Evaluation of Metal Cutting Forces using Tool Holder Developed by Rapid Prototyping Technique-SLS

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Abstract:- The purpose of this research is to utilize selective laser technique Rapid Prototyping Technique for developing a Machine tool holder which was used in metal cutting during turning operation. In the present work an attempt has been made to develop the tool holder for holding the turning tool and evaluate the metal cutting forces during machining. The Selective Laser Sintering(SLS) are the most utilized technique in the development of tool holder and the forces from the dynamometer shows the little variation in using the RPT tool holder and can be used effectively. SLS is a sintering process in which designed parts are built up layer by layer from the bottom up using different powder materials. A laser beam scans the powder bed fills in the each layer's CAD-image by heating the selected powder pattern to fuse it. The CAD Model was developed using SOLIDWORKS and then the prototype developed using SLS and was tested on a conventional Lathe machine and evaluated the metal cutting forces using dynamometer, the results have been compared with conventional tool holder with same machining parameters in turning operation, It has beenobserved that there is a little variation in the forces obtained from the tool holder developed through RPT technique and from the experimental results it can concluded that the RPT tool holder can be used in place of conventional tool holder so that rigidity of the tool can be improved under same machining parameters.

Keywords: **Turning Tool Holder, RPT Technique, Selective Laser Technique.**

I. INTRODUCTION

Rapid Prototyping (RP) can be defined as a group of techniques used to quickly fabricate a scale model of a part or assembly using three-dimensional computer aided design (CAD) data. What is commonly considered to be the first RP technique, Stereo lithography, was developed by 3D Systems of Valencia, CA, USA. The company was founded in 1986, and since then, a number of different RP techniques have become available. Rapid Prototyping has also been referred to as solid free-form manufacturing; computer automated manufacturing, and layered manufacturing. RP has obvious use as a vehicle for visualization.When the RP material is suitable, highly convoluted shapes (including parts nested within parts) can be produced because of the nature of RP. There is a multitude of experimental RP methodologies either in development or used by small groups of individuals. This section will focus on RP techniques that are currently commercially available, including Stereo lithography (SLA), Selective Laser Sintering (SLS®), Laminated Object Manufacturing (LOM™), Fused Deposition Modeling (FDM), 3D printing, and Ink Jet printing techniques. The reasons of Rapid Prototyping are (1) To increase effective communication. (2) To decrease development time.(3) To decrease costly mistakes.(4)To minimize sustaining engineering changes. (5) To extend product lifetime by adding necessary features and eliminating redundant features early in the design. Rapid Prototyping decreases development time by allowing corrections to a product to be made early in the process. The ultimate advantage of RP processes is the production of complex mechanical geometries with minimal lead time and no part-specific tooling. A major motivating factor in the development of RP processes has been the reduction in product development time. Therefore, the build time of RP processes is a major concern. Build time in RP processes consists of three major components: preprocessing, fabrication, and post processing. Preprocessing involves the conversion of CAD solid models into the control data needed to operate RP machine tools. Post processing involves manual, labor-intensive part cleaning and finishing of the part after the automated fabrication cycle. Because RP processes involve a high degree of automation, computer planning and control software is essential to their operation. Planning software is needed to generate control data from CAD geometric data during preprocessing. This function is generally handled by specialized CAM software unique to each RP process. Typically, information regarding the geometry of the part is fed to the planning software in the form of stereo lithography files. STL files are faceted solid representations of the part generated by tessellation, that is, representation of the part surface as an interconnected network of triangles for the purpose of reducing the electronic file size. The STL format is the default standard for the RP industry, having been developed for the first RP process, stereo lithography (SL), in the late 1980s.All major CAD solid-modeling packages allows solid models to be exported in STL format. The planning software essentially slices the tessellated solid representations into a series of cross-sectional layers on the order of 0.004 in. (0.10 mm) thick. These slices are reduced to a series of tool paths used to guide the selective deposition of energy or materials used to pattern each layer in the process. The process control software then uses these slices to operate the RP machine tool. Process control is handled differently for different processes and equipment.

