Ovality Correction In Manufacturing of The Valve-Seat

Vikrant Nichit[1], Sarang Khandarkar[2], Nikhilesh Karwa[3], Vaishnavi Sonawane[4], Komal Patil[5]
[1, 2, 3, 4, 5]Dept of Mechanical
[1, 2, 3, 4, 5] K. K. Wagh Institute of Engineering Education and Research, Nashik.

Abstract- *Ovality is the deviation of the job from desired circular periphery, usually expressed as the total difference found at any one cross-section between the individual maximum and minimum. The necessary geometric constrains are concentricity and circularity which is a corresponding match with the valve plug with tolerances in the order of 10 microns. The main objective of this project is the corrections of the ovality caused by clamping pressure by using a holding fixture assembly to avoid the clamping of workpiece directly to machine chuck, thus eliminating the prime cause of ovality. This project accounts for the versatile capability of fixture to hold the job ensuring that close constrains are maintained. The design also encapsulates the easy mounting of the work piece using self guiding features maintaining close tolerances. The expected outcomes are to reduce the rejection of the manufactured jobs, maintain the quality of manufacturing and simplification of process cycle thus reducing time of manufacturing.*

Keywords- Clamping pressure, Ovality, Concentricity, Circularity.

I. INTRODUCTION

A fixture is a mechanism used in manufacturing to hold work piece, position it correctly with respect to machine tool and support it during Machining Widely used in manufacturing, fixtures have a direct impact upon product quality, productivity and cost. Generally the cost associated with fixture design and manufacture can account for 10-20% of total cost of manufacturing system.

Therefore with the increasingly intense global competition which pushes every manufacturer in industry to make best effort to sharpen its competitiveness by enhancing the product quality squeezing the production cost and reducing the lead time to bring new product to the market. The development of computer aided fixture design technology over the past decades can be attributed to fulfilling of this goal.

KOSO India Pvt. Ltd. is a valve manufacturing company of Ambad MIDC, Nashik. They manufacture many types of valves. The product rejection in the KOSO India Pvt. Ltd. was observed, the causes of the rejection included dimensional inaccuracy, tolerances in circularity, Concentricity of the outer diameter and inner bore diameter, these inaccuracies lead reduction in the operational capabilities of the valve seat that includes improper fit of the valve plug causing leakage. Uneven wear of the plug due to unbalanced force application.

The root cause of these errors was narrowed down to the ovality induced in the valve seat while manufacturing in the CNC lathe due to the improper clamping and deformation of the material due to clamping pressure(10-12 bar) of the CNC 3 jaw hydraulic chuck.

By observation of Table 1 we narrow down the root cause of Ovality.

The conventional process used in the KOSO India Pvt. Ltd is as shown in the Flowchart 1.

This method includes the clamping of the job directly into the CNC Machine after the rough machining the next process is of Stelllite welding for the hardness of the rim of the seat. This is followed by first side machining then the workpiece is removed from chuck and then inserted inverted to work on the second side machining on the same machine. Here the ovality is introduced during this change of orientation and re-tightening of the workpiece. The next step is to grind the internal diameter. The finale step is of milling the slots on the collar finally the de-burring of the seat is done and the finished seat is sent for inspection.

The above procedure has a great chance of job rejection as it was observed in the observation tables and the data provided by the industry at the time of the initial phase of this project.

1.2 Objectives

1. Designing of the holding fixture assembly to avoid deformation by the clamping pressure of hydraulic chuck.

2. Analysis of the designed prototype to ensure a good life under the forces of the machining operations with the help of FEA software Ansys.
3. Manufacture of the prototype
4. Reduction of the mounting time and rejection rate of the manufactured jobs.

