STUDIES ON THE INFLUENCE OF FIXTURE AND HIGH SPEED MACHINING ON DIMENSIONAL AND GEOMETRIC DEVIATIONS OF CRITICAL THIN WALLED COMPONENTS

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Abstract: Post machining geometric distortion is the key problem in critical structural aerospace parts under the category of thin walled components**.** The redistribution of stresses induced by machining causes dimensional and geometric deviations and impacts the capacity of the components to withstand its designed loading and assembly requirements. It also leads to increased scrap volumes and problems associated with quality during assembly of components. One of the greatest challenges in the aeronautical industry is machining the component shapes from axisymmetric and prismatic bars into part features with wall and floor thickness respectively and they are very similar to sheet metal components. The present work involves the investigation of the influence of method of component holding and High Speed Machining (HSM) technology on dimensional deviations of aluminum monolithic thin walled critical cylindrical parts.

IndexTerms – High speed machining, Thin walled, monolithic components, residual stress, dimensional errors, distortion.

I. Introduction

Since aluminum alloys posses many important properties such as light weight, high strength, corrosion resistance, etc., are widely used in the aerospace applications. Minimizing the fuel consumption is one of the prime factors in the design of modern aircrafts and hence the aircraft weight plays a critical role in fuel efficiency. Supporting structural components are designed to maintain optimum weight for maximum rigidity with minimum material thickness.

During machining of thin walled components, it has been observed that there are situations where it is required to remove more than 90% of the bulk material from the billets. Machining of such thin walled components results in inducing the residual stresses at the boundary of the components**.** In addition to this bulk residual stresses which were within the material before machining will also add to the total residual stresses [1].

Zheng Zhang, et. al studied an accurate cross-sectional residual stress determination method for minimizing machining distortion. This methodology has been applied to prevent or reduce parts twisting in advance by adapting machining strategies or process conditions [1].

The manufacturing cost of the aircraft structures and aerospace components can be minimized considerably by designing and producing integral metallic structures by eliminating costly, time-consuming, multi-part manufacturing and the assembling of parts together into a finished sub assembly. These Monolithic designs are quickly substituting sheet metal and multi – part assemblies because of their excellent strength to weight ratios and reduced assembly costs. This method of design and machining of these intricate parts has eliminated thousands of hours required for mechanical assembly processes with lots of benefits [2].

The distribution of machining induced stresses can affect the component dimensional and geometrical deviation which leads to high rejection rates and quality-related problems [3] [4]. The cutting parameters in milling that have the highest influence on the dimensional changes are the depth of cut followed by width of cut [5]. The amount of deformation of a thin walled part is mainly dependent on heat and the shape of a component [6] Application of natural seasoning at reducing deformations of thin-walled elements made of aluminium alloys may prove an alternative to the difficult intermediate heat treatment [7].

The various factors that affect the distortion of the thin walled components have been presented in Fig 1. The two factors considered in the present work to study their influence on the dimensional and geometrical deviations are the type of fixture and application of high speed machining. Except these two factors all others are assumed as insignificant**.** The dimensions and geometries are validated using Co-Ordinate Measuring Machine and Ultrasonic testing gauge.