II. LITERATURE REVIEW

There are several good places to begin surveying the literature of rapid prototyping. Review articles include one by Conley and Marcus and earlier ones by Kruth, Au and Wright. Burns provides an extended overview of the field, describing current processes an applications as well as some related topics. An earlier overview is provided by Kochan, this work revolves around descriptions of available machines and the processes they use. From a research perspective, some of the most interesting works are those which describe the development of particular processes - particularly noteworthy are the books by Jacobs. While he does describe other processes, he focuses on the evolution of Stereo lithography, with which he was closely involved. These two books describe the incremental process improvements which have improved accuracy and created new applications. The latest monograph on rapid prototyping, focusing more on the Selective Laser Sintering process, was written by Beaman. Its second chapter has the most complete comparison of development and release dates for commercial and research systems.The Rapid Prototyping Journal began recently, but rapid prototyping papers have appeared in a wide variety of journals, and will continue to do so. Almost all of these rapid prototyping machines make parts from polymer materials, although the processes involved vary widely. To begin constructing a part, a thin layer of part material powder is spread over a platform and then levelled by a roller. A laser then draws the first layer of the part, fusing powder particles together. This sequence is cyclically repeated to build an entire part. The part is built within an environmental chamber which maintains a temperature just below the glass-transition temperature or the melting point of the part material.

III. SELECTIVE LASER TECHNIQUE

The implementation shown is used by 3D Systems and some foreign manufacturers. A moveable table, or elevator (A), initially is placed at a position just below the surface of a vat (B) filled with liquid photopolymer resin (C). This material has the property that when light of the correct color strikes it, it turns from a liquid to a solid. The most common photopolymer materials used require an ultraviolet light, but resins that work with visible light are also utilized. The system is sealed to prevent the escape of fumes from the resin.A laser beam is moved over the surface of the liquid photopolymer to trace the geometry of the cross-section of the object. This causes the liquid to harden in areas where the laser strikes. The laser beam is moved in the X-Y directions by a scanner system (D). These are fast and highly controllable motors which drive mirrors and are guided by information from the CAD data.

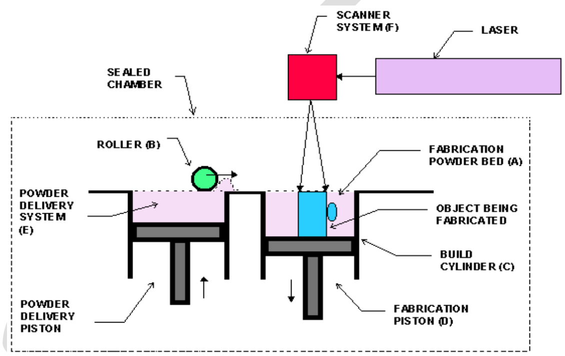


Fig 1: Selective Laser Sintering

After the layer is completely traced and for the most part hardened by the beam, the table is lowered into the vat a distance equal to the thickness of a layer. The resin is generally quite viscous, however. To speed this process of recoating, early stereo lithography systems drew a knife edge (E) over the surface to smooth it. More recently pump-driven recoating systems have been utilized. The tracing and recoating steps are repeated until the object is completely fabricated and sits on the table within the vat. In this case, however, a laser beam is traced over the surface of a tightly compacted powder made of thermoplastic material (A). The powder is spread by a roller (B) over the surface of a build cylinder (C). A piston (D) moves down one object layer thickness to accommodate the layer of powder. The power supply system (E) is similar in function to the build cylinder. It also comprises a cylinder and piston. The piston moves upward incrementally to supply powder for the process. Heat from the laser melts the powder where it strikes under guidance of the scanner system (F). The CO_2 laser used provides a concentrated infrared heating beam. The entire fabrication chamber is sealed and maintained at a temperature just below the melting point of the plastic powder. Thus, heat from the laser need only elevate the temperature slightly to cause sintering, greatly speeding the process. A nitrogen atmosphere is also maintained in the fabrication chamber which prevents the possibility of explosion in the handling of large quantities of powder. After the object is fully formed, the piston is raised to elevate the object.

IV. MAGIC'S RP

Magic's RP software can import most standard 3D formats - STL, VDA, IGES, STEP, VRML - and native CAD formats like UG/Para solid and Catia. Growing numbers of customers also work with scanned data. To meet their needs, Magic's offers the import and export of point clouds. The imported files are converted to a digital CAD structure according to user defined accuracy. The conversion process includes correction of common errors. The resulting STL file is ready to produce prototypes or tools without the need for further conversion. Magic's RP is a must for every RP service bureau. You can't afford to lose time in conversion. Neither can your clients. Magic's RP allows you to get right to work on a file with a very high triangulation quality. Materialize has developed a compression format called MGX. MGX shrinks an STL to about 1/20 of its original size. The MGX format thus saves space and speeds up distribution, download and transfer of STL files. With Magic's, you can easily zip STL files and unzip MGX files. Magic's give you full control over your STL files. You are provided with a wide variety of features to interact directly on the STL files.