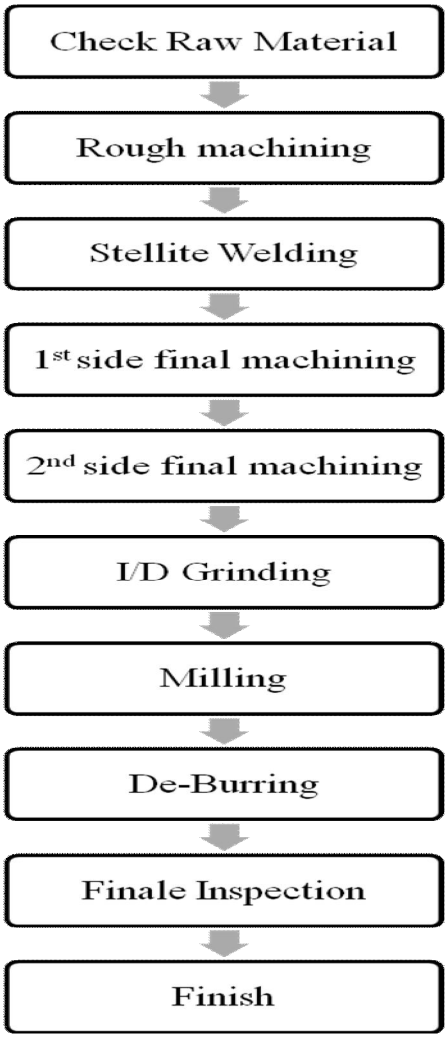

Fig.1 Traditional process of seat manufacturing

1.3 Scope

The scope of the project is the study of the fixture designing procedure and various approaches to make a better design of the fixture then the procedure to calculate the dimensions and design feature to ensure the durability of the fixture by analysis of the model with the respective working forces experienced during the manufacture of the component then the study of the prototype of the proposed fixture for the experimentation on the mating of the fixture and the component.

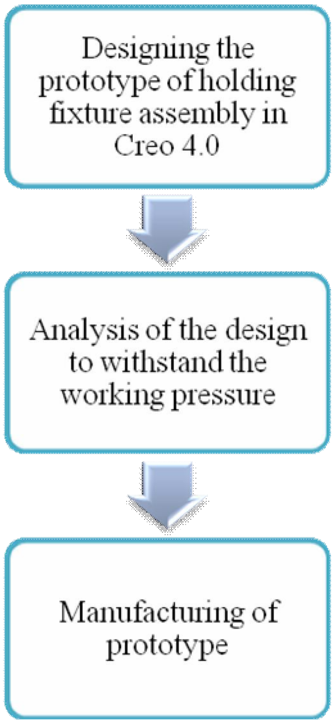

Fig.2 Flow chart 1

1.4 Methodology

Methodology used in this project covers many grounds which includes following steps initial step is Study of the current manufacturing process of the valve seat and brainstorming for the causes of rejection of the workpiece. Problem once identified, then the surveys of the previous literature were done and the design process was formalized. The design has many features for workpiece guiding and reduction of the cycle time of clamping and de-clamping of the job. The design proposed for the prototype is Analyzed using Analysis Software Ansys with respect to the working loads experienced during the machine work on the job. This gives the threshold pressureand design thickness required for the manufacture of the prototype.The prototype is made for the primary reason of the hands on mating of the workpiece with the fixture designed and any physical in-capabilities or assembly condition.

1.5 Organization of Dissertation

This project work includes the detailed introduction to the problems faced by the industry in manufacturing of the valve seat. This includes the rejection percentages and the causes of the problem. Which help the deduction of the root cause of Ovality i.e. the clamping pressure of the CNC chuck. Further it includes the methodology used to eliminate the problem.

Table 1 Problem Identification

Sr. no.	Existing Technology / Process	Problem(s) Identified	Impact on the job	Proposed Solution	Expected result
1	Direct clamping of workpiece	Deformation of job due to clamp pressure	Geometric tolerances are not met	Use of holding fixture.	Elimination of the deforming force.
2	Holding of finished portion in chuck	Surface finish is disturbed	Poor finish and difficulty in assembly.	Use of fixture with continuous contact surface	Avoiding the unwanted clamping dents.
3	Clamping of side two with manual truing	Loss of concentricity in I.D and O.D.	Lead to leak due to improper sealing of plug	Fixture with bore of O.D to guides the job. Truing not required	Increase in precision of manufacture

In next chapter literature review on previous study research paper is carried out whichare related to fixture design. It includes detailed study of particular research paper, noting observations and drawing conclusions from them. Depending upon that, the further design steps are decided. It forms base line for deciding further strategies for work to be done in next stage of project.

