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A Study on Application of Ecological Engineering Principles to Design a Green Methodology for Machining an Intricate Part with Thin Ends

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Abstract

Ecological engineering is a new field with its roots in the science of ecology, it uses ecology and engineering to predict, design, construct or restore, and manage ecosystems that integrate human society with its natural environment for the benefit of both. This paper is meant to serve as a bridge between ecologists and engineers. It reports a developmental approach in the application of CNC-machining for the rapid manufacturing process based on principles of engineering ecology. The purpose of this paper is to design a green methodology for machining parameters to be used for machining an intricate part which can significantly reduce pollution and is therefore to the benefit of environment and ecosystem. The present study also calculates the maximum values of force, feed, velocity and power required for machining an intricate part with thin ends with SSF as a fixture using CNC-RP machining. Practical implementation of principles of engineering ecology to design parameters is used for machining an intricate part with thin ends with SSF using CNC-RP process only in industries.

Keywords: ecological engineering, CNC-Machining, design, deflection

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INTRODUCTION

The engineering profession is now in the position to make a substantial contribution to the "greening" of the planet through ideas such as ecological engineering. In this retrospective period of human history, it is important to determine, without necessarily questioning all that has been built and engineered to date, (1) whether to continue practices as usual (and whether we can afford to do so), and (2) what new approaches are available to engineers for restoring the "bodily functions" of nature on which we depend. Many signs indicate that a shift is taking place both within and outside the engineering profession to accommodate ecological approaches to what was formerly done through rigid engineering and a general avoidance of any reliance on natural systems. For example, engineers, resource managers, and ecologists are rethinking whether to restore the upper Mississippi River levees to their state before the 1993 floods or to take a more ecologically friendly approach. The U.S. Army Corps of Engineers is now "greening" and some in that organization see themselves as the nation's ecological engineers. Agricultural engineers, known for the efficiency with which they drained the landscape, are retooling in many locations to rebuild wetlands. The Kissimmee River in Florida is being "restored"--at enormous cost--to something resembling its former self before it was straightened 20 years ago.

Ecological engineering, defined as the design of sustainable ecosystems that integrate human society with its natural environment for the benefit of both, has developed over the last 30 years, and rapidly over the last 10 years. Its goals include the restoration of ecosystems that have been substantially disturbed by human activities and the development of new sustainable ecosystems that have both human and ecological values. It is especially needed as conventional energy sources diminish and amplification of nature's ecosystem services is needed even more. Mitsch and Jorgensen [3] summarized five basic concepts that differentiate ecological engineering from other approaches to addressing problems to benefit society and nature: 1) it is based on the self-designing capacity of ecosystems; 2) it can be the field (or acid) test of ecological theories; 3)

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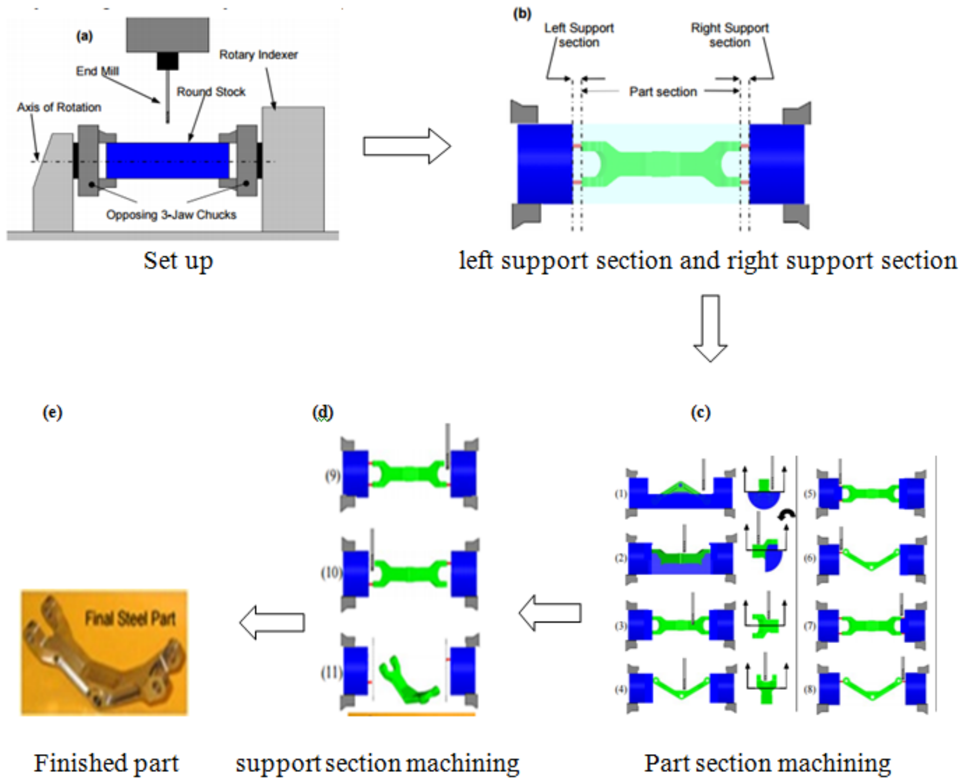


Fig. 1. Generalized standard process for the development and fabrication of SSF design

it relies on system approaches; 4) it conserves non-renewable energy sources; and 5) it supports ecosystem and biological conservation.

Basic purpose of fixtures is to give support to the part during machining and preserve environment. Traditional fixturing system consists of devices such as vices, v -blocks, clams and modular plates etc. required a great deal of time, money and technical skill for its making. Moreover these fixturing devices lack the flexibility to hold the intricate parts. Ecological engineering researchers worked on the continuous improvement in the fixture design begin in 1994 to improve the various factors of fixturing system. Researcher's works to make the machining process rapid for rapid prototyping processes in subtractive manufacturing. Some existing methods such as modular, phase change fixturing and dedicated are more suitable for large batches and mass production. These methods required more investment cost and set up time. The research for completely subtractive or hybrid process (additive/subtractive) RP system was done but each has had to confront the problem related to flexibility of fixture to support and hold the intricate part shape (Barroqueiro et al. 2016).