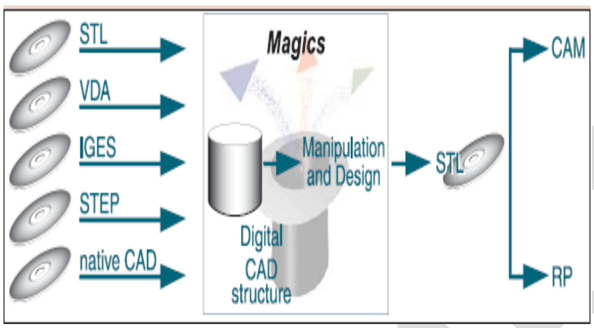


Fig 2: Overview of Magic's – RP.

In Magic's you can open stl files and Mgx files (AMgx file a compressed stl file. It was developed for the Magic's Communicator Software to allow easy sending over the internet). With the conversion software, you can import files that are not stl or Mgx files. Magic's RP offers the opportunity to import iges, VDA, CatiaV4, CatiaV5, UG/Para solid, Step, point clouds, Pro-E, VRML and DXF. DXF (only 3D faces) and PLY/ZCP can be imported in Magic's Base. For all the other file types, extra software is needed. This is added in the form of modules. There are 2 ways of fixing a part. It also offers extensive analysis functions, highly automated fixing tools and Magic's will advise you based on this information a fixing step. More advanced users sometimes prefer the fixing tool sheet that offers direct access to the fixing tools and offer tools for advanced fixing. With the translation cursor, the part can be dragged over the screen.

V. PROCEDURE OF DATA PREPARATION

Good data preparation is a prerequisite for the correct function of the building process. Poor data or data errors can cause a job to crash or result in poor parts quality. The following schematic diagram shows the basic sequence for data preparation.

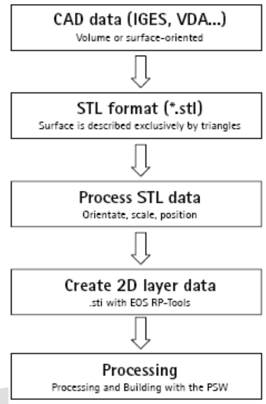


Fig 3: Sequence for Data preparation

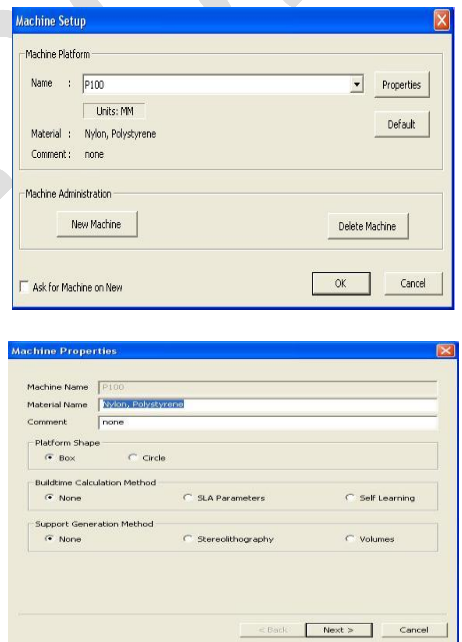


Fig 4: Machine setup of FORGIMA P100

The parts should be position in the middle of the building area as far as possible. It is possible to utilize the complete building area of 200 x 250 mm and a building height of 330 mm. However, here it must be noted that the temperature distribution over the building area is not exactly the same. The closer the parts are positioned to the edge of the building area, the greater the risk that parts could be torn out or that parts could be deformed. The distance between the parts should be at least 5 mm. The parts must be positioned at a Z position of at least 6 mm. At least 6 mm must be applied to the parts in layers before they start, otherwise the parts can start to curl or deform. After aligning, positioning and scaling the parts, they should be saved with a new name. First you should obtain an overview of the part to be built and give consideration to which is the best building position for the part. During this process the following pointsare considered to ensure high process stability, sudden changes in surface area should be avoided, i.e. parts start with small surface areas and grow slowly in the x- direction. Angles of less than 15° should not be used as otherwise steps will be formed on the surface of the part. For optimal part quality and a short building time, parts should be positioned as flat as possible. The axes of cylindrical bodies, e.g. very precise bores, should be aligned vertically if possible. With complex parts it is seldom possible to achieve ideal orientation, as there may be bores on several axes and the surfaces of the part may have different angles such that it is not possible to avoid angles less than the limit angle at some points.

