A Review on Identification and Elimination of Ovality in Circular Holes During Manufacturing of Hollow Cylindrical Components

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Abstract. This review paper aims toward the investigation of manufacturing process of hollow cylindrical component to identify the defects causing ovality in circular holes. The manufacturing refers to the processes required to convert raw material into the final product which may include casting, machining, welding, finishing, heat treatment processes and ends with final inspection to check for defects. Mostly the circular holes of hollow cylindrical components show ovality after manufacturing, exceeding tolerance values and such defect leads to poor fittings. After careful study of the variety of research papers related to ovality, it was found that the ovality may occur due to component characteristics or due to defects in manufacturing process of the component. The results of these research papers concluded that machining parameters, unbalanced workpiece, clamping pressure, clamping geometry and clamping technique influence the dimensional deviations and it can be prevented by improving the production with corrective techniques.

Keywords. Defects, Ovality, Manufacturing, Component characteristics, Production

1. Introduction

Manufacturing can be defined as the process of converting the raw materials into useful products and this is achieved by following some steps such as design of product, raw material selection, and machining. There are various conventional and non-conventional manufacturing processes to manufacture a product, each process has its advantages and disadvantages. The manufacturing processes have been evolved from traditional approaches to the recent advancements due to the requirement of high quality finished good.

In this paper, study of manufacturing a cylindrical component is investigated to identify the defects that can cause ovality in the component. The machining parameters as well as geometry of the component are also investigated to find the source of error causing the ovality. The ovality is usually expressed as deviation from a circular periphery i.e. total difference at the cross-sections between the individual maximum and minimum diameters. Ovality can be expressed as shown in Equation 1.

\[ e = 2 \times \frac{b-a}{b+a} \]  

Where, \( e \) is ovality, \( b \) and \( a \) are the major axis and the minor axis of elliptical hole respectively. The holes are mostly drilled in the workpieces or present during the casting and further finished by the boring operation. Hence, the workpieces need to be clamped while machining to avoid slipping. During machining of these holes in the workpiece, elastic residual stresses are developed which gets relaxed after removal of clamps and causes deformation. In industry, holding multi-rod as well as gear systems in such hole results in failure due to poor fitting.

2. Literature Review

Kulkarni and Bagale (2017) studied the processes involved in manufacturing of components and how parameters of those processes affect the final product. They identified defects leading to outside
or inside diameter undersize, oversize and oval shapes during CNC machining and are presented in Table 1.

| Problem, cause and solution when inaccuracy occurs. | Problem | Cause | Solution |
|-----------------------------------------------|---------|-------|---------|
| Concentricity or offset, Parallelism error | Centerline or Angular misalignment of chuck | Check the alignment of chuck, tailstock and tool before start of production properly. |
| Roundness deviation | Non-uniform geometry of workpiece | Ensure proper clamping by checking workpiece alignment with the rotating or cutting axis |
| Tool or workpiece chatter | Vibration of machine | Proper tool setup and insert installation reduces tool chatter and controlling the feed rate reduces the workpiece chatter. |
| Incorrect program | Syntax or motion or setup mistakes | Proper code writing and verification eliminates this defect. |

Han et al. (2010) focused their study on the ovality occurred in round castings in continuous castings because of the mechanical as well as thermal strain. They selected diameter of strand and hot pressure of molten metal as variables. The calculation analysis concluded that, the large mechanical deformations are generated because of the excessive hot pressure and the groove design of drive roller along with range of round section size should be considered while determining the optimum value of hot pressure.

Ghetiya and Panchal (2014) worked towards reducing the problem of ovality in turning of a clutch component. The principal parameter causing the ovality has been detected within machining variables. They used the RSM and investigated the radiography, work piece balancing, and used finite element analysis for determining the centrifugal force in the component.

- Ovality depends on the depth of cut as it increases, workpiece experiences more force.
- High feed rate leads to high heat generation, eventually plastic deformation starts taking place with higher stress which decreases the ovality.
- Cutting speed and feed rate causes less ovality compared to depth of cut. With increasing cutting speed till 0.150mm/min, ovality decreases but further increasing the cutting speed, increases ovality.

Pandya et al. (2015) analyzed the effect clamping force, hole eccentricity, hole diameter, and angular position of hole on the ovality of holes occurring after the drilling process. They created a simulation plan of L25 orthogonal array by using Taguchi method with 2 mesh settings. To identify very small deformations of cylinders, it is important to consider a fine mesh.

After analyzing the simulation results, they concluded:
- To reduce oval shape, the hole to be machined should be aligned with clamps at 45°.
- Ovality does not affected by hole diameter as it is a dimensionless entity.
- The displacement of hole center is function of clamping force and it should be as minimum as possible while ensuring firm contact.