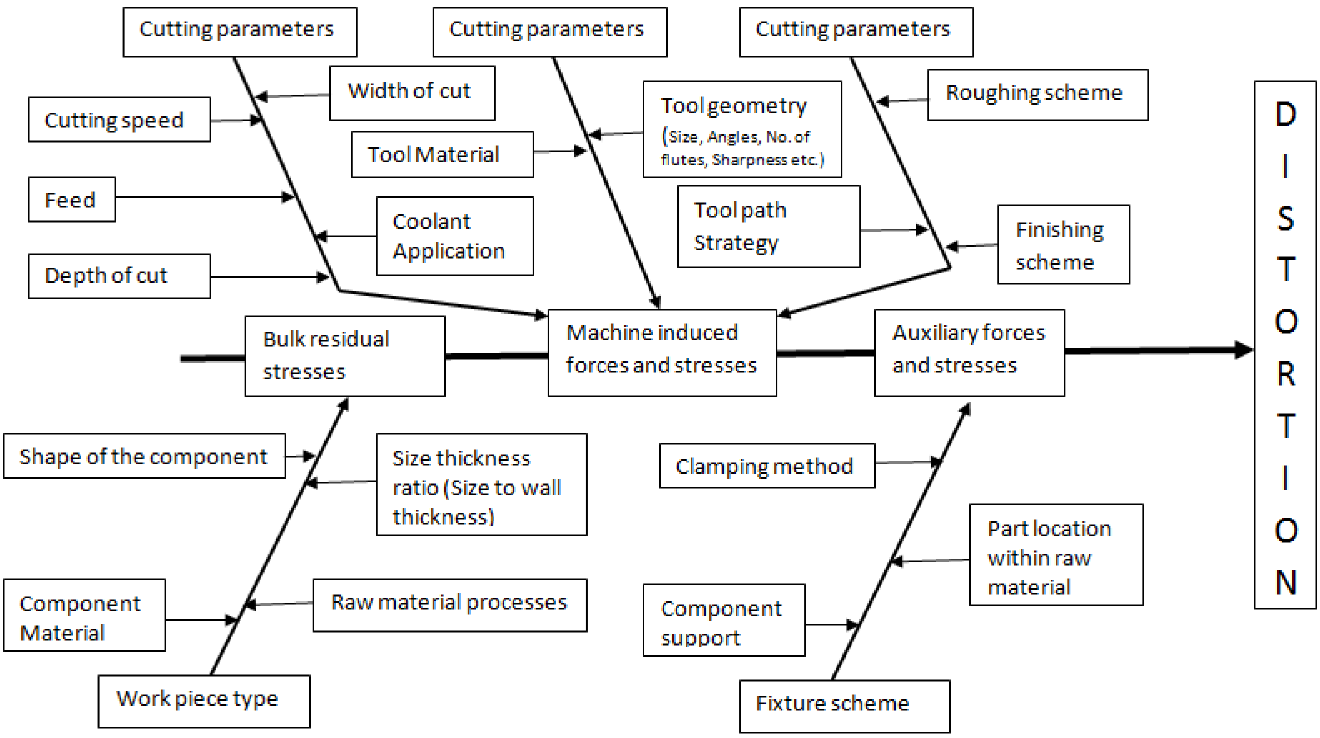

Fig: 1 Parameters affecting the distortion of thin walled components.

II. EXPERIMENTAL METHODOLOGY FOR DIMENSIONAL AND GEOMETRIC ERRORS MINIMIZATION.

The component (ring) considered in the present work has a maximum diameter of 3000mm, height of 100mm and thickness ranging from 6mm to 12mm shown in Fig 2**.**

The manufacturing method followed earlier for finish machining operation of critical thin walled rings, used eight aluminium blocks as fixture, each of these blocks are to be loaded on machine and trueing was done. Manual machining was carried out to prepare these blocks to receive the part. Part loaded for finishing operation, clamping is done at inner diameter groove and machining is carried out to maintain the height, outer diameter and flange thickness. Than clamps are changed to the flange surface and machining is carried out to maintain the inner diameters and thickness. The operation sketch for this old method is as shown in Figure 3.

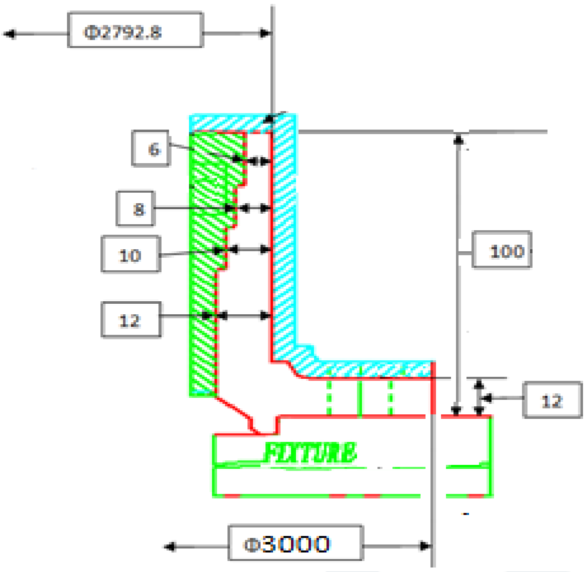

Fig: 2 Component considered for the work.