II. LITERATURE REVIEW

Nirav P. Maniara,*,Dr. D. P. Vakhariab [1]developed the procedure for calculation of the unbalanced weight of the fixture during the designing phase and adding the counterweight in the manufactured fixture. This is achieved by using the software Creo/ ProE 5.0 for model making the unbalance weight is calculated and the counter weight is added in the fixture to balance the fixture assembly while using in CNC Lathe. This paper also provides approaches for balancing

1. VI quadrant balancing
2. VIII quadrant balancing
3. VIII diamond quadrant method

An integrated approach of design, manufacturing and mass balancing of rotary fixture has been adopted in this work. This approach is of crucial importance in real manufacturing environment. Actually HMC is the best solution for performing the required operations on component considered in this work, but a designer cannot ask industry to replace already existing set up of CNC turning centre with HMC as HMC costs around 12.5 million rupees whereas CNC turning centre costs only about 2.5 million rupees. Here the research work of this paper is proved; 10 million rupees are saved in machine installation cost. A simplified, analytical method of use of Creo Elements/Pro 5.0 is proposed to solve the balancing problem. This approach is very useful as it opens the door to a more general class of problem and difficult tasks such as asymmetrical fixture as is the case in this work. However, it is expected to have more flexibility in its application, since it is not sensitive to dynamic conditions. The present research work proposes three alternate methods for Computer Aided Mass Balancing Method (CAMBM), which ease fixture designer from tedious and time consuming work of solving mass balancing problem. IV quadrant and VIII diamond quadrant methods are found more accurate than VIII quadrant method. However, VIII diamond quadrant method is found marginally better than IV quadrant method.

Li Hui, Chen Weifang, Shi Shengjie[2]discussed methods about the mounting of un-even work pieces in the working machine centers. The mass of such workpieces are non-symmetrically distributed which leads to the unbalance in mounting which leads to the formation of stress in the work piece while the operations are carried out.

Flexible fixture allows the mounting of such workpiece due to the provided flexible/ adjustable supports this ensures the proper resting of the work piece. The main feature of fixture is adaptive control on the fixture in real-time. Sensors are also provided to detect the placing and give appropriate signals to adjust the support positions

Iain Boyle, YimingRong , David C. Brown[3]reviewed the current method used for designing of the support fixture using computer aided machine drawing. The review shades light on the main key observations as the current research on the CAFD is segmented in nature. And there is less focus over the physical structure of the fixture.

The process discussed here follows a simple approach consisting of 4 stages

1. Setup planning
   a. To identify the configuration of workpiece i.e. Orientation
   b. Determination of the datum of fixture and relative position of the workpiece
2. Fixture planning
   a. Define required parameter to be met by the fixture.
   b. Decide the layout of the fixture.
3. Unit Design
   a. Concept building as per design criteria using software simulations.
   b. Detail unit design as for the production drawing with revised and appropriate dimensions.
4. Verification
   a. Verify the fixture requirements are met during manufacturing or not.

The collaboration of most of the current techniques and their specific focus on the CAFD approach and categorization of research don till date under the same hence achieving the unification of different approaches to optimize the fixture design bit by bit.

N. P. Maniar, D. P. Vakhariaet.[4] has derived a detailed design approach of the component manufacturing for a petrochemical industry (a tee junction in pipes). This approach is a cost reduction idea which approximates the saving of 10 million rupees due to use of the CNC machine instead of the costly horizontal machining center. This is an extension to the paper2.1 as in the use of technique of calculate the unbalanced force in the fixture design and balancing in the design itself before the manufacturing of actual component.
This technique is cost efficient and models the fixture with at most accuracy and increases the life of the manufactured fixture due to balanced design. As the CNC machine has the fixture to be rotated about axis the balancing is must as to avoid the vibrations of the component during the working phase of the component.

The discussed techniques for balancing of the fixture are

1. IV Quadrant Computer Aided Mass Balancing Method
2. VIII Quadrant Computer Aided Mass Balancing Method

R. J. Menassa,W. R. DeVrieset[5] proposes optimization technique to assist in design and evaluation of fixtures for holding prismatic work pieces this formulation of fixture design problem takes into account deflection of the workpiece subjected to assembly of machining loads. By using minimum deflection of work piece at selected