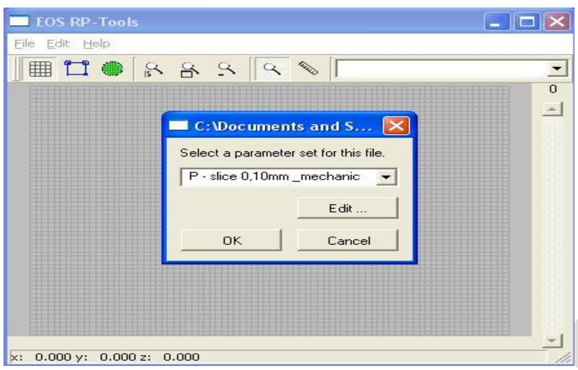


Fig 5: Slicer modulation of EOS RP-Tools

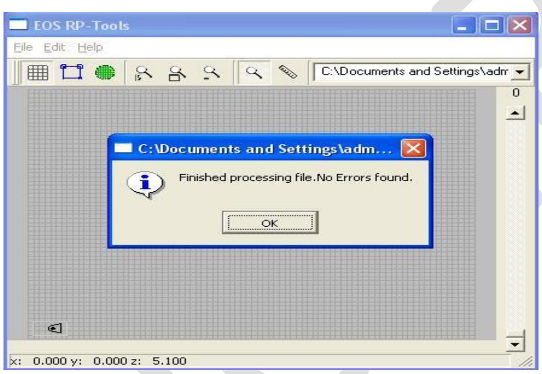


Fig 6: Slicer modulation of EOS RP-Tools

The layers in the SLI file are analyzed using ***SLIFIX module.*** Data errors are detected and corrected automatically. Errors caused by errors in the STL file are corrected, e.g. overlapping inverted polygons or duplicated polygons. This module is used for viewing layer data that are available in SLI or CLI files, i.e. two-dimensional layer data are displayed with the aid of polygons. It is very important that the default job matching the material is loaded. Creating a job, loading parts, Deleting parts, creating, ungrouping and deleting part groups. The parts loaded are exposed in the order in which they are listed in the Job parameters window. Optimal sorting of the parts prevents unnecessary jumps between the parts during exposure and therefore reduces the building time. Different exposure parameters can be used for each loaded part. In the same manner, different part-specific scaling and beam offset values can be set. A part can also show part-specific shrinkage in addition to material-specific shrinkage due to particular part properties. It can therefore be necessary to additionally scale the corresponding part. It is possible to adapt the beam offset for individual parts so that they are allocated specific undersize or oversize.

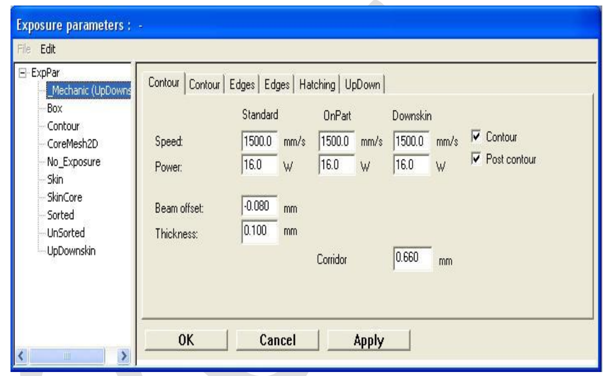


Fig 7: Exposure parameters of FORGIMA P100

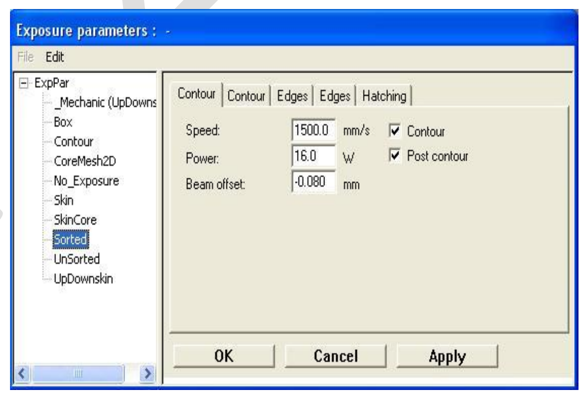


Fig 8: Exposure parameters of FORGIMA P100.

FORMIGA P 100 - small, fast, efficient**,** e-Manufacturing in the Compact Class Plastic laser-sintering system for the direct manufacture of series, spares parts and functional prototypes**.** The FORMIGA P 100 represents laser-sintering in the compact class. With a build envelope of 200 mm x 250 mm x 330 mm, the FORMIGA P 100 produces plastic products from polyamide or polystyrene within a few hours and directly from CAD data. The machine is ideally suited for the economic production of small series and individualized products with complex geometry – requirements which apply among others to the medical device industry as well as for high-value consumer goods. At the same time, it provides capacity for the quick and flexible production of fully functional prototypes and patterns for plaster, investment and vacuum casting. With turnover times of less than 24 hours the FORMIGA P 100 integrates itself perfectly in a production environment that requires the highest level of flexibility. Thus, the system is ideally suited for small, filigree components such as connectors, just to name one example. The revolutionary dosage and recoating system ensures a high product quality and process stability.

