Comparing the Geometrical Accuracy of a 3D Printed Pattern to a Metal Pattern

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Abstract. Rapid prototyping is a new field where the depths are still being analysed, this paper is in regards for applying the subject to the field of pattern making. The work also extends to the area of comparing the low cost rapid prototyping to that of a pattern produced by CNC in terms of the geometrical accuracy so as to check the usage of the 3D printing in the field of pattern making. Possible foreseen actions that could benefit the pattern making industry are that of cost reduction and the time to produce a work piece. The scope of the paper lies in terms of the accuracy and the surface roughness since these affect the quality of the product to be produced. Since the dimensional accuracy is an important factor while pattern making is used, critical dimension which including the taper at a lower distance and some angle is also used so that the best results would be obtained. The dimensions are also checked by using a coordinate measuring machine, vernier callipers and machine vision. Machine vision has been applied so as to check whether they provide a scope for replacement of the conventional technique of quality inspection in the pattern making industry.

Keywords: Rapid prototyping, CNC, geometrical accuracy, surface finish, coordinate measuring machine, machine vision.

1. Introduction

The work focuses on the application of the rapid prototyping onto the field of the casting industry in terms of the pattern making, the work also extend to the field of machine vision, where the feasibility of machine vision based techniques to analyse the dimension of the patterns are analysed so that we can check whether the dimensions are within the required deviational parametrical values. The basic dimensions are found out the help of vernier calliper and CMM. The linear values like those of the diameter, linear length etc are measured by using the vernier whereas the nonlinear values like those of the cylindricity, flatness etc., are measured by using a coordinate measuring machine. The resultant value is compared to that of the actual one i.e., the original dimension taken for design and the divergence of the values are analysed to understand the deviation. The work is done to check the feasible extend to which the costly process of CNC machining could be replaced by that of the low cost 3D printing. The analysis for the cost and time is done and the results are interpreted.

The analysis is carried out with respect to the parameters namely i) Time and cost, ii) Dimensional accuracy, iii) Cylindricity, iv) Flatness, v) Feasibility of using machine vision to measure the dimension. By which we could analyse the extent to which the dimension accuracy can be met. Likewise whether the machine vision can be used to measure the dimensions of the given part so that the time spent on quality inspection can be reduced.

The aimed output is to check whether 3D printing can be used to make patterns for the casting industry, which could possible reduce the time and network labour required. And to the extent in which the low cost machine vision setup can be used to measure parameters, so that the time taken to
measure the parameter can be reduced, and in future the possibility of using artificial intelligence in the same field could be studied, thereby making a higher efficient practice in pattern making industry, without compromising on the parameters.

Jain et al. [1] used a model of a Oldham coupling to make analyse the use of the rapid prototyping in the casting industries where they made a pattern out of the 3D printing and used it to make a cast and concluded that the rapid prototyping is a better feasible way, when parts with complex geometry plate has to be produced.

Gnanasekaran et al. [2] in their research concerning to 3D printing of CNT- and graphene-based conductive polymer nano composites by fused deposition modelling, which states the use rapid prototyping techniques to build non-conventional polymer composites and concerning to this printability, electrical conductivity, crystallinity, morphology and viscoelastic properties of the 3D printed structures were evaluated, and concluded that optimum printing parameters do not change for CNT based elements.

Dimitrov et al. [3], carried out an investigation of the achievable accuracy of three dimensional printing by 3D printing of a gimble and concluded that the most contributing parameter are material used, dimensional axis requirement and the magnitude of dimensions used, and the performance tolerance along each axis.

Kitsakis et al. [4], carried out a study of the dimensional accuracy obtained by low cost 3D printing for medical application likely for that of a neuro-surgery, dental application. Here a CT, MRI scan reports are used to analyse the actual human conditions at a present situation and from which cloud points are obtained and a 3D model would be manufactured, from a low cost machine, this study possible represents a greater future scope for application of rapid prototyping for medical applications.

