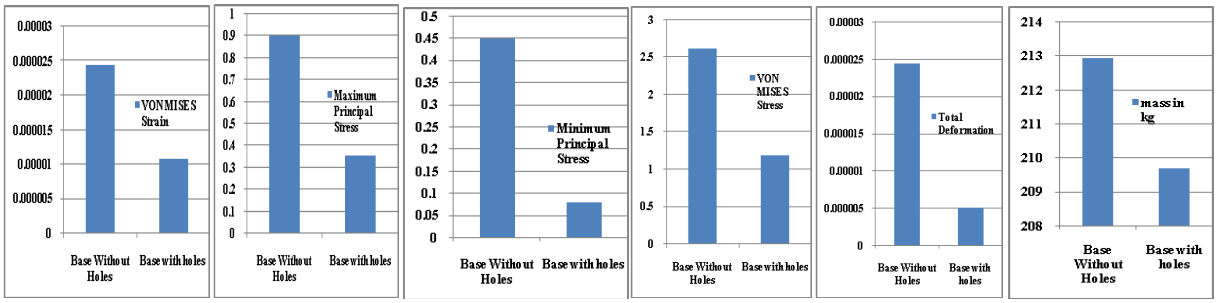


Fig. 11. Comparative Numerical results

## 5. Conclusion

The Complete fixture is designed with sufficient numerical analysis and presented for decreasing the manufacturing cycle time, increasing the accuracy, cost effective and for assuring quality and reliability in the brush seal manufacturing by completely eliminated the multiple fixing of job for machining at various machine centres, in process quality checks and reworks if necessary. The designed complete fixture is not only for particular brush seal manufacturing, but also for the range of brush seal up to 1300 mm arc length. The structural analysis iterated with various size of holes until the weight reduced with safe stress. The weight reduction achieved considerably. The weight reduction attempt also reduced the stress on the machine base considerably. Hence the proposed complete fixture can be employed with single setting of job for complete manufacturing of brush seal and it can be reconfigured for range of brush seal manufacturing.

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