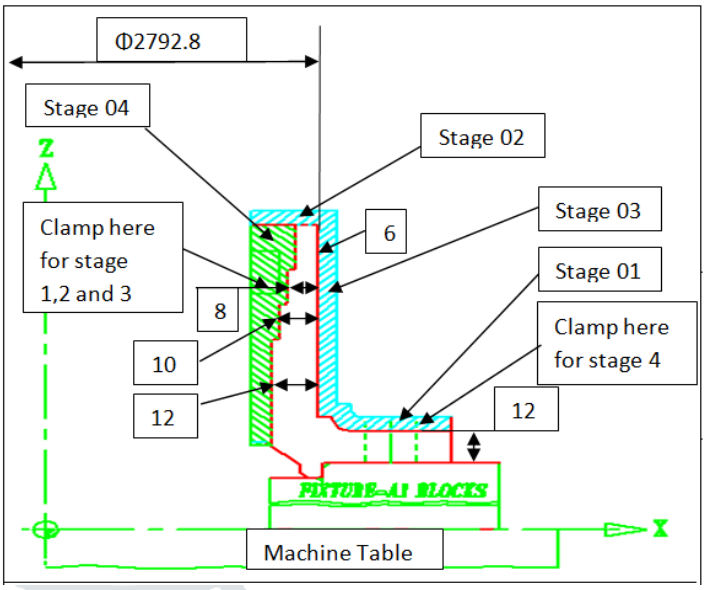

Fig: 3 Operation sketch for old method.

The test samples were fabricated from rolled AA-2014 T652 aluminium alloy bar. The chemical compositions of the alloy are shown in Table 1.

Table 1 Chemical composition of AA2014 T652

Elements	**Percentage by Weight**
Copper	3.9 to 5%
Silicon	0.5 to 1.2%
Ferrous	0.74%
Manganese	0.4 to 1.2%
Zinc	0.25%
Magnesium	0.22 to 1.8%
Titanium	0.15%
Others	0.15%
Aluminium	remaining

. The rough machining process carried out with a vertical Turn Mill COMAU 36H 3 axis turn- mill centre. After rough machining, part was kept in laboratory environment to study the natural distortion of the part. Part was kept for about two weeks and recorded daily the distortion at the top face perpendicular to the machined surface. From the recorded data it has been found that the maximum distortions noticed for first seven days after which it remained almost constant. Hence it has been suggested that all parts after rough machining are to be kept seven days for natural stress relieving. The residual stresses due to finish machining of the component are not considered as this tends to be very small.

The two methodologies considered in the present work to minimize the dimensional and geometric errors of thin walled aeronautic component are:

1. Change of fixture (M_1):
2. Change of machining operation from turning to milling (HSM) (M_2):

For methodology M_1 vertical Turn Mill COMAU 36H, 3 axis turn- mill centre and for methodology M_2 Lecreno 3 Axis Machining center is used for finish machining operation.

Cutting parameters used for machining are listed in Table: 3.

Table 3 cutting parameters for four methodologies

Sl no	Methodology	Tool Material	Cutting speed m/min	Feed mm/rev mm/min	Depth of cut mm	Spindle rev. rpm
1	M_1	Carbide	150-400	0.1-0.2	0.25-1	20-100
2	M_2		60-180	2000-3000	0.25-1	12000-15000

1. Change of fixture (M_1):

When large diameter rings (diameter ranges between 2.8m to 3.9m) are to be machined, one serious complication is maintaining the ovality of the ring as well as locating the ring material in symmetry with machine center/chuck.