Nowag et al. (2007) investigated the influence of machining parameters (feed rate, cutting speed, depth of cut and nose radius) on distortion of bearing rings made of 100Cr6 (SAE 52 100). Along with that they analyzed the two clamping techniques and Figure 1 shows both the clamping techniques i.e. external clamping and internal clamping. After turning, the geometry and residual stresses along the circumference of ring is measured.
The results analysis concluded:

- With the changing the clamping strategy, residual stress distribution around the ring’s circumference can be altered. The ideal condition of clamping the ring was from inside the diameter with the mandrel.
- With rising feed and nose radius, the surface residual stresses increase and there is no significant impact of speed, feed, depth of cut and nose radius on ring distortion, when using perfect clamping system i.e. internal clamping.

Gorog and Gorogova (2018) studied the impact of clamping forces on roundness of turned pipes made of steel S355J2H (STN 41 1503). The machining condition used were cutting speed- 180m/min, depth of cut- 1mm and feed rate- 0.2mm. The machined pipes were measured on Rondcom 16A roundness machine.
This paper concluded:

- Wall thickness of the pipe affects the roundness. With smaller wall thickness of pipe, the roundness is higher.
- Roundness depends on the clamping forces or tightening torque. The roundness increases with increasing clamping forces.

Gorog et al. (2012) focused their study on deviations generated during the turning process. The clamping pressure was assumed to influence the deviations. The material was a hollow cylinder with the outer diameter of 60mm made of low carbon steel. In order to measure the deviation, they used ZVL MK 300C device with three different filters.
After the analysis, they concluded that:

- The clamping pressure induces elastic deformations, causing the roundness deviation in machined hollow cylinder and therefore the shape of the part before and after machining is not equal.
- The roundness deviation proportionally depends on set out of the part from the chuck as well as on clamping pressure.
- To avoid deformations and obtain lower roundness deviation a different clamping system e.g. collet should be used.
Shao et al. (2013) proposed an algorithm which can predict the machining error generally developed due to release of the clamping force. The Figure 2 shows the oval holes formed due to clamping pressure.

![Figure 2. Machining error caused by clamping force.](image)

After analysis, the proposed algorithm was found to be effective because, the deformation due to clamping force with FEM can be predicted, calculates the spring back deformation using grid mapping method, and obtains the machining error by error analysis and also the experimental values follow the simulation value. They concluded:

- The error due to factors which are cutting speed, vibration, cutting heat, and tool wear is higher as compared to clamping released error.
- The clamping error can be minimized by improving the manufacturing planning and setup.

Winzenz and Dyler (2001) focused their study on effects of rotating unbalanced workpieces on the final turned product and its precision. The analytical as well as experimental results shows that in order to have tight concentricity, roundness, or surface finish tolerances of eccentric parts or workpieces, it is necessary to balance the chuck and workpiece assembly. The workpiece gets unbalanced due to casting weight variation or due to machining parts with interrupted cuts.

Zohoor and Yousefi (2019) studied the surface roughness and dimensional accuracy of hardened steel machined using CBN. The results showed that surface roughness changes with changing feed rate and dimensional accuracy gets affected by cutting depth and spindle speed. Nose radius does not affect dimensional accuracy. Dimensional accuracy also a function of the tool wear and vibration as they have major impact on it.

Yang and Hu (2016) investigated the relation between machining parameters and ovality in hollow shafts in Cross Wedge Rolling (CWR) process by examining the effect of circular as well as helical contact area between workpiece and tool with the help of finite element method. They concluded that ovality of hollow shafts can be minimized by decreasing stretching angle and rising the forming angle, also the ovality can be predicted by defining the coefficient which will make selecting process parameters simple.
Shendage and Borkar (2019) focused their study on reducing the ovality of KTM bike SMC (Starter motor cover) parts by optimizing the process parameters. The machining processes were facing, turning, step turning, grooving followed by boring. The analysis was done by using Taguchi method, ANOVA and RSM techniques. The conclusion was that ovality increases by increasing cutting speed, increasing depth of cut and decreasing feed rate and the defect arouse due to lower wall thickness and high heat generation. The optimized process parameters were feed rate (0.08mm/rev), depth of cut (0.3mm) and cutting speed (420rpm).

Ji et al. (2016) established a numerical simulation model to predict the ovality of hollow engine valve without mandrel in CWR process. After analyzing the experimental and numeric results, it was concluded that ovality was best with forming angle 30°-34°, stretching angle 5°-7°, mold void width 20mm-30mm and area reduction 65%-70%.

Ramesh et al. (2013) studied the effect of machining parameters on ovality of drilling holes on non-laminated Glass Reinforced Plastic (GFRP) composites. Taguchi’s orthogonal array and ANOVA were used to study the correlation between ovality and parameters. The results identified the optimal parameter values which were 1000 rpm cutting speed, 10mm diameter twist drill and 0.15mm/rev. The ovality varies with drill rod geometry and the type of laminated composites.