Computer numerical control rapid prototyping (CNC-RP) combines the CNC machining with RP methodologies to create a functional intricate part in low volume using verity of material in an automated manner. CNC-RP is a subtractive rapid prototyping process. For making CNC machining a rapid prototyping process extra fourth axis of rotation is provided using indexer so that the tool can remove the material in all direction simultaneously by milling and turning. Rapid planning and rapid tooling are important factors to make CNC machining a CNC-RP process (Boonsuk and Frank 2009, Al-Jiffri and Alsharif 2017).

Sacrificial support fixture (SSF) is very realistic method of fixturing and should be used for small batches of parts, rapid prototyping with CNC machining and parts with irregular shapes by doing ecological study of the process. Research study analyzes the use of ecological engineering method as a function of the number of parts to be produced, the number of features on the part, the ratio material removed to the final part volume and basic part geometry. CNC-RP uses fourth axis of rotation and SSF is implemented as a small feature at the ends of intricate part which are created parallel to the axis of rotation of part during machining as shown in **Fig. 1**. In CNC-RP instead of adding material to the intricate part, the sacrificial supports are added to the CAD model before tool path planning and consequently created along with other intricate part feature during machining. Machining of various parts such as alignment block, femur bone and bike suspension part was done using cylindrical SSF only. They did not study the force analysis or experimental study of machining parameters such as forces for CNC-RP process. Forces they used are based on the power requirement of the cutting tool generated by material removal rate and the unit horsepower.

The main advantage of using SSF as a fixture for CNC-RP is to support ecosystem and hold the moderately intricate part during rapid machining, improved the accuracy of part, reduces machining time and saves the cost of complicating fixturing. New concept of rapid planning on computer numerical control (CNC) machining is presented by (Wang et al. 2014). They developed the concept of SSF environmental design for CNC machining. They used $2^{1/2}$–D tool paths orientation about the axis of rotation and the concept of visibility of part using fourth axis CNC machining. They investigated that the part with complex geometries that is visible about the axis of rotation can be machined and even simple part which is not visible about the axis of rotation cannot be machined using fourth axis CNC machining. They concluded that SSF design greatly reduced the cost in short production runs or batch processing of the part. Research work on CNC fourth axis planning was done to provide complete surface coverage while machining a part on CNC. Researchers worked on the issues such as multiple setup operations and stock material management. They investigated an algorithm to improve the efficiency, and reliability of multiple layers based removal steps for rapid machining. Osman et al. and Suresh Kumar et al. studied and investigated that surface finish of the machined part is a function of the cutting tool to be used in CNC-RP machining. The flat and ball nose end mills can be used for better surface finish through rapid machining. Chattering of end milling tool during machining was studied by using finite element analysis modeling and stability analysis of chatter in end milling machining.

Frank (2007) proposed a process planning for rapid CNC machining in the application of rapid manufacturing. They developed intricate coding and connected it with CAD software. They built an intricate program for building a machining of all kinds of parts to reduce process planning time and process planning complexity. By using SSF and intricate program they fabricated many parts such as femur bone, toothbrush stick, propeller, Earphone and prop mount. Frank et al. (2004) investigated that the capability of CNC machining for rapid machining operation will improve by using dissimilar end mill tools for finishing. They introduced new layer removal methodology using indexing device to clamp the work piece and using SSF to hold the part for rapid machining. Frank et al. investigated the machine set up planning, SSF design and tool path planning using advance geometric algorithm and interface it with CAD/CAM to allow automatic NC code generation directly from CAD model.

To determine the environmental process parameters, finite element analysis (FEA) is widely used and recognized as a one of the powerful tool. FEA study and literature review for finite element analysis is done for checking the effect of the bending and torsional deflection produced in a machining of part using SSF as a fixture for CNC-RP machining.

Genesis of the Problem and Novelty of the Study

In order to create the physical prototype from 3D model of intricate part using CNC- RP part is rotated about the axis of rotation until all the surfaces of the part are machined by milling and turning simultaneously. By using conventional fixturing techniques such as vises, clams and v blocks it is very difficult for an intricate part to rotate about the axis of rotation. Multiple manual set up is required to hold the intricate part while machining using traditional fixturing so this prohibits an approach of CNC-RP to be considering as rapid machining technique (Frank et al. 2006, Kahveci et al. 2017).

In the previous research work SSF used as a fixture are cylindrical in shape and used for CNC-RP processes only i.e. CNC machining having axis of rotation only. SSF can be used for providing a completely automatic rapid machining system, and it is exceedingly flexible in securing a vast array of intricate parts with little human intervention or skill. The generalized methodology of machining of intricate part with SSF and its impact on environment using CNC-RP is shown in **Fig. 1** (Munoz and Sheng 1995). Cylindrical shape supports are robust in design, easy of placement and are having deflection within allowable limit. Several researchers' works on CNC-RP machining for improving the process efficiency by considering the various parameters of the CNC-RP process while machining intricate part using SSF as a fixture. Rapid planning and rapid tooling, SSF design, CNC-RP machining economics study by machining several parts all these studies done by researchers to improve the CNC-RP machining process to machine intricate parts. However, there is still good opportunity left for performance improvement of CNC-RP machining for machining a part using SSF as a fixture.

During machining of part using CNC-RP the accuracy of a final finished part is dependent on the machining parameters to be set to the machine. During CNC-RP machining bending and torsional deflections occurs in a part. As the designed SSF are small structure created parallel to the axis of rotation of part during CNC-RP machining, it will not tolerate the force and other machining parameters value which are used for traditional CNC-machining. During machining if the values of machining parameters are not set properly it will leads to the vibration and bending of part during CNC-RP machining as we are using SSF as a fixture to hold the part during machining. During machining a part using SSF as a fixture allowable limit of deflection produce in a part during CNC-RP machining is dependent on the machining parameters to be set during machining. In previous research work force and other machining parameters used for CNC-RP machining of part using SSF was not studied and was used as per power requirements of the cutting tool generate by material removal rate and unit horsepower. Machining a part with SSF as a fixture using four axis CNC-RP machining required albeit comparatively small forces compared to traditional machining. Petrzelka and Matthew (2010) studied the design of SSF as a fixture but did not performed any finite element analysis and experimental work particularly for machining parameters such as force, feed, velocity and power required for machining a part with SSF as a fixture using CNC-RP.