Table 1: Technical Data for FORMIGA P100

Effective building volume	200 mm x 250 mm x 330 mm
Building speed	up to 24 mm height/h (0.94 in/h)
Layer thickness	typically 0.1 mm (0.004 in)
Laser type	CO2, 30W
Precision optics	F-theta lens
Scan speed	up to 5 m/s (16.4 ft/sec)
Power supply	16 A
Power consumption (nominal)	2 Kw

The plastic powder types are Polyamide powder-unfilled, pure polyamide powder-filled mixture of polyamide powder and a filler material with which different mechanical or visual properties are achieved. Plastic powder from the exchangeable frames which must be sieved and regenerated before further usage, The Recommended storage conditions are plastic powder should be stored in closed powder bins, The room temperature Room temperature is around 20 - 25 °C with 50 % humidity. The plastic powder from the exchangeable frame is sieved. Sieving and mixing may cause electrostatic charging. The plastic power cannot be used immediately. Store the plastic powder between the individual processing steps (1)In open powder bins (2) For at least 24 hours at 20 - 25 °C and 50 - 60 % atmospheric humidity (3)Protected against soiling.(4)If the plastic powder is not further processed immediately after storage, the powder bins must be closed.PA2200 is suitable for use in all EOS systems with fine polyamide option.

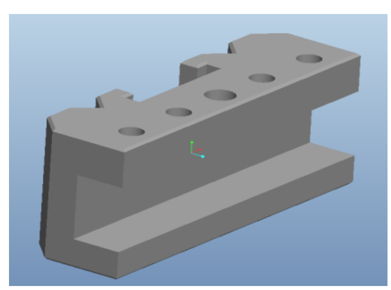
Table 2: PA2200 - Material Properties

Average Grain Size	60	µm
Bulk Density	0.435 - 0.445	gm/cm^3
Density of Laser Sintered Part	0.9 - 0.95	gm/cm^3
Tensile Modulus	1700 ± 150	N/mm^2
Tensile Strength	45 ± 3	N/mm^2
Elongation at Break	20 ± 5	%
Flexural Modulus	1240 ± 130	N/mm^2
Charpy - Notched Impact Strength	4.8 ± 0.3	kJ/m^2
Izod - Impact Strength	32.8 ± 3.4	kJ/m^2
Ball Indentation Hardness	77.6 ± 2	

The mechanical properties on x y z position and the exposure parameters used. Application PA3200GF is suitable for use in all EOS systems with polyamide option. The parts fabricated from this material have excellent mechanical properties, very smooth surfaces and high accuracy. The recommended layer thickness is 0.15mm. Unexposed powder can be reused. Depending on the building time it has to be mixed with fresh powder by a ratio of 2:1 to 1:1 (old: new) in order to guarantee constant process parameters and persisting part quality.

VI. CAD Model Of Turing Tool Holder

Solid Works is a Para solid-based solid modeler, and utilizes a parametric feature-based approach to create models and assemblies. Parameters refer to constraints whose values determine the shape or geometry of the model or assembly. Design intent is how the creator of the part wants it to respond to changes and updates. For example, you would want the hole at the top of a beverage can to stay at the top surface, regardless of the height or size of the can. Solid Works allows the user to specify that the hole is a feature on the top surface, and will then honor their design intent no matter what height they later assign to the can. This shape is then extruded or cut to add or remove material from the part. Operation-based features are not sketch-based, and include features such as fillets, chamfers, shells, applying draft to the faces of a part, etc. Building a model in Solid Works usually starts with a 2D sketch (although 3D sketches are available for power users). The sketch consists of geometry such as points, lines, arcs, conics (except the hyperbola), and spines. Dimensions are added to the sketch to define the size and location of the geometry. Solid Works also includes additional advanced mating features such as gear and cam follower mates, which allow modeled gear assemblies to accurately reproduce the rotational movement of an actual gear train. Finally, drawings can be created either from parts or assemblies. Views are automatically generated from the solid model, and notes, dimensions and tolerances can then be easily added to the drawing as needed. The drawing module includes most paper sizes and standard.