Adam Patalas et. al, in their study, thin-walled part deformation during finishing turning process caused by gripping force of hydraulic lathe chuck was investigated. Bearing ring was taken as an example of thin-walled part that undergoes finishing turning operation. Finite Element Method (FEM) was used to analyze the deformation of examined part. The aim of this research was to compare the deformation of bearing ring caused by gripping force of hydraulic 3-jaw chuck and 6-jaw chuck for different values of total gripping force. Based on the obtained results, they concluded that application of 6-jaw chuck result in reduction of residual stress and hence deformation of thin-walled parts significantly [8].

L. Nowag et al, studied the effect of clamping technique on the residual stresses and distortion of bearing rings. They considered two different types of clamping mechanisms, a mandrel clamp and segmented jaws. The study showed that the uniform residual stresses were induced in the part which is supported by mandrel. When the part is supported by segmented jaws, residual stresses were induced at 3 real contact locations 120 degrees apart that results in bulging at these locations [9].

Christian Grote et. al, reported that the minimization of the radial deviation and the wall thickness deviation of bearing rings can be done by using standard clamping systems only. Three tests were conducted to minimize the form and wall thickness deviations caused by inhomogeneous material removal. In the first test, hard jaws and segmented jaws are used to clamp the test piece at outer and inner diameter respectively; intention is to minimize the form deviation. In the second test, form locking jaws and mandrels are used to clamp the test piece at outer and inner diameter respectively. The intention is to minimize the form and wall thickness deviation. In the third test form hard jaws are used to clamp the test piece both outer and inner diameter with an intention to minimize the wall thickness deviation. Results concluded that outer form deviation of rings can be minimized by using hard jaws for outer clamping and segment jaws for inner clamping, constant wall thickness of rings is possible with the use of mandrel, clamping force required for form locking jaws is less compared hard jaws, wall thickness deviation can be minimized by using hard jaws only[10].

In M_1 strategy forged ring machined to receive the part is used as fixture. A fixture ring is easier to locate due to ease of trueing comparison to the set of Aluminium blocks. Moreover, the forged ring fixture offers more rigidity to the work piece (ring) during machining, as compared to the Aluminium blocks. Even slightest chance of bending or turning is prohibited. Hence the dimensions may be obtained within acceptable tolerance limit.

Fig 4 shows the sequence of steps to be followed In M_1 strategy.