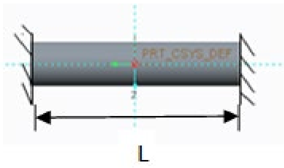
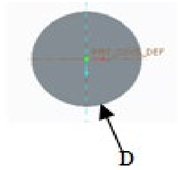
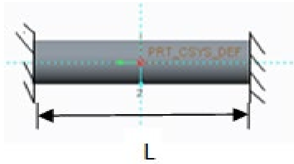
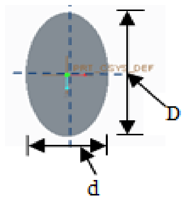
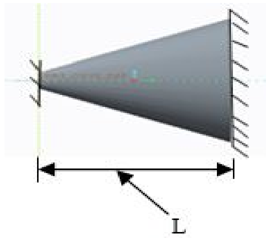
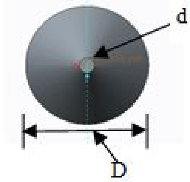
So this study focuses on the static structural analysis of machining parameters such as force, feed, velocity and power required for machining a part with SSF as fixture as a function of deflection produced in a part during CNC-RP machining. In this paper finite element analysis (FEA) study is done by taking different iterations of forces and feed for different shapes of SSF so as to get the deflection and normal stresses produced in a part is within allowable limit. Corresponding to that force and feed values having deflection and normal stresses within allowable limit power required for CNC-RP machining is calculated. Case study of medical part such as hip joint for permissible deflection and normal stresses is done using FEA by taking different iterations of force and feed values. To date, we have determined the values of machining parameters such as force, feed, velocity and power required for machining a part using different shape of SSF as a fixture using CNC-RP so as to get the deflection and normal stresses produced in a part within allowable limit. This paper presents an approach to solve the complex problem of machine parameters study such as force, feed, velocity and power values so as to get the deflections and normal stresses produced in a part via SSF as a fixture using CNC-RP machining within the allowable limit with the help of finite element analysis. The challenge is that the investigated values of force, feed, velocity and power used during CNC-RP machining should not produce too high bending or vibration in part (Osman Zahid et al. 2014a).

The implementation section will describe the case study of proposed method by creating an SSF design for intricate medical part with thin ends such as hip bone. Hip joint part having thin ends using stainless steel 316 L material is being machined using CNC-RP. The dimension of the part is (149.95mm*47.089mm*16.68mm). This paper covers the fallowing major areas to determine the force, feed, velocity and power values for different shapes of SSF designed for intricate parts with thin ends. At first different shapes of SSF intended for part with thin ends are design and validated with result of literature furthermore simulated computationally using Ansys 14.0 software. Then static structural analysis using Ansys 14.0 software will be performed for the performance evaluation of the validated SSF design that are created at the ends of hip joint part for different iterations of machining parameters such as force, feed, velocity and power so as to get deflection and normal stresses within allowable limit. For getting more insights into the machining of hip joint part with SSF as a fixture, effect of variation of different values of forces, feed, velocity and corresponding to that power required are investigated. Finally the significance of the proposed static structural analysis of machining parameters intended for machining of modified SSF design created at the end of hip joint part is highlighted by comparing its performance against that with the existing well performed model already machined using cylindrical SSF as a fixture for allowable deflection limit and corresponding normal stresses reported in a literature (Osman Zahid et al. 2014b).

DESIGN CONSIDERATION OF THE PROPOSED SACRIFICIAL SUPPORT STRUCTURE

In previous research work design parameters such as length, shape, size, and number of supports and location of supports were studied for cylindrical shape supports only intended for parts with thick ends. In this paper two more different shapes of SSF are designed intended for part with thin ends using CNC –RP machining based on the existing literature work as shown in **Table**

Table 1. Different shapes of sacrificial support fixture

Sr. No	Shape of SSF	Front view	Top View
1	Cylindrical SSF		
2	Elliptical SSF		
3	Tapered SSF		

1. Design of SSF should be rigid enough so that it can tolerate the forces and vibrations acting on it while CNC-RP machining. Finding optimal solution for support design is very difficult since by varying the one parameter of support have effect on the other parameters. For example varying the size i.e. diameter of support will have its effect on the length of support. From theory of machine deflection produce in a beam is a function of length and diameter of beam. The length and diameter of the beam depend upon the shape of the beam and part diameter. The design parameters of the support will vary according to the shape of supports. So here we did the optimization of the shape and design parameters intended for parts with thin ends and found out the best optimized shape and design parameters for SSF with minimum bending and torsional deflection using static structural analysis as shown in **Table 2** (Spitler et al. 2003). Meshing of the SSF is done using Ansys 14.0 software. Supports are fixed at both the ends and force of 22N was applied at the center of the support considering it as a fixed end beam model. The radius of the supports are kept constant and varying the length of support by taking different iterations of length to radius ratio and found out the deflection and normal stress produced at the middle of the supports such that it is less than 0.025mm as per benchmark study. The bending and torsional deflection produced in SSF during CNC-RP machining using finite element analysis (FEA) should be less than 0.025mm as per benchmark study and our calculated length to radius ratio (L/R) for different shape of SSF as shown in **Table 2** is below 0.025mm. The static structural analysis results of the novel designed SSF are validated with the previous work done by frank in 2007 in designing of SSF where it is found out that the bending and torsional deflection using static structural analysis of our designed SSF intended for part within thin ends for CNC-RP machining are less than 0.025mm so the results are validated as shown in **Fig. 1**. The results of the static structural analysis of the our designed SSF are shown in **Table 2** shows the selected values of the different designed parameters for cylindrical, elliptical and tapered SSF respectively. From the bar graph shown in **Fig. 2** it is clear that the tapered support having minimum values of bending deflection and little higher value of torsional deflection compared to cylindrical support. Elliptical support having high value of bending and torsional deflection compared to cylindrical and tapered SSF. So tapered support are preferred as a SSF for machining a part with thin ends using CNC-RP machining as cylindrical support cannot be used because it requires higher surface area to be located at the end of the part so cylindrical supports are best suited for machining a part having thick ends using CNC-RP.