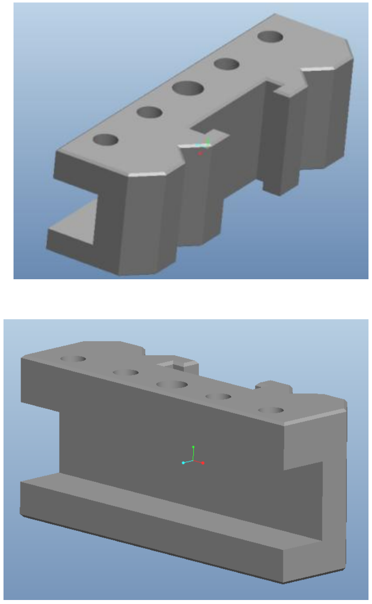


Fig 9: CAD model of turning tool holder

STL (Stereo Lithography) file is the most widely used and the de-facto standard of Rapid Prototyping (RP) processes. Most CAD vendors provide an STL output format.The surface is tessellated or broken down logically into a series of small triangles (facets). Each facet is described by a perpendicular direction and three points representing the vertices (corners) of the triangle. These data are used by a slicing algorithm to determine the cross sections of the 3-dimensional shape to be built by the RP machine. An STL file consists of a list of facet data. Each facet is uniquely identified by a unit normal and three vertices. The normal and each vertex are specified by three coordinates each, so there is a total of 12 numbers stored for each facet. First, the direction of the normal is outward. Second, the vertices are listed in counterclockwise order when looking at the object from the outside (right-hand rule). Typically, an STL file is saved with the extension "stl", case-insensitive. The slice program may require this extension or it may allow a different extension to be specified. The STL standard includes two data formats, ASCII and binary.

VII. EXPERIMENTAL WORK

Precision Lathe is used for turning AISI 304 Stainless Steel with Tungsten Carbide Insert as tool. Its rigid rectangular section with wide bed along with short spindle and shaft for maximum drive rigidity power provides precision and versatility for achieving unmatched capabilities in precision turning.Work piece was taken as AISI 304 Stainless steel and turning operation was carried out on NH 26 Precision Lathe. Machining parameters like cutting speed, feed rate and depth of cut were taken as input and performance of different inserts were analyzed onbasisof flankwear of insert, surface roughness of machined work piece and cutting forces generated during machining. Consecutively, dynamometer was fixed on the tool post and cutting forces were recorded..