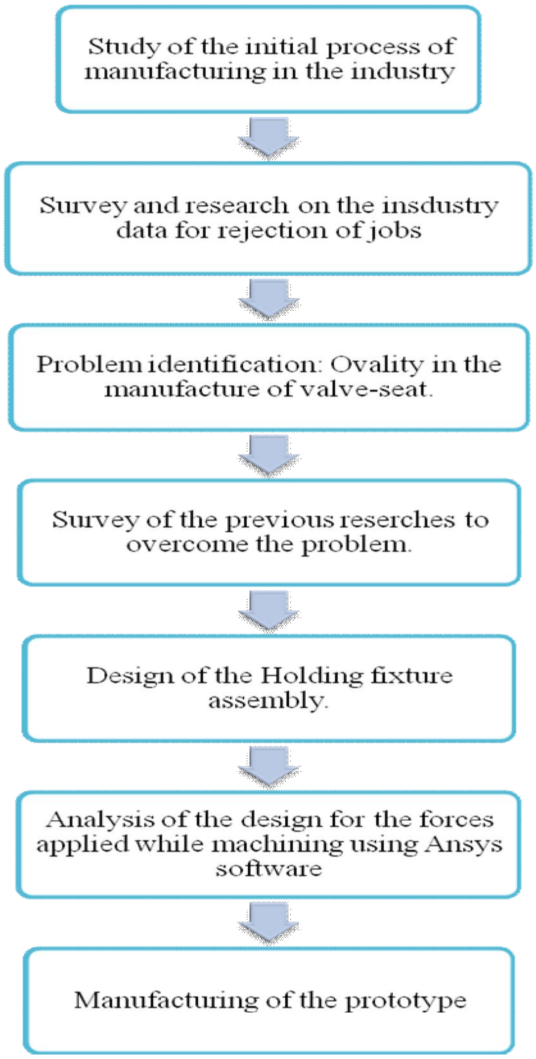

Fig.3Proposed methodology

points the design problem is determined by positions of fixture support. For deciding positions of fixture and calculating deflections Finite Element Method is used. The specific objectives of this research paper are

- Treat fixture design as an optimal design problem by formulating an objective function to determine the location of fixturing support
- Describe the FEM Method used in computing the deflection of work piece that are needed in evaluating the objective function

Asada et. al. (1985) studied the fixture design and the setup procedure are performed automatically by a computer integrated system and robot manipulator thus the layout of fixture is designed on CAD System. Workpiece accessibility and detachability are account in derivation of finale location of parts and fixture elements. To provide an initial configuration of fixture components necessary condition is kinematic feasibility i.e. Ensure that tool points are in contact with the work piece and restrict sliding and rotation of a part when located and held in fixture i.e. to minimize workpiece deflection.

Lee and Hynes et. al. (1986) developed a method of analysis to minimize various criterion that ensure sound machining and assembly tasks. Usually large clamping forces and high stresses are imparted on machining work that lead to workpiece failure. The Finite Element Method (FEM) is used and treat the work piece as isotropic deformable body based on linear elasticity and friction. The software uses finite element program that is capable of graphing the deformed and un-deformed work piece when subjected to manufacturing process.

Mani and Wilson(1988) et. al. studied the fixture layout and planning. The work piece geometry is first extracted from a solid geometric modeler and then displayed in 2D view so that fixturing plan conducted in cross sectional plane. ParagVichare ,AydinNassehi& Stephen T. Newman [6]proposed a model of Unified Manufacturing Resource Model (UMRM) for representing fixture-specific information for CNC manufacture. The UMRM has a rich data model, which has a promising potential for representing manufacturing resource domains such as machine tools, material handling systems including fixturing setup. Fixturing is the mechanism that can be used for executing various functions such as locating, supporting and clamping. The modular fixturing elements were classified according to their functions:

1. Base plate elements, where all the locating, supporting and clamping elements and work piece can be mounted
2. Locating element, such as location pins, V-blocks, location pads etc;
3. Supporting elements, such as adjustable spacers, shims etc for supporting work piece;
4. Clamping elements, used for clamping the work piece.

Another example of fixture blocks can be found in the pallet system where multiple work pieces are clamped on a single pallet. This type of fixturing is more prevalent in the flexible manufacturing system (FMS) due to its reconfigurable nature. By using UMRM the fixture specific information can be coupled with the machine tool specific information.

UMRM represent the kinematic chain between tool and work piece considering fixture configurations. In addition to geometric entities, unlike commercially available tools, UMRM can represent the logical purpose of the available manufacturing resources. Further developments, especially for modeling the application-oriented behavior of the resource elements, are aimed at the extension for representing CNC machining system. UMRM's resource information can be considered as a focal aspect for developing solutions for ever-challenged research areas.