Table 2. Design parameters of the different shapes of sacrificial support fixture

Sr. No	Shape of SSF	L/R ratio for temporary support	L/R ratio for permanent support	Length of support (mm)	Radius of support (mm)	Part diameter (x) and support radius (y) relation (mm)	Part diameter (x) and support length (y) relation (mm)
1	Cylindrical temporary	12	6	51.25	4.125	y=0.25x-0.5	y=1.5x-3
2	Cylindrical permanent	12	6	16.2	2.7	y=0.25x-0.5	y=1.5x-3
3	Elliptical	12	6	13.5	2.25	y=0.25x-0.5	y=1.5x-3
4	Tapered with 30 degree	12	6	10.47	1.748	y=0.25x-0.5	y=1.5x-3

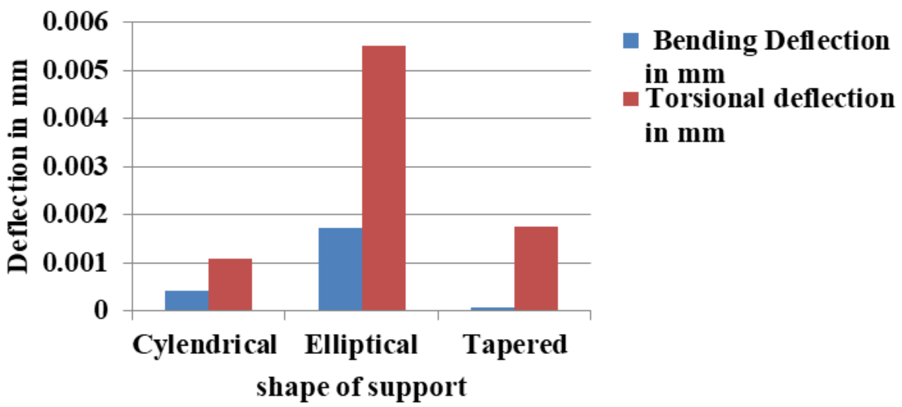


Fig. 2. Static structural analysis results and comparison of bending and torsional deflection for L/R ratio of six for different shapes of sacrificial support structure

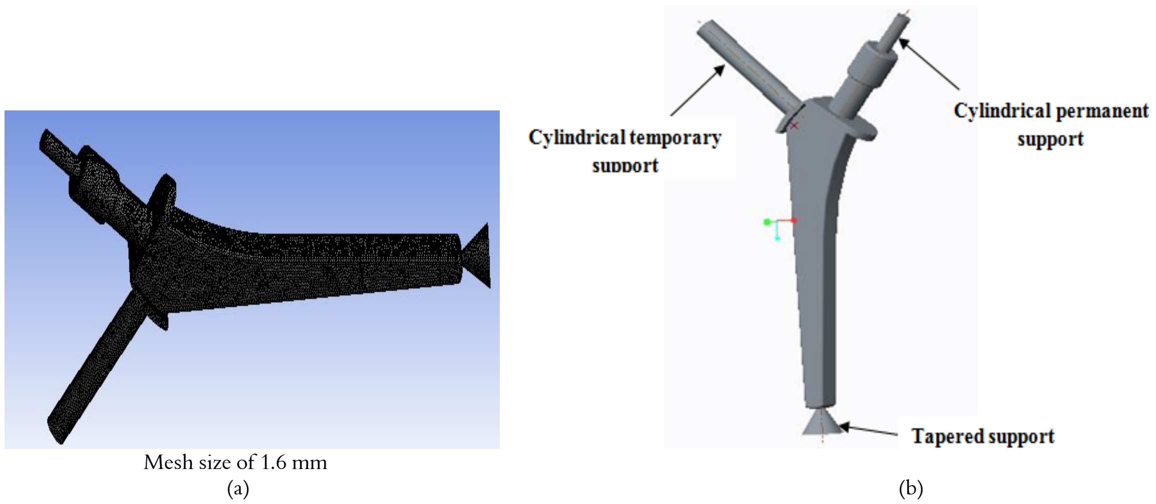


Fig. 3. Hip joint parts with (a) meshing and (b) with combination of cylindrical and tapered supports

COMPUTATIONAL MODELING

Three dimensional (3D) model of hip joint using designed SSF are created using creo-parametric software as shown in **Fig. 3b**. 3D model of various parts using cylindrical SSF are created by Frank et al. (2002) and validated with the experimental result. The proposed novel design consists of the hip joint part with combination different shapes of the SSF designed to hold the part with thin ends during CNC-RP machining as shown in **Fig. 2**. The model has a length of 172mm, width of 89mm and thickness of 17mm. The maximum deflection was set to 0.0012728 mm; resulting in diameter of permanent cylindrical support to be calculated as 5.4mm and length of 16.2mm, diameter of temporary cylindrical support to be calculated as 8.25mm and length of 51.25mm and diameter of tapered support to be calculated as 3.496mm with the taper of 30 degrees at the rear end having diameter as 9.54mm and length of 10.47mm respectively. The supports are created at the center of ends of the parts. The 3D model of part is created using Pro-E software and then support are created at the part ends as per the designed parameters. The supports are created automatically by implementing the designed methodology using C^{++} and chooks within the Master CAM CAD/CAM software. The developed model has