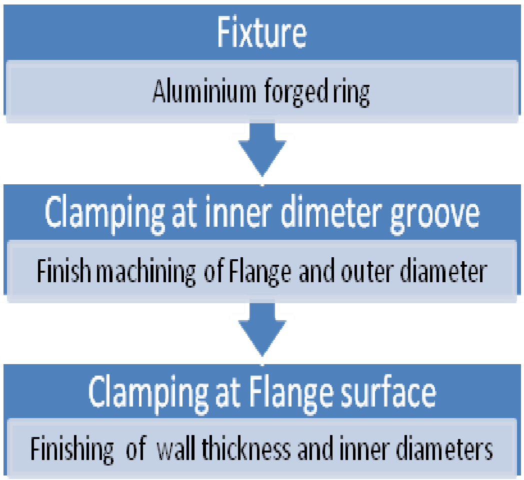

Fig: 4 Machining Procedure for Method 1

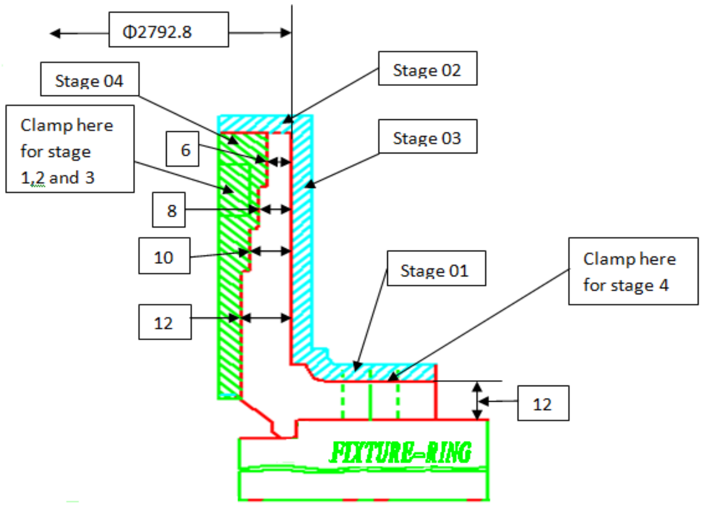

Fig: 5 Operation sketch for method 1 (M_1).

The process involved in M_1 strategy is as follows:

a) Cleaning of chuck surface and aluminium forged ring which is used as fixture and load the fixture on to machine chuck and maintain concentricity of fixture ring with machine axis within limit using dial gauge.

b) Load the part on the fixture and machining is carried out as per operation sketch (Figure 5) to maintain the dimensions and geometries.

The dimensional report of this M_1 strategy is presented in Table 2.

2 Change of machining operation from turning to milling (HSM) (M_2):

Xiaoming Huang et. al, reported that a high-speed milling experiment by means of orthogonal method with four factors was conducted for aluminium alloy AA7050-T7451. The residual stresses (RS) on the surface and subsurface of the work piece were measured using X-ray diffraction technique and electro polishing technology. It has been observed that increase of the cutting speed and decrease of the feed rate lead to significant decrease of machine- induced compressive residual stresses on AA7050-T7451 finished surface. To some extent, the analysis of the machining forces and thermal effects provides explanations for the observed residual stress transformation trends [11].

Paweł Bałon et. al, have highlighted that high speed machining (HSM) or High Speed Cutting (HSC) is currently one of the most important technology used in the aviation industry. The difference between HSM and other milling techniques is the ability to select cutting parameters such as depth of the cut, feed rate and cutting speed. At the same time it ensures high machining efficiency, high quality and precision of the machined surface. Use of high milling speed not only enables economical manufacturing of integral components by reducing machining time but also improves the quality of the machined surface. This happened due to the fact that cutting forces are significantly lower for high cutting speeds than for standard machining techniques [12].

Considering the properties of high speed cutting (HSC) and high performance cutting (HPC), HSC can be defined as machining at high cutting speeds and low machined layer cross-section values. HPC uses moderate cutting speeds at much higher axial and radial traverse (i.e. cutting depth and width values) and feed per tooth values

When machining is carried out at high speed about 12000 rpm, the cutting forces will be reduced and also duration of the tool contact with the part is minimum and hence thickness variation and ovality may get within specified limits. This is the unusual method of machining the circular ring on a rectangular bed.

Fig 6 shows the sequence of steps to be followed In M_2 strategy.