Hui Wang, Yiming(Kevin)Rong, Hua Li, Price Shaun[7] has done a literature survey of computer aided fixture design and automation over past decade is proposed. This paper is mainly focused on recent research and trends. A fixture is a mechanism used in manufacturing to hold the workpiece, position it correctly with respect to machine tool, and support it during machining. It is widely used in manufacturing e.g. welding, turning, milling etc. Typically fixture design involves the identification of clamps, locators and support points and selection of corresponding fixture elements for their respective functions. Over a past decade much focus has been put on intelligent methods for computer aided fixture design. Currently, even though numerous techniques concentrating on fixture design have been proposed and made achievements, mature and commercial CAFD applications also are very limited. In CAFD, methodology needs to clear two crucial problems: how to represent fixture design knowledge in computer and how to implement the problem solving procedure.

It is apparent that almost all the literature is focused on machining fixtures field beside a few on welding fixture research. This puts a question of theoretical value of fixture research in other industrial field and more rigid comparative study of fixture design. Another attractive field is fixture design in micro and nano-machining. Because the nano-metric machining has very different physics from conventional machining.Eg. In manufacturing process, material and physical phenomenon, existing fixture design methodology cannot handle the meso-scale fixturing problem. With respect to this, micro and nano-fixturing technology appears promising. Additionally, trends in manufacturing flexibility and customized small production also suggest more deep comparisons, analysis and research on the applications on computerized modular fixtures and dedicated fixtures.

Yunbo Zhou, Yingguang Li, Wei Wang [8] proposes a feature based approach for the manufacturing of the fixture. Traditionally designing of fixture is done for a specific job/workpiece due to fixed dimensions of the manufactured fixture. The approach devised by the paper consist of 3D modeling of the fixture for certain common feature which are used frequently in many assemblies or jobs such as Pocket, Slot, Stepped hole etc. these features having a generic model of fixture stored in the database of the server any time any feature has to be made on the job the generic structure of the fixture can be called on the system from the database and keeping it as a base the modifications need to be done for the given task. This technique provides a solid foundation for the fixture to be made and the manufacturing or designing of fixture from scratch is avoided.

The manufacturing of aircraft structural parts is a relatively mature process and the details of manufacturing methods, parameters and tooling are similar. Fixtures used by different parts are also similar in structure. Such features are stored in the Case library. In Case library fixture is stored as a single feature but the constituent components are stored parametrically so as to modify them whenever required for the specific job.

The initial part of this approach is the feature recognition. The aircraft parts are large in size and complex in structure and include many free form surfaces, broken faces, edges and interactive features. It is difficult to recognize machining features from the 3D part model.

Yingguang Li et. al. proposed a new concept called Holographic Attribute Adjacent Graphics(HAAG), that added the face attribute and edge attribute in AGG to represent machine features of aircraft structural parts and gave a HAAG-based feature recognition approach to solve the problem of feature recognition of aircraft structural parts.

III. DESIGN PROCEDURE

3.1MATERIAL SELECTION

Selection of proper material for machine component is one of the most important step in process of machine design. The best material is one which will serve the desired purpose at minimum cost. Fixtures are made from variety of materials, some of which can be hardened to resist wear. It is some time necessary to use nonferrous materials like phosphor bronze to reduce wear of mating parts or nylons or fiber to prevent damage to work piece. The factors which should be considered while selecting the material for machine component are as follow.

1. Availability
2. Cost
3. Mechanical properties
4. Manufacturing consideration

There are different methods which are used for the material selection; one of them is weighted point method.

WEIGHTED POINT METHOD:-

Steps for the weighted point method-

1. Study and listing down the properties
2. Assigning the values
3. Calculation of points
4. Summation of points

According to our application, we have selected five materials for getting desired properties. They are as follows.