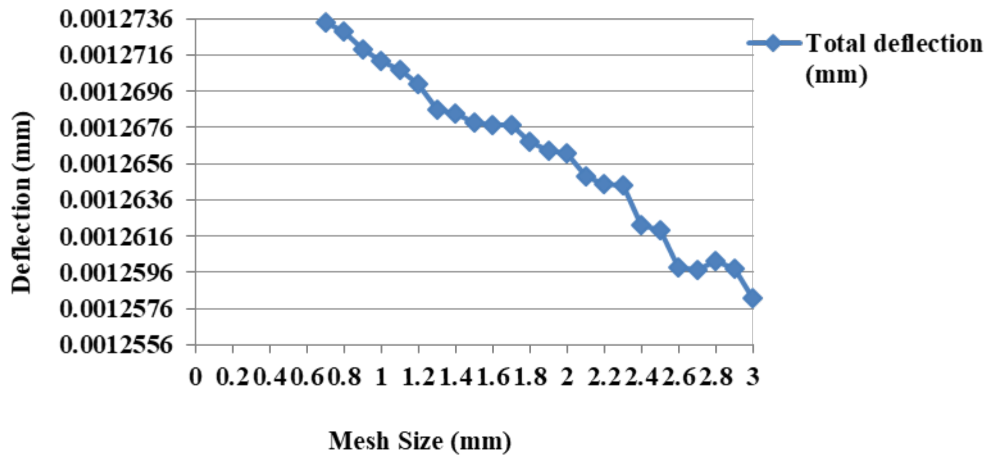


Fig. 4. Mesh size verses deflection graph

been now forwarded to the solver in Ansys. 14 software and mesh generation is carried out using mush Ansys 14.0 software with mesh size of 0.8mm as shown in **Fig. 3a**. The number of iterations is taken for the getting confined mesh with mesh size varying between the 0.7-3 mm with the increment of 0.1mm as shown in **Fig. 4**. It found that mesh size of 1.6- 1.7mm is same values of deflection produced in hip joint part. Hence using triangular mesh with mesh size of 1.6 mm giving more confined mesh. Computational conditions used for the static structural analysis of hip joint part using SSF are given below (McBrearty et al. 2004, Wang and Wang 2013).

Material used- Stainless Steel 316L

Density = 8,000 Kg/m^3

Modulus of elasticity = 1.93*10^9 Pa

Poisson's ratio = 0.25

Tensile yield strength = 205*10^6 Pa

Tensile ultimate strength = 515* 10^6 Pa

Mesh size = 0.3

Force=22

MACHINING PARAMETERS STUDY USING STATIC STRUCTURAL ANALYSIS

Performance of CNC-RP for machining an intricate part with thin ends with SSF as a fixture can be improved by calculating the maximum values of machining parameters such as force (F), feed (f) and power (P) required so as to get the bending and torsional deflection within allowable limit. Force required for machining is a directly a function of length as shown in Eq. (3) and varies inversely with time as shown in Eq. (2). This means as the force values increases the time required for machining decreases.

$$F=M*A \quad (1)$$
$$F=M*(V/t) \quad (2)$$
$$F=M*(x/t^2) \quad (3)$$

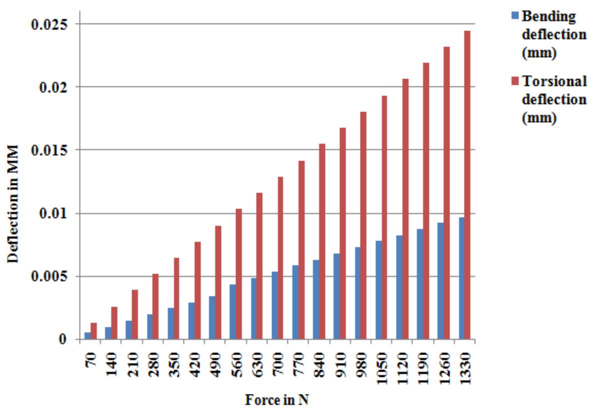
where A=V/t and V=x/t
where M is a mass in kg, A is acceleration due to gravity in (meter/sec^2) and V is velocity in (meter/ sec).

During machining process according to the theory of machine for fixed end beam two different types of deflection occurs in a fixed end beam i.e. deflection due to bending (Y_b) and deflection due to torsion (θ_t) shown in Eq. (4) and (5) respectively. Deflection produced in part during machining is directly proportional to force acting on it. From the Eq. (4) and (5) it is directly shown that as the force and torque acting on the part during CNC-RP machining increases, bending and torsional deflection increases respectively. So to machine an intricate part with SSF as a fixture without bending or torsional deflection during CNC-RP machining required the fixed amount of force, feed, velocity and power. For calculating the fixed force range for machining intricate part with SSF as a fixture using CNC-RP we used static structural analysis.

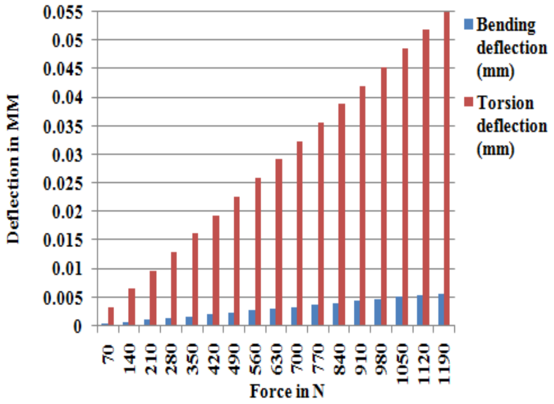
$$Y_b= (F*L^3)/(192*E*I) \quad (4)$$
$$\theta_t= (T*L)/(4*J*G) \quad (5)$$

where, I= (π*D^4)/64, T= F*L and J = (π*D^4)/32.

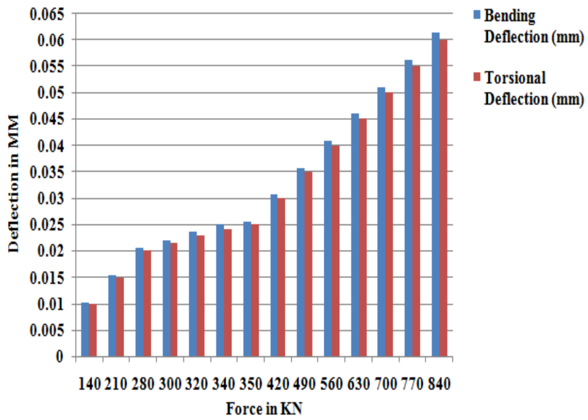
T is torque applied due to force F in (N), L is length in (mm), J is polar moment of inertia in (m^4) and G is modulus of rigidity in (Pa), D is diameter of the beam in (mm), E is modulus of elasticity in (Pa) and I is



(a) Cylindrical



(b) Elliptical



(c) Tapered

Fig. 5. Static structural analysis results of force verses deflection for (a) cylindrical support (b) elliptical support (c) tapered support

moment of inertia in (kg-m^2) (Osman Zahid et al. 2015).