Malagi et al. [5], in their study of Development of casting pattern using rapid prototyping had used a method to compare the patterns produced by 3D printing and that of a wooden pattern and did a impact test along with a roughness test of the pattern to be produced and concluded that the rapid produced part has less surface finish than the wooden pattern and impact strength of the both are same.

So, based these literatures it could be concluded that the scope lies in analysing the usage of the rapid prototyping in the field of pattern making in casting industry, and based on the literature review it was concluded that comparing the geometrical accuracy of a 3D printing pattern to a metal pattern would be a new unexplored area in the field.

2. Methodology and Material used
For the study, the work material such as Al6061, ABS was selected for the CNC machining and for rapid prototyping respectively. The detailed methodology is shown in the Figure 1 which represent the overview of how the process flows.

2.1) Rapid prototyping
3D printed prototypes are one of the most important methods for realization of concepts in design, manufacturing and analysis. Rapid prototyping is one of the most essential parts of product development and manufacturing cycle required for assessing the form, fit and functionality of a design before a significant manufacturing it. The Specification of 3D printer used is shown in Table 1.
Table 1. Specification of 3D printer.

| Title                      | Specification                  |
|----------------------------|--------------------------------|
| Manufacture                | RAISE 3D                       |
| Printing technology        | Fused Filament Fabrication     |
| Build Volume               | 305 × 305 × 305 mm             |
| Nozzle Diameter            | 0.4 mm                         |
| Printing technology        | 170-300°C                      |
| Material Type              | PLA, PLA+, ABS, PC, PETG, TPU, HIPS, Bronze filled, Wood filled |
| XY Positioning accuracy    | 12.5 microns                   |
| Layer thickness            | Minimum 10 microns             |

2.2) CNC Turning centre

Turning is an engineering machining process in which a cutting tool, typically a non-rotary tool bit, describes a helical tool-path by moving more or less linearly while the workpiece rotates. The Specification of CNC Turning Center used for the experiments is shown in Table 2.

Table 2. Specification of CNC Turning Center

| Description              | Specification |
|--------------------------|---------------|
| Chuck dia. Max           | 170 mm        |
| Max. Turning dia         | 130 mm        |
| Max. Turning Length      | 230 mm        |
| Spindle speed            | 4500 rpm      |
| Spindle motor power      | 5.5 / 7.5 Kw  |
| Cross travel X-axis      | 250 mm        |
| Longitudinal travel Z-axis| 300mm         |
| Rapid traverse rate X/Z axes | 20          |

Figure 1. Experimental Methodology
2.3) Line diagram and 3D model of pattern

The diagram of the final component in terms of casting to be made is as follows:

Type of pattern used – **SPLIT PATTERN**.

Allowance to be given:
1. **SHRINKAGE ALLOWANCE** - The allowance for aluminum per dimension is 1mm
2. **MACHINING ALLOWANCE** - The allowance is to be added to every dimension as 1mm.
3. **DRAFT ALLOWANCE** - The draft needed not be given for aluminum as the shrinkage is very high, but for taper part it would be considered as 1°.
4. **SHAKE ALLOWANCE** - It is a negative allowance that is given, so that it can be taken out easily and it is given as 1mm. So the pattern is produced to the required size by considering the allowances also.

The final dimensions are:

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**Figure 2.** Dimensions of the product.

**Figure 3.** Dimensions of the pattern.
3. Results and description
The components are made from the 3D printing and from CNC machining which is shown in Figure 5 and 6. The Time and cost, Cylindricity, Flatness, Dimensional accuracy and Machine vision are the area taken for the comparison study between the metal and the 3D pattern formed.

3.1) Time and cost

| ProductionDetails       | RapidPrototyping(for similar size) | CNCTurning    |
|-------------------------|------------------------------------|---------------|
| Design time             | 10 minutes                         | 10 minutes    |
| Fabrication Time        | 3 hour                             | 3.57 hours    |
| Total time              | 3.17 hrs                           | 3.74 hrs      |
| Total cost(INR)         | 1000                               | 1700          |

Considering the time and money as factors in this case the one with the 3D printing is considered more feasible since it takes lesser time and the cost involved is less.