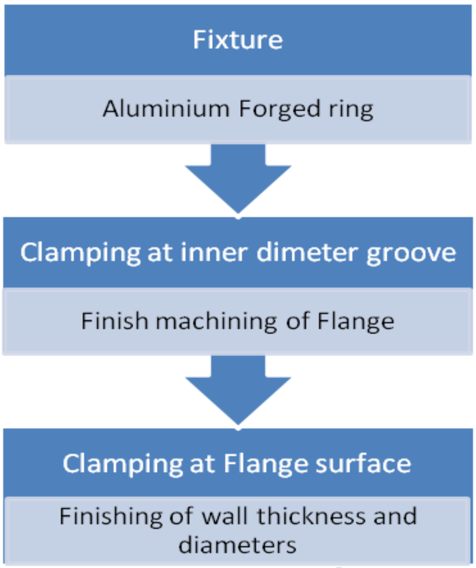

Fig: 6 machining procedure for Method 2

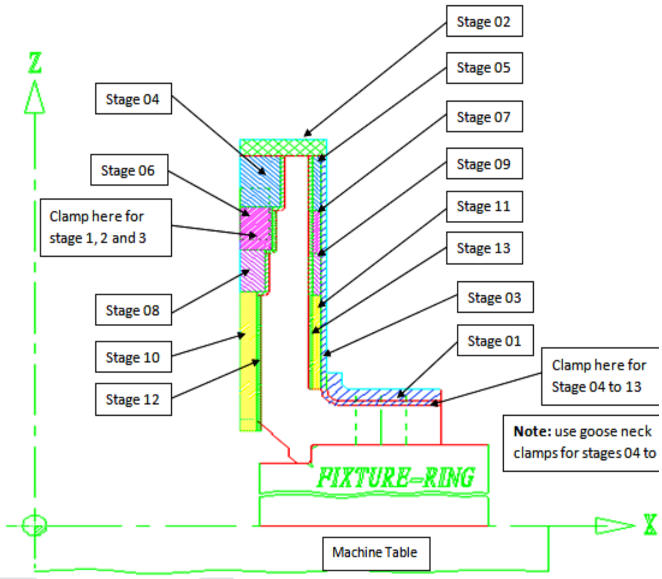

Fig: 7 Operation sketch for method 2.

The process involved in M_2 strategy is as follows:

a) Cleaning of machine table surface and aluminium forged ring which is used as fixture and load the fixture on to machine table.

b) Load the part on to fixture and machining is carried out as per operation sketch (Figure 7) to maintain the dimensions and geometries.

The dimension report of M_2 strategy is presented in Table 2.

III Evaluation of thin-walled part dimensions and geometries.

Once the machining process is completed it is necessary to validate the component as per drawing requirements. For validation LAMBDA model co-ordinate measuring machine and ultrasonic thickness measuring gauge is used. Co-ordinate measuring machine used here is a numerically controlled 3D machine.

Fig: 8 Ovality Vs Methods

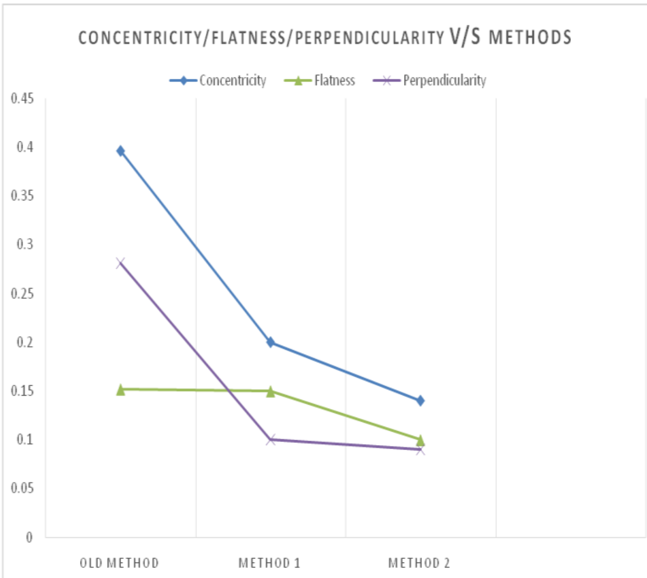

Fig: 9 Concentricity/Flatness/Perpendicularity Vs Methods

The summary of dimensional inspection reports of all four methodologies has been presented in Table2:

Table: 2 inspection report of all three methodologies:

Param NO	Nomenclature	Drawing value	Actual measurements			Remarks
			Old method	M_1	M_2	
01	Concentricity	0.2	0.396	0.2	0.14	
02	Flatness	0.3	0.152	0.15	0.10	
03	Thickness	$6^{+/-0.1}$	6.41	6.29	6.08	
04	Thickness	$8^{+/-0.2}$	8.36	8.25	8.12	
05	Thickness	$10^{+/-0.2}$	10.31	10.20	10.10	
06	Thickness	$12^{+/-0.2}$	12.35	12.20	12.10	
07	Perpendicularity	0.3	0.281	0.1	0.09	
08	Diameter 2795 ovality as per 3D report	0.2	0.846	0.35	0.18	
09	Diameter 2783 ovality as per 3D report	0.2	0.851	0.38	0.16	
10	Diameter 2792.8 ovality as per 3D report.	0.2	0.758	0.29	0.15	
11	Diameter 2860 ovality as per 3D report	0.2	0.854	0.32	0.10	