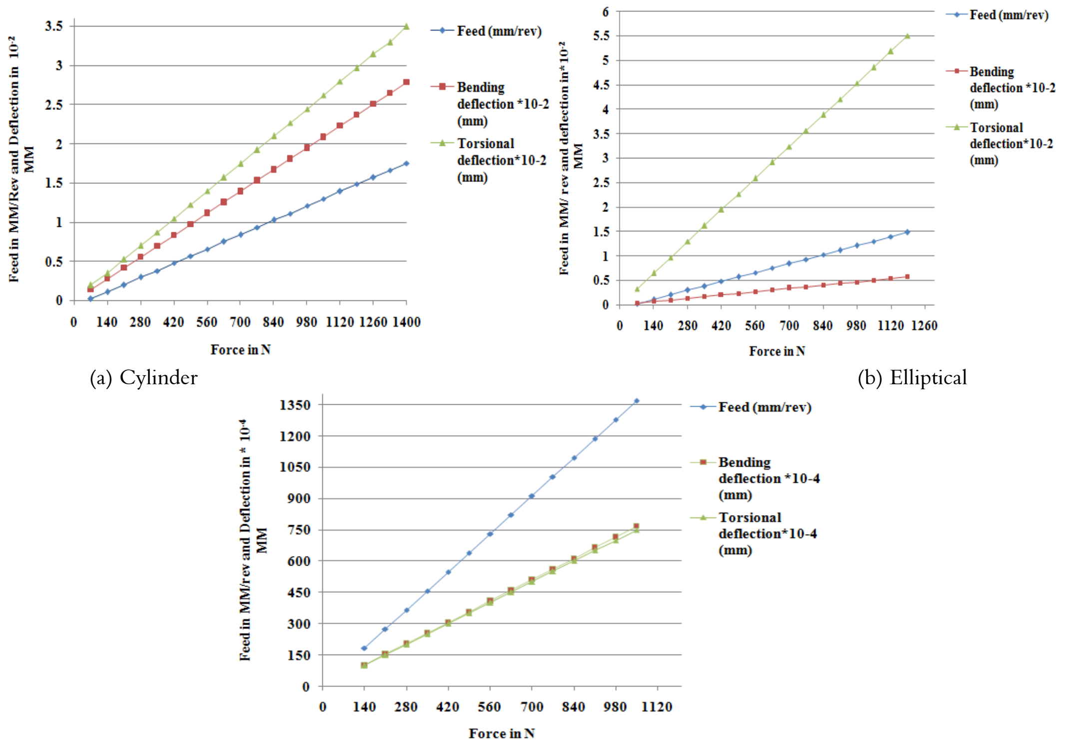
RESULT AND DISCUSSIONS

Effect of Force on Deflections Produced in a Part with Sacrificial Support Structure using CNC-RP Machining

First we will calculate the force values for cylindrical, elliptical and tapered support using static structural analysis by using computational conditional as discuss in Section 3 for allowable deflections values. Mesh size of 1.6 mm is used for meshing using Ansys 14.0 software. Both ends of the support kept fixed and considering it as a fixed end beam model. For calculating the force values using static structure analysis for cylindrical, elliptical and tapered support length to radius ratio of six for permanent support and twelve for temporary support are kept constant for them respectively. Now taking number of different iterations by applying different values of forces at the middle of different shapes of support so as to get the bending and torsional deflection produced in a support using static structural analysis is below 0.025mm. The results of static structural analysis as shown in **Fig. 5**, it is found that the forces in the range of 420N-980N, 210N-490N and 140KN- 340KN for cylindrical, elliptical and tapered support respectively having bending deflection values as 0.019482mm, 0.0023487mm and 0.025071mm and torsional deflection values as 0.024438mm, 0.022668mm and 0.024928mm respectively as shown in **Fig. 5a**-**5c** which is less than 0.025mm. So from the given static structural analysis results it is concluded that the forces in the ranges of 420N- 980N, 210N-490N and 140KN-340KN are used for cylindrical, elliptical and tapered support respectively for machining using CNC-RP as the forces in said range produces bending and torsional deflection less than 0.025mm.

Effect of Feed on Deflection Produced in a Part with Sacrificial Support Fixture using CNC-RP Machining

Earlier literature work done by Wang et al. (2014) researchers found out the relation between the cutting



(a) Cylinder (b) Elliptical

(c) Tapered

Fig. 6. Static structural analysis results of force and feed verses deflection for (a) cylindrical support (b) elliptical support (c) tapered support

force and feed for the dry turning of AISI 316L stainless steel using coated carbide tool. The same relation is applied for the machining of part with SSF made with stainless steel 316L using CNC-RP machining as given by Eq. (6). Using the same relation, we have calculated the allowable feed values for the corresponding values of force using finite element analysis and plotted a graph for the different values of feed for corresponding different values of forces verses deflection for cylindrical, elliptical and tapered support structure as shown in **Figs. 6a-6c**.

$$F_c = 51.38+766.75f \qquad (6)$$

where F_c is cutting force in (N) and fis feed in (mm/rev).

From the graph as shown in **Fig. 6** it is directly shown that the force and feed have the linear relationship. The feed values corresponding to the force range of 420N-980N, 210N- 490N and 140KN-340KN for cylindrical, elliptical and tapered support are 0.48mm/rev-1.21mm/rev, 0.2mm/rev-0.57mm/rev and 182.521mm/rev-456.404mm/rev. respectively. These values of feed in mm/rev corresponding to the forces values which we have calculated using static structural analysis will have deflection values produced in a part using CNC-RP machining is less than or equal to 0.025mm. As per the earlier research work done by the researcher the maximum allowable deflection to be produced in a part was set to 0.025mm so our calculated values of forces for different shapes of SSF using static structural analysis and feed calculated corresponding to that forces values is having deflection produced in a part is less than or equal to 0.025mm as shown in **Fig. 6a-6c** (Tong et al. 2003).