3.2) Cylindricity
Cylindricity is a 3-Dimensional tolerance that controls the overall form of a cylindrical feature to ensure that it is round enough and straight enough along its axis. Here CMM is used to measure the cylindricity. Measurement has done on the part with 19mm diameter.
The value of error of cylindricity of metal =0.021 mm and for the plastic pattern the value of error is=0.017 mm. For measuring the value of cylindricity the CMM measures 6 points i.e., 3 points along one circle and other 3 along different circle.In the 3D printer since the vibration is very less as compared to that of the CNC the 3D printed part shows lesser error in terms of cylindricity. Another possible method of explaining the same is that the CMM could also have measured the identical circle that are along the axis by and chance these values cause a less error in cylindricity, to avoid this error multiple time the measurement had been carried out but it yielded in similar values.

3.3) Flatness of the part
The flatness control defines how much a surface on a real part may vary from the ideal flat plane.Flatness has been measured along the surface of the diameter 10 $^{0.5}$.5 x 19 $^{0.5}$.5 part.

For the metal pattern the value of error is =0.0255 mm and for the plastic pattern the value of error is=0.078mm.The value of the flatness error is more for 3D printed part and less for the metal part because in the case of the 3D printing the rate of cooling of the various layer in the plastic deposition is different due to its difference in time of cooling, thus creating a variation in the flatness value along the surface, which is not same as the case of CNC machining because in CNC machining the material is removed on a larger quantity so the rate of cooling is for a comparatively larger surface is more uniform when compared to that of the 3D printing which primarily improves the value of flatness in CNC machining.

3.4) Vernier calculation
Vernier has been used to measure the dimensional accuracy of the dimensions of the pattern. The value of the dimensions of the original pattern is:
Figure 11. Actual value of the pattern

For the simplicity the dimension are assumed as follows:

Table 4. Measured values for diameter of the component

| Parameters | Metal Pattern | 3D Printed Pattern (Measured Value) | 3D Printed Pattern (Actual Value) |
|------------|---------------|------------------------------------|-----------------------------------|
| A          | 10.11 ±0.01  | 7.4 ±0.1                           | 9.85 ±0.133                     |
|            | x 19.03 ±0.01| x 14.15 ±0.05                      | x 18.867 ±0.4                   |
| B          | 19.03 ±0.01  | 14.15 ±0.05                        | 18.867 ±0.4                     |
| C          | 52.21 ±0.01  | 39.14 ±0.02                        | 52.187 ±0.03                    |
It is evident that the value of the dimensions vary drastically in the case of the 3D printed component. Thus in this case it is proves that in terms of geometrically accuracy the parameters formed from the values of the 3D printed component is of highly deviating making the case of CNC more preferable to the 3D printed one. But a notable point form this is that the deviations of the values are way within the specified limit and so the 3D printed component is indeed a chance to explore into.

### Table 5. Measured values for Length value of the component

| Parameters | Metal Pattern (Measured Value) | 3D Printed Pattern (Actual value) |
|------------|-------------------------------|----------------------------------|
| D          | 39.5 ± 0.02                   | 29.45 ± 0.05                    |
|            |                               | 39.27 ± 0.10                    |
| E          | 29.03 ± 0.03                  | 21.85 ± 0.05                    |
|            |                               | 29.13 ± 0.07                    |
| F          | 19.95 ± 0.07                  | 15.09 ± 0.07                    |
|            |                               | 20.12 ± 0.10                    |

3.5) Roughness value

The primary effect of surface roughness value is to make sure that the pattern after ramming can be removed easily. The one with the higher roughness adhere by raising the cohesive force between the surfaces of the pattern and the surface.

### Table 6. Measured values for roughness of the component

| Type of Pattern | Average Roughness |
|-----------------|-------------------|
| Metal Pattern   | 0.52 µm           |
| 3D Printed Component | 2.25 µm           |

Thus from the value it is clear that the value of roughness is high for the 3D printed value so making it not feasible for the casting because as roughness value rises it also causes a rise in the adhesiveness of the cast sand and the pattern making it difficult to use.