Shastry et al. (2014) investigated the effect of process parameters on ovality of carbon-carbon composite plates which were used in space crafts. The HSS and TiN coated carbide material tools were used while drilling on CNC drilling machine. The comprehensive analysis concluded that better hole quality was achieved with TiN coated carbide tools and the optimal parameters were point angle 118°, cutting speed 2000 rpm, feed rate 100mm/min.

More et al. (2015) focused their study on optimization of process parameters while drilling GFRP composites using tungsten carbide tool. Taguchi method as well as L9 orthogonal were used for this designing the experiments and the experimental results concluded that feed rate is most influential factor in inducing ovality.

Shrivanshu et al. (2013) performed experiments on flow forming machine with AA6082 alloy flow formed tube considering axil feed of the roller, roller radius and speed of the mandrel as machining parameters. The analysis found that ovality is influenced by roller feed and controlling it can reduce this inaccuracy.

Nichit et al. (2019) eliminated the ovality problem arose during manufacturing of valve seat by clamping the workpiece in machine chuck by using fixture. Computer Aided fixture design, Feature Based fixture design, Flexible design fixture and the Computer aided mass balancing method is used while designing the fixture.

Hoffman et al. (2009) investigated the roundness deviation caused due to residual stresses arose during manufacturing of bearing rings. The experiments were carried with changing clamping conditions i.e. clamping the bearing from inner and outer diameter with simultaneous quenching during turning operation. After analysis, it was concluded that residual stresses induced after unclamping the bearing rings i.e. stress relief which causes plastic deformation and eventually roundness deviation.
Abe et al. (2016) studied the effects of process conditions on ovality caused during cold pilgering of tubes made of stainless steel and zircaloy-4. The experiments conducted with feed rate (1, 1.5, 2 and 2.5 mm/stroke), stroke speed (140, 180 and 200 strokes/min) and turn angle (40°, 60° and 80°). The results concluded that with increasing feed rate the residual stresses developed in tubes and hence spring back effect takes place which lead to ovality. Also, the turn angle has significant impact on ovality.

Kopac et al. (1999) worked for improving dimensional accuracy and reducing production cost during finishing of cold formed parts. The analysis concluded that the tolerances should be met by using near net shape machining technology and advanced tools.

Dijkman et al. (2007) provided an experimental setup for controlling the turning operation online i.e. during process. The setup includes ultrasonic measurement device, global control unit and fast tool unit. The tests of this setup showed that the clamping force of chuck can be compensated equally to eliminate ring wall thickness and diameter deviations.

Cicek et al. (2012) investigated the influence of deep cryogenic treatment along with drilling parameters while drilling of AISI 316 austenitic SS by M35 HSS twist drills. Taguchi technique was used for evaluating optimal control parameters and obtained minimum geometric deviations with 14 m/min cutting speed and 0.08 mm/rev feed rate and they also found that changing cryogenic temperatures affects roundness deviation.

Deng et al. (2005) investigated the hole roundness in BTA deep hole drilling process by applying Taguchi method. The analysis concluded that the roundness deviation of holes can be minimized by optimizing control parameters which were tool diameter, shaft length, feed rate, rotational speed and day of the week.

3. Conclusions

This review paper identifies the reason behind occurrence of ovality in cylindrical components. It also puts forward the powerful tools and techniques to eliminate ovality problem.

1. In casting process, the mechanical deformations are dependent on the diameter of strand and hot pressure of molten metal. The thermal and/or mechanical strains can introduce ovality at circular sections. This can be reduced by using optimum value of hot pressure and diameter of strands.

2. In machining processes like turning, drilling and boring, the machining parameters such as cutting speed, depth of cut and feed rate plays an important role in causing inaccuracies in the component. The faulty selection of values can cause vibrations, large heat generation, chatter which can give rise to deformations and product rejection problems. Hence, optimization of machining parameters is important to control output parameters.

3. The ovality can also be introduced in the component due to elastic residual stresses. The elastic residual stresses get retained while drilling a hole in a component in clamping condition and when clamps are removed the geometry of the hole changes.

4. Sometimes the geometry of component is not symmetric which results in unbalancing of workpiece. This causes difficulty in clamping of component as well as unbalanced rotation of workpiece. In such case increase in clamping pressure may ensure sufficient clamping but majorly impacts on the shape change of the component. The fixture design is important in this case.

References

[1] Kulkarni C and Bagale G 2017 Defect identification in CNC manufactured products and their control measure, International Journal of Innovative Research in Science, Engineering and Technology 6, pp 13930-13936.
[2] Han J, Liu K and Zhang J 2011 Ovality Defect Control for Round Casting based on Mechanical Deformation Analysis, Advanced Materials Research 154, pp 151-157.