Velocity and Power to be Calculated for Machining a Hip Joint Part with Sacrificial Support Structure using CNC-RP for Allowable Deflection Limit

Scheider (1997) worked on the machining parameters effect in the dry turning of AISI 316L stainless steel using coated carbide tools for CNC machining and derive the relation between the power, velocity and feed. Power required during CNC machining depends upon the cutting speed, and feed. In an earlier section we have calculated the feed values corresponding to the force values so as to get the deflection produced in SSF during CNC-RP machining is less than or equal to 0.025mm. Currently we are using the cutting speed ranging from 500 m/min-670m/min and feed of 0.48 mm/rev from the selected feed range as discussed in section 5.2. As we use the cutting speed less than 500m/min results in a very less power required. The relation between the power in

Table 3. Power needed for the machining of sacrificial support fixture using CNC-RP machining for different values of cutting speed and constant feed

Sr. No	Feed (*f*) in mm/rev	Cutting speed (V_c) in m/min	Power in KW
1	0.48	500	29.26
2	0.48	530	168.2
3	0.48	570	354.26
4	0.48	600	493
5	0.48	640	679
6	0.48	670	764.5

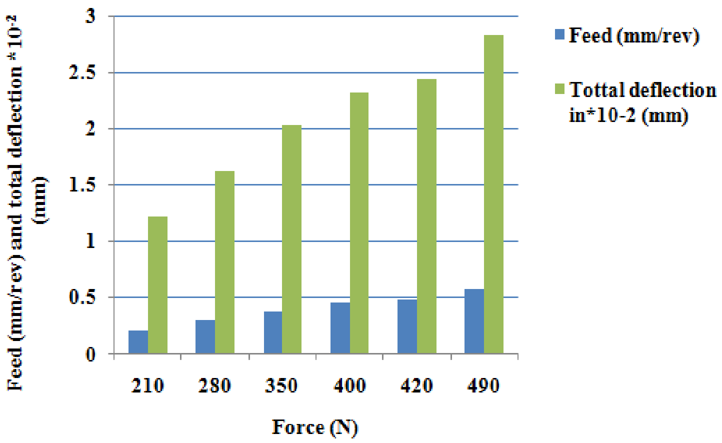


Fig. 7. Results of static structure analysis of different iterations of forces and feed values for deflection produced in a hip joint part sacrificial support structure

(KW), cutting speed (V_c) in (m/meter) and feed (f) in (mm/rev) is given by Eq. (7). Power is calculated by using a feed value of 0.48mm/rev and cutting velocity in the range of 500 m/min- 670 m/min respectively as shown in **Table 3**. So selecting a cutting velocity of 500 m/min and feed of 0.48 mm/min because it will result in a minimum power requirement of 29.26 KW as shown in **Table 3** for machining a SSF using CNC-RP.

$$\text{Power} = -0.382+4.65*10^{-3}*V_c+10.94*f-31.10*f^2 \quad (7)$$

Validation of Machining Parameters by Machining Hip Joint Part with Sacrificial Support Structure and Comparing the Results with the Benchmark Literature Work

Hip joint part having thin ends with designed SSF as a fixture is machined using CNC-RP as shown in **Fig. 3b**. The model has a length of 172mm, width of 89mm and thickness of 17mm. The important design parameters required for the design of SSF are discussed in Section 2 and the computational parameters required for the static structural analysis of the hip joint part with SSF are discussed in Section 3. The meshing of the hip joint part is done using Ansys 14.0 software with mesh size of 1.6 mm as shown in **Fig. 3a**. For static structural analysis one end of hip joint part with cylindrical SSF's are fixed inside the indexer and the other end with tapered SSF is fixed in tailstock during CNC-RP machining. So we are considering the hip joint part with both ends fixed on the indexer and tailstock respectively as an indeterminate fixed end beam model. Using static structural analysis we applied a force at the middle of the part with supports fixed at both the ends. From the Section 5.1 we calculated the force range for different shapes of SSF so here we set the minimum values of force limit as 210 N and maximum value of force limit as 490 N for the machining the hip joint part with SSF as fixture so as to get the total deflection produced in a part using static structural analysis will be below 0.025mm. From the graph shown in **Fig. 7** it is clear that the after applying a force of 210N at the middle of part and using a feed of 0.2mm/rev the maximum total deflection produced in a part using static structural analysis is 0.01215 mm and normal stress corresponding to this deflection is 39.772N as shown in **Fig. 8**. After applying a force of 420N and feed of 0.48mm/ rev the maximum total deflection and normal stress produced in a hip joint part using static structural analysis is 0.0243mm and 79.545Mpa respectively as shown in **Fig. 9** which is below the standard allowable deflection value set by the benchmark design of part machining with SSF as a fixture. If we use the force value of 490N and feed of 0.57 mm/rev results in a maximum total deflection of 0.028349mm as shown in **Table 4** which is greater than the benchmark study which will result in a vibration and bending of part during CNC-RP

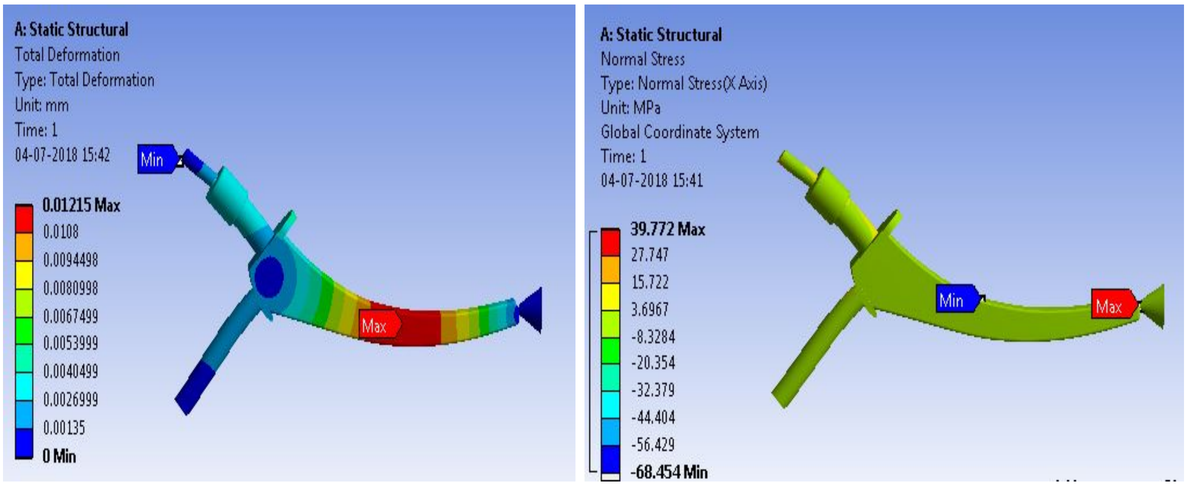


Fig. 8. Static structural analysis results of total deflection and normal stresses produced in a hip joint part with SSF after applying a force of 210N and feed of 0.2mm/rev