3.6) Machine vision

The primary motto of using the setup is to see whether the machine vision system can be used to measure the dimensions which could possible reducing the time of quality inspection and in future would induce the possibility of AI to the field of measurement. The following contains a few screenshots regarding the setup in machine vision:
As per the shorted data as given in the figure the values of the measured component are:

| Parameters | Metal Pattern | 3D Printed Pattern (Measured Value) | 3D Printed Pattern (Actual Value) |
|------------|---------------|-----------------------------------|----------------------------------|
| A          | 20.31         | 15.59                             | 20.79                            |
| B          | 20.31         | 14.93                             | 19.91                            |
| C          | 19.84         | 15.95                             | 21.27                            |
| D          | 14.77         | 11.544                            | 15.39                            |
| E          | 19.9          | 14.918                            | 19.89                            |
| F          | 14.15         | 10.786                            | 14.38                            |
Table 8. Measured values for diameter using machine vision

| Parameters | Metal Pattern | 3d Printed Pattern (Measured Value) | 3d Printed Pattern (Actual Value) |
|------------|---------------|------------------------------------|----------------------------------|
| A          | Dia 9.811 x 20.014 | Dia 6.922 x 15.007 | Dia 9.23 x 20.009 |
| B          | 20.014        | 15.007                             | 20.009                           |
| C          | 53.007        | 39.47                              | 52.6                             |
| D          | 41.389        | 30.27                              | 40.3                             |
| E          | 30.133        | 22.705                             | 30.273                           |
| F          | 20.83         | 15.167                             | 20.223                           |

Thus low cost machine vision is not a feasible way of measuring the pattern because the deviations that are caused are way above the tolerance value given leading to the case of rejection of the good components. But if the setup of machine vision is ramped up to a camera with more vision sensing capabilities it could be a possible alternative in future.

4. Conclusion
Thus from the following observation it is clear that the low cost rapid prototyping is a comparative alternative to the CNC machined component in terms when the dimensional tolerance of the given part are comparatively large, the low cost rapid prototyping part take the least time for production and cost for production is comparatively less than compared to the CNC based machined component. The cylindricity of the part that is produced with the rapid prototyped part is high since due to the fact that the vibration is reduced in this case, but in terms of flatness the value of the CNC machined component occupies a upper hand because in rapid prototyped part the rate of cooling of the layers are comparatively different causing a difference in the output, the dimensional tolerance of the product is well within the specified limit (larger tolerance scale), making both a feasible alternative. In terms of roughness the CNC based machining is an better alternative because in terms that it has a fine surface finish when compared to that of the rapid prototyped component, if the sand used in casting has a lower adhesiveness then the rapid produced part is indeed a alternative to the set up done by the counter CNC produced part. The low cost machine vision has also been evaluated to see the possible chance of measurement but these geometrical values and is found to differ very much from the alternative values measured by vernier scale and also goes above the predefined limit thus making it a non-feasible alternative to measuring the pattern.

Reference
[1] D. Dimitrov, W. V. Wijck, K. Schreve, N. Beer. Investigating the achievable accuracy of three dimensional printing 2009. Rapid Prototyping Journal 12:42 – 52
[2] K. Gnanasekaran, T. Heijmans, S. V. Bennekom, H. Wolthuis, S. Wijnia, H. Friedrich. 3D printing of CNT and graphene-based conductive polymer nano composites by fused deposition modelling (2017) Journal of Applied Materials 9:21-28.
[3] P. Jain, A. M. Kuthe. Feasibility Study of manufacturing using rapid prototyping: FDM approach 2013. Journal of Applied Materials 63:4 – 11.
[4] K. Kitsakis, P. Alabey, J. Kechagias, N. Vaxevanidis. A Study of the dimensional accuracy obtained by low cost 3D printing for possible application in medicine 2016.
Journal of Materials Science and Engineering 161:10-20, 2016.

[5] R. R.Malagi, S. B. Mahendra, A. Pol, P. Raikar. Development of casting pattern using rapid prototyping 2014. *Intl Journal of Research in Engineering and Technology*, eISSN: 2319-1163.