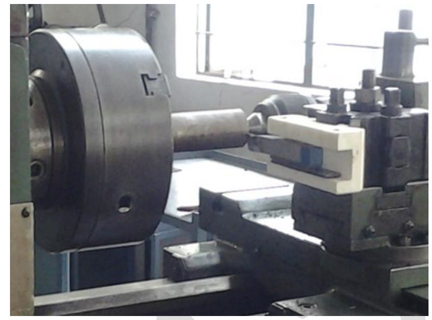


Fig. 10: Experimental set up for turning with RPT tool holder

Fig 11: PSBNR 2525 M12 right hand tool holder

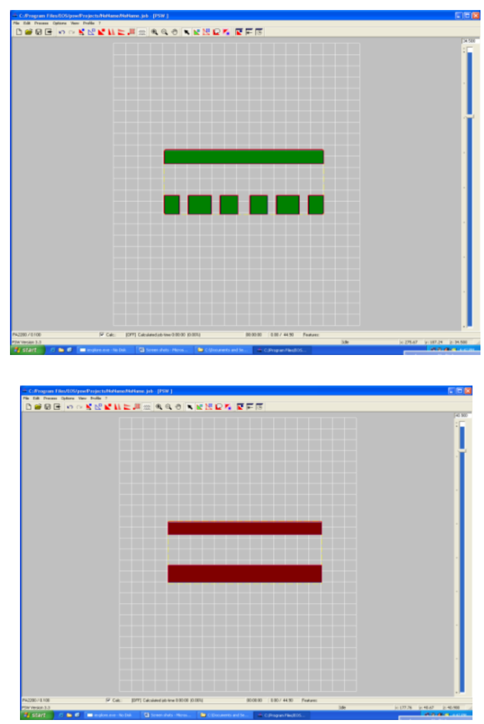


Fig 12: Sintering process at layer 34 Sintering process at layer 40

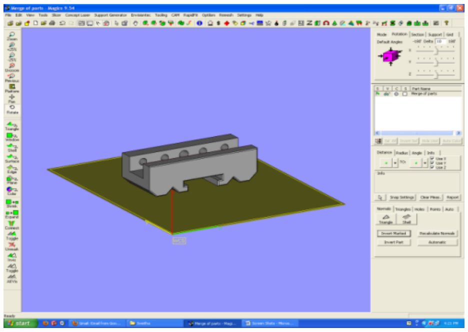


Fig 13: Positing parts to be prototyped

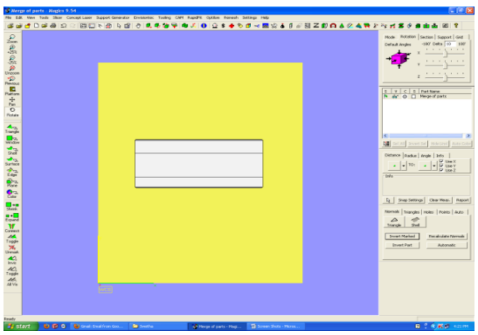


Fig 15: Merge of parts to be prototyped

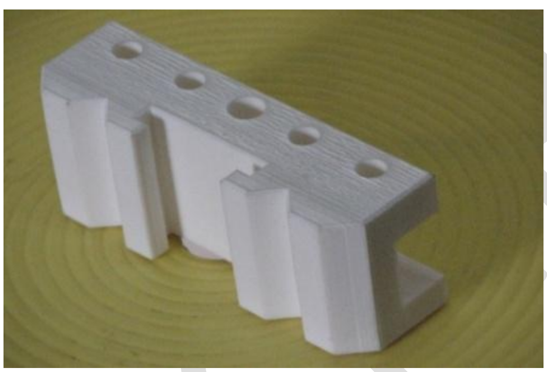


Fig 14: Prototyped Part of turning tool holder

Tungsten carbide inserts are used for machining AISI 304 austenitic stainless steel, which are categorized below 1. PVD coated Tungsten Carbide P 30 Insert, Uncoated Tungsten Carbide P 30 Insert, SNMG 120408 TN 4000 08, SNMG 120408 TTR 08.The Dynamometer comprises of three independent digital display calibrated to display force directly using three component tool dynamometer. This instrument comprises independent DC excitation supply for feeding strain gauge bridges which compute respective force value for direct independent display in Newtons. Instrument operates on 230v, 50 c/s AC mains.

Table 3: Specifications of lathe tool dynamometer

Range of Force	Model 620A 100 kg force for XYZ direction
	Model 620B 200 kg force for XYZ direction
	Model 620C 500 kg force for XYZ direction
Sensor	4 arm bonded strain gauge bridge for each force
Bridge Resistance	350 Ohms
Excitation Voltage	12V DC
Accuracy	±1% of full scale

IX. EXPERIMENTAL RESULTS

The study was undertaken to investigate the effect of process parameters on surface roughness, tool wear and chip formation produced by turning operation when turning solid material Aluminum, Brass and mild steel. Machining data of surface roughness, tool wears and chip formation were tabulated accordingly. The following are the results for machining Aluminum with HSS tool on Kirloskarlathe machine.

Table 4: measured forces used by conventional tool holder with tool overhang 20mm

S.NO	BarDiameter	CuttingSpeed	FeedRate	Depth of Cut	Fx	Fy	Fz
	(mm)	(rpm)	(mm/rev)	(mm)	(N)	(N)	(N)
1	40	315	0.045	1	27	27	20
2	40	315	0.045	0.5	21	43	12

3	40	315	0.045	0.25	21	43	10
4	40	500	0.045	1	12	32	12
5	40	500	0.045	0.5	12	22	10
6	40	500	0.045	0.25	12	22	0
7	40	775	0.045	1	12	22	18
8	40	775	0.045	0.5	12	22	27
9	40	775	0.045	0.25	12	8	0

Table 5: Measured forces used by conventional tool holder with tool overhang 30mm

S.NO	Bar Diameter	Cutting Speed	Feed Rate	Depth Of Cut	Fx	Fy	Fz
1	40	315	0.045	1	20	80	10
2	40	315	0.045	0.5	20	10	10
3	40	315	0.045	0.25	20	20	0
4	40	500	0.045	1	30	10	90
5	40	500	0.045	0.5	10	40	10
6	40	500	0.045	0.25	10	20	10
7	40	775	0.045	1	20	40	10
8	40	775	0.045	0.5	20	20	10
9	40	775	0.045	0.25	10	10	40

Table 6: Forces developed by conventional tool holder and RPT tool holder

Conventional Tool Holder				RPT Tool Holder			
S.NO	Fx	Fy	Fz	Fx	Fy	Fz	% variation
1	30	30	20	27	32	20	1.25
2	20	40	10	25	32	12	1.43
3	20	40	10	27	31	10	2.86
4	10	30	20	14	28	17	1.67
5	10	20	10	12	17	10	2.50
6	10	20	0	11	18	0	3.33
7	10	20	20	12	19	18	2.00
8	10	20	30	12	21	25	3.33
9	10	10	0	11	9	0	0.00