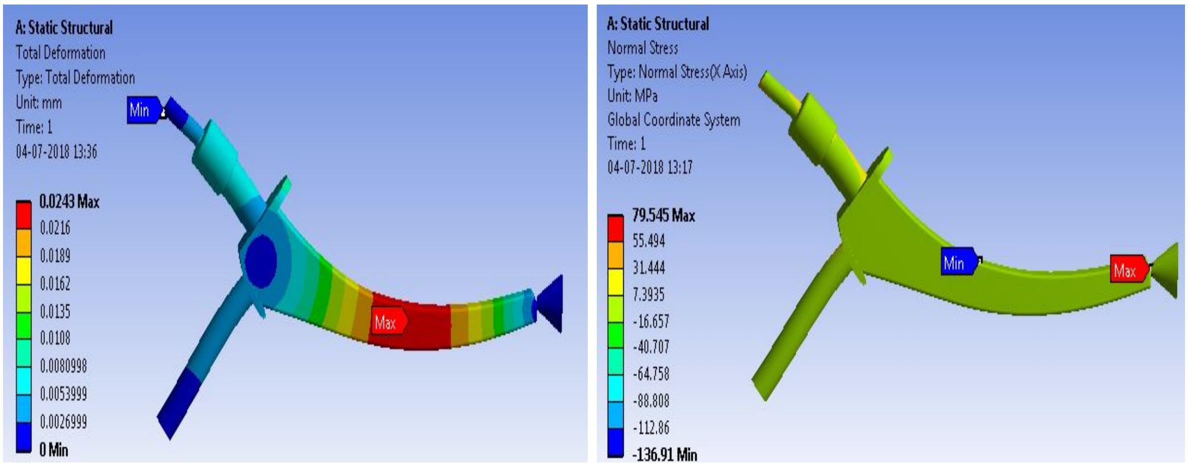


Fig. 9. Static structural analysis results of total deflection and normal stresses produced in a hip joint part with SSF after applying a force of 420N and feed of 0.48mm/rev

Table 4. Static structural analysis results of forces and feed values for total deflection and normal stresses produced in a hip joint part with sacrificial support structure

Sr. No	Force (N)	Feed (mm/rev)	Total deflection (mm)	Normal stresses (Mpa)
3	210	0.2	0.01215	39.772
4	280	0.3	0.0162	53.03
5	350	0.38	0.02025	66.287
6	400	0.45	0.023142	75.757
7	420	0.48	0.0243	79.545
8	490	0.57	0.028349	92.802

machining. So we investigated that from the current static structural analysis of the machining parameters study for machining of hip joint part with SSF as a fixture using CNC-RP that the force in the range of 210N-420N, feed in the range of 0.2 mm/rev-0.48mm/rev, cutting velocity of 500 m/min gives better results and produces total deflection in part using SSF as a fixture is less than 0.025mm and with the very less power requirement of 29.26kw as shown in **Table 3**.

CONCLUSIONS

In this work, firstly based on principles of ecological engineering the effect of machining parameters on the three different types of SSF which are used as fixture for machining a part via CNC-RP using static structure analysis have been analyzed and the results are discussed. Then effect of green machining parameters method on the new innovating method for machining a hip joint part with different shapes of SSF using CNC-RP using static structure analysis with Ansys 14.0 software are discussed. Based on the discussion on obtained results, the following conclusions are drawn (Wang et al. 2014).

- Deflection produced in a part during machining is directly proportional to the forces applied on it during machining. Forces applied should be such that it produces the allowable deflection in part within tolerance limit so as to get the distortion free final part. From the result of discussion, it is concluded that the forces required for machining of cylindrical, elliptical and tapered SSF are in the range of 420N-980N, 210N- 490N and 140KN- 340KN respectively to get the bending and torsional deflection produced in a part is below 0.025mm.

- Feed range corresponding to the force range of 420N-980N, 210N- 490N and 140KN- 340KN for machining cylindrical, elliptical and tapered SSF are 0.48mm/rev-1.21mm/rev, 0.2mm/rev-0.57mm/rev and 182.521mm/rev-456.404mm/rev respectively results in a deflection below 0.025mm.

- Minimum value of force required for machining a hip joint part with SSF is 210N, feed 0.2mm/rev results in a total deflection and normal stress of 0.01215mm and 39.772Mpa respectively. Maximum amount of force required for machining a hip joint part with SSF is 420 N, feed 0.48mm/rev results in a total deflection and normal stress of 0.0243mm and 92.802Mpa respectively.

- Cutting velocity of 500m/min and feed of 0.48 mm/rev results in the requirement of minimum value of power of 29.26 KW and cutting velocity 670m/min and feed of 0.48mm/rev results in the requirement maximum value of power of 764.5 KW for machining a hip joint part with SSF for CNC-RP machining.

- The validation of the studied machining parameters such as force, feed and cutting velocity was done by doing a static structural analysis of hip joint part with SSF as a fixture and comparing the results with the benchmark study for allowable deflection limit shows that the investigated machining parameters gives better result.

- Machining of hip joint part with SSF using designed machining parameters of force 420N, feed 0.48mm/rev, cutting velocity 500m/min results in minimum power requirement of 29.26KW and results in a reduction in time of machining with deflection and normal stress of 0.0243mm and 39.772 Mpa produced in a part which is below the allowable tolerance limit of deflection i.e. 0.025mm set by benchmark study for CNC-RP machining of part.

- Reduction in time required for fixture planning and fabrication of traditional fixturing methods by using designed SSF for CNC-RP machining which significantly reduces pollution.

Thus, it can be inferred that the innovating machining parameter study for machining a part using SSF as a fixture for CNC-RP machining proposed in the present work can well be used for real life industrial four axis CNC machining applications.

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