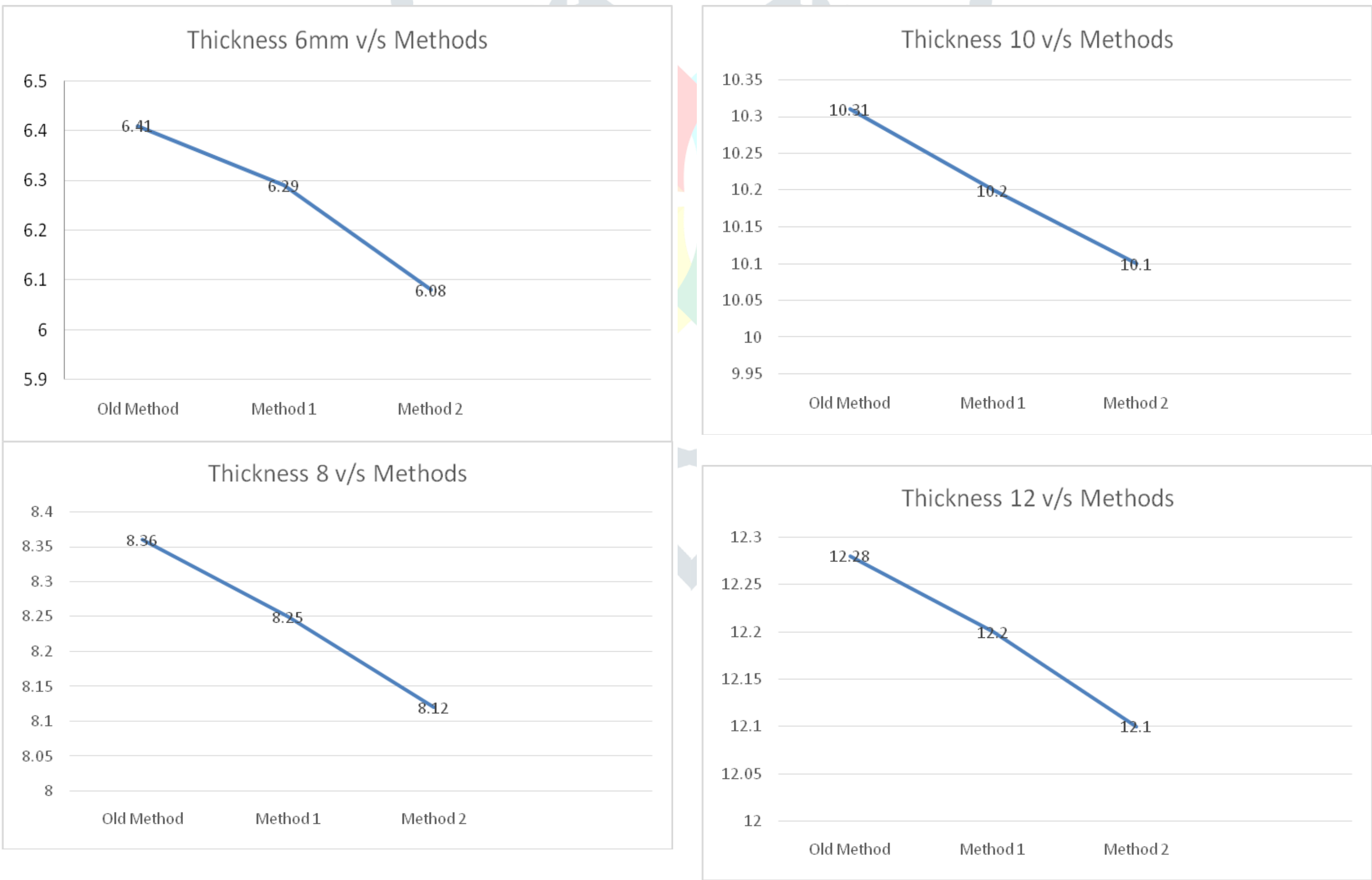

Fig: 10 Thickness vs. methods

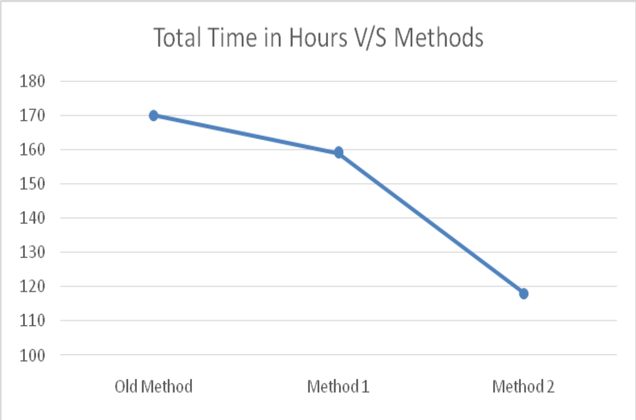

Fig: 11 Total time vs Methods

IV. RESULTS:

The dimensional test results were analyzed for both change of fixture (M_1) and change of machining operation from turning to milling (HSM) (M_2) methodologies and compared with old method of machining the thin walled ring.

Summary of Inspection report of all three (including old method) methodologies are provided in Table 2.

From inspection reports of change of fixture method (M_1), the concentricity reduced from 0.396mm to 0.2mm, flatness reduced from 0.152mm to 0.15mm, thickness variation reduced to 6.29mm, 8.25mm, 10.20mm and 12.20mm, perpendicularity reduced from 0.281mm to 0.1mm. Diameter 2795mm ovality reduced from 0.846mm to 0.35mm, Diameter 2783mm ovality reduced from 0.851mm to 0.38mm, Diameter 2792.8mm ovality reduced from 0.758mm to 0.29mm, Diameter 2860mm ovality reduced from 0.854mm to 0.32mm. Total machining time is reduced from170 hours to 158 hours 56 minutes.

From inspection reports of change of machining operation from turning to high speed milling method (M_2), the concentricity reduced from 0.396mm to 0.14mm, flatness reduced from 0.152mm to 0.10mm, thickness variation reduced to 6.08mm, 8.12mm, 10.10mm and 12.10mm, perpendicularity reduced from 0.281mm to 0.09mm. Diameter 2795mm ovality reduced from 0.846mm to 0.18mm, Diameter 2783mm ovality reduced from 0.851mm to 0.16mm, Diameter 2792.8mm ovality reduced from 0.758mm to 0.15mm, Diameter 2860mm ovality reduced from 0.854mm to 0.10mm. Total machining time is reduced from170 hours to 118 hours 08 minutes.

Table 2 shows the summary of dimensional and geometric deviations of two components machined from two methodologies. The obtained results from method1 (M_1) revealed that all parameters except 6mm thickness, 8mm thickness and ovality are within limit specified in the drawing, and from method 2 (M_2) revealed that all parameters are within limit specified in the drawing. Further analyzed that the total machining time is minimum for second (M_2) methodology.

V. CONCLUSION:

From the present investigation, concluded that:

- From the analysis it can be concluded that both fixture and High speed machining technology have significant effects on the dimensions and geometries of the thin walled components.
- From the summary of inspection report of the components produced from methodologies one and two, all dimensions and geometries were well within the drawing specified limits for second methodology (M_2) where in the component is held using aluminium forged ring as fixture and machined using HSM technology. In other words the cutting forces effects significantly on dimensional and geometrical deviations of thin walled components compared to fixture.
- From the results it can also be concluded that the total machining time required for producing the thin walled ring is reduced to 158 hours 56 minutes for first methodology (M_1) and 118 hours 08 minutes for second methodology (M_2) from 170hours.

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