Table 7: % of variation between conventional and RPT tool holder

Conventional tool holder		RPT tool holder	
S.NO	MRR. (mm^3/min)	MRR, (mm^3/min)	% variation
1	3.12	3.22	3.11
2	4.16	4.21	1.19
3	4.16	4.26	2.35
4	3.12	3.18	1.89
5	2.08	2.13	2.35
6	2.08	2.16	3.70
7	2.08	2.14	2.80
8	3.12	3	4.00
9	1.04	1.06	1.89

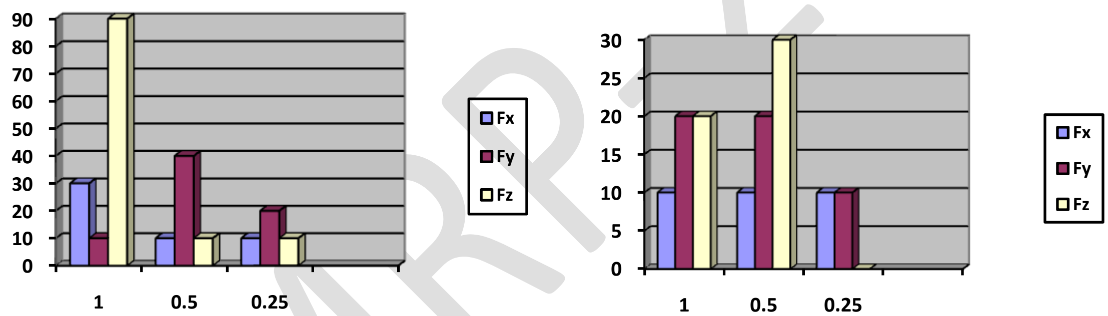


Fig 15: Forces obtained by Dynamometer with Conventional and RPT tool Holder, Forces obtained by using tool over hang 23mm with different depth of cut for RPT tool holder

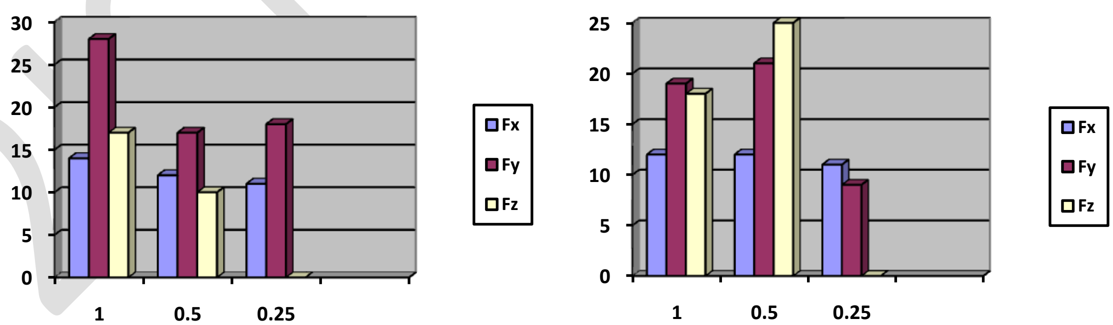


Fig 16: Forces obtained by Dynamometer with Conventional and RPT tool Holder at Cutting Speed at 500RPM and 775 RPM

X. Conclusion

In rapid prototyping using additive fabrication, the physical, real and the virtual components all have similar features can be manufactured. In the present project RPT technique is used to develop the tool holder and used in turning operation. By the application of the developed RPT model it has been observed the tool holder with a lighter weight and more rigid performing the same function as that of conventional tool holder and on mass production the cost price will also be less.It has been observed that the measured forces from the dynamometer with and without RPT Tool holder is around 3%.Thus the tool holder developed from the RPT Technique is also rigid and provide good rigidity during machining. The results also revealed that using a long tool length may set excessive vibrations that could be efficiently controlled by the use of short tool length. With a long tool length, the cutting variables become important factors to control in order to significantly improve surface roughness results no matter what type of bar is used.With the developed RPT tool holder detection with different combination of machine parameters. Design modification can be made to arrange multiple tools in a single slot of the tool holder. Developing the tool holder with different RPT techniques to include strain based sensors in the prototype for measuring deflection of the tool.The measured forces in the present work was recorded by a dynamometer, which is relatively expensive only and usually inconvenient for industrial applications. Other types of sensors, particularly accelerometers, may potentially replace the dynamometer due to their lower cost and easy installation. RPT technique can be implemented for manufacturing a various industrial components in future.

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