[3] Ghetiya N and Panchal S 2014 Some Studies on Reduction in Turned Component -Case Study, Nirma University Journal of Engineering and Technology 3, 39-46.

[4] Apte P, Shah V, Pandya P and Ahmed P 2015 Minimization of Ovality of Circular Holes in Drilling Process, Applied Mechanics and Materials 800, pp 393-396.

[5] Nowag L, Solter J, Walter A and Brinksmeier E, Effect of Machining Parameters and Clamping Technique on Residual Stresses and Distortion of Bearing Rings, Mat. -wiss. u. Werkstofftech 37, pp 45-51.

[6] Görög A., Görögová I., Research of the Influence of Clamping Forces on the Roundness Deviations of the Pipes Turned Surface, Research Papers Faculty of Materials Science and Technology in Tmava Slovak University of Technology in Bratislava,26, 47-54, 2018.

[7] Maračeková M, Zvončan M, and Görög A 2012 Effect of clamping pressure on parts inaccuracy in turning, Technical Gazette 19, pp 509-512.

[8] Shao X, Liu S, Zhang L and Lin Z 2013 Simulation of Workpiece Deformation caused by Releasing the Clamping Force, Transactions of the Canadian Society for Mechanical Engineering 37, pp 703-712.

[9] Winzenz W and Dyer S 2001 Effects of Rotating Unbalance on Turning Precision: Analytical and Experimental Investigations and Real-Time Compensation, American Society for Precision Engineering 16, pp 1-6.

[10] Yousefi S and Zohoor M 2019 Effect of Cutting Parameters on the Dimensional Accuracy and Surface Finish in the Hard Turning of MDN250 Steel with Cubic Boron Nitride Tool, For Developing A Knowledge Base Expert System, International Journal of Mechanical and Materials Engineering 14, pp 1-13.

[11] Yang C and Hu Z 2016 Research on the Ovality of Hollow Shafts in Cross Wedge Rolling with Mandrel, International Journal of Advanced Manufacturing Technology 83, 67-76.

[12] Shendage D and Borkar B 2019 Experimental Effect of Various Machining Parameters on Machining of Cylindrical SMC Part, International Journal of Advance Research and Innovation Ideas in Education 5, 481-492.

[13] Ji H, Liu J, Wang B, Lin J and Tang X 2016 The Process Parameters Effect of Ovality in Cross Wedge Rolling for Hollow Valve without Mandril, MATEC web of conference 80, pp 1-6.

[14] Ramesh B, Elayarperumal A, Balaji A and Rakesh N 2013 Optimization of Ovality on Drilling Glass Fiber Reinforced Plastic Composites with Coated Tungsten Carbide Tool, International Journal of Innovative Research in Science, Engineering and Technology 2, pp 2801-2819.

[15] Shastry K, Rao V, Kumar M and Velayudham A 2014 Experimental Analysis of Hole Quality in Drilling of Carbon-Carbon Composites, Applied Mechanics and Materials 592, pp 294-301.

[16] More U 2015 Influence of Process Parameters on Ovality in Drilling of GFRP Composites using Tungsten Carbide Tool, International Journal of Advances in Computing and Management 4, pp 1-5.

[17] Shrivanshu M, Komaraiah M and Rao K 2013 Application of Response Surface Methodology to Predict Ovality of AA6082 Flow Formed Tubes, International Journal of Manufacturing, Materials, and Mechanical Engineering 3, 52-65.

[18] Nichit V, Khandarkar S, Karwa N, Sonawane V and Patil K 2019 Ovality Correction in Manufacturing of the Valve-Seat, International Journal for Science and Advance Research in Technology 5, pp 1158-1166.

[19] Hoffman F and Surm H 2009 Influence of clamping conditions on distortion during heating of bearing rings, Mat. -wiss. u. Werkstofftech 40, pp 396-401.

[20] Abe H, Iwamoto T, Yamamoto Y, Nishida S and Komatsu R 2016 Dimensional Accuracy of Tubes in Cold Pilgering, Journal of Materials Processing Technology 231, pp 277-287.

[21] Kopac J and Sokovic M 1999 Dimensional Accuracy and Cost Optimisation in the Finish Machining of Cold Formed Parts, Journal of Materials Processing Technology 92, pp 335-343.
[22] Dijkman M, Stobener D, Allers S, Kuhfuss B and Goch G 2007 In-Process Control of Cutting Depth during Turning, *SICE annual conference*, pp 2984-2989.

[23] Cicek A, Kivak T and Samtas G 2012 Application of Taguchi Method for Surface Roughness and Roundness Error in Drilling of AISI 316 Stainless Steel, *Journal of Mechanical Engineering* 58, pp 165-174.

[24] Deng C snd Chin J 2005 Hole Roundness in Deep-Hole Drilling as Analysed by Taguchi Methods, *International Journal of Advanced Manufacturing Technology* 25, pp 420-426.