1. High speed steel
2. High tensile medium steel
3. High tensile alloy steel
4. Mild steel
5. Grey cast iron

The weightages given are:

Hardness-5
Compressive strength-4
Yield strength-3
Cost -2
PART 1: Calculation of weightage points for high speed steel
STEP 1: Points for hardness

The sum of hardness of 5 materials is given by

$320+190+444+150+200=1304$
Therefore, for high speed steel, the per cent hardness is given by

$320 \div 1304=0.245$

Since weightage for hardness is 5, the points for high speed steel are given by

$0.24 \times 5=1.2$

STEP 2: Points for compressive strength

The sum of compressive strength of 5 materials is given by

$768+65+1550+45+230=5140$

Therefore, for high speed steel, the per cent compressive strength is given by

$768 \div 5140=0.14$

Since weightage for compressive strength is 4, the points for high speed steel are given by

0.14×4=0.56

STEP 3: Points for yield strength

The sum of yield strength of 5 materials are given by

750+44+130+250+276=1450

Therefore, for high speed, per cent of compressive strength is given by

750÷1450=0.51

Since weightage for compressive strength is 3, the points for high speed steel are

0.51×3=1.53

STEP 4: Points for cost

Table 2 Property table of available materials

Sr. no	Material property	High speed steel	High tensile steel(medium)	High tensile steel(alloy)	Mild steel	Grey cast iron
1	Hardness(BHN)	320	190	444	150	200
2	Compressive strength(MPa)	768	65	1550	45	230
3	Yield strength(MPa)	750	44	130	250	276
4	Cost(Rs/Kg)	300	75	90	52	45

Table 3 Point table of different materials

Sr. no	Material property	High speed steel	High tensile steel(medium)	High tensile steel(alloy)	Mild steel	Grey cast iron
1	Hardness(BHN)	1.2	07	1.7	0.55	0.75
2	Compressive strength(MPa)	0.56	0.05	1.2	0.032	0.176
3	Yield strength(MPa)	1.53	0.09	0.267	0.51	0.57
4	Cost(Rs/Kg)	0.096	0.038	0.32	0.54	0.64
	TOTAL	3.38	1.22	3.48	1.63	2.136

There is inverse relation between cost and material
The sum of cost factor is given by

(1÷300)+(1÷75)+(1÷90)+(1÷52)+(1÷45)=0.069

Therefore, for high speed steel, the per cent for cost factor is given by

300÷0.069=0.048

Since weightage for cost factor is 2, the points for high speed steel are given by

0.048×2=0.096

STEP 5: Total points

1.2+0.56+1.53+0.096=3.38

similarly, total points for other material are tabulated in Table 3.

Result: From the point table above the total points of the high tensile steel are least (1.22) so this material is selected as optimum characteristics

3.2 Design Calculations

Design of base plate:

Purpose

It provide support to work piece & used for alignment. And it also used for holding the job. It provides arrangement to apply face plate through Allen bolt.

Functional requirement
Jaw width = 38.5mm

Outer diameter = 159.5mm
Material used = high speed alloy steel
Syt = 1300 Mpa
Factor of safety (FOS) = 3
Modulus of Elasticity = 2.07×105 N/mm2
Volumetric pressure = 40 bar
Poison's ratio (μ) = 0.3
Allowable stress = (Syt/FOS)
= 1300/3
=433.3 Mpa

By relation of Modulus of Elasticity (E) & Bulk modulus (K),
$E = 3K(1-2\mu)$
$K = E/(3(1-2\mu))$
$= [2.07\times(10)^5]/[3(1-2(0.3))]$
$K = 1.725\times105$ N/mm^2
Initial volume of cylinder = $\pi/4 \; d0^2 \; L$
Change in volume of cylinder = $(\pi/4)\,(d0^2 - di^2)L$
As we know that, Bulk modulus,
K = (applied pressure)/(volumetric strain)
$K = dp/(\delta v/v)$
$K = [4\times(\pi/4 \; d_o^2 \; L)]/[(\pi/4)(d_o^2 - d_i^2)L]$
$1.725\times10^5 = [4\times(159.5)^2]/[(159.5)^2 - d_i^2]$
$di^2 = 25439.66$ mm
di = 159.489 mm
Change in diameter is (do - di),
δd=159.5-159.489
δd =0.001849 mm

The deviation is in 1 micro meter which is under the design tolerances.

Hence the design is safe.

Design of face plate 1:

Purpose

It constraints the axial moment of work piece & facilitate the face clamping of work piece.

Design:

Consider it as a simply supported beam.
For composite disk,
Mass moment of inertia about neutral axis is given by,

For small disk, $I_1 = \pi/32(D_o^4-D_i^4)$
$= 9164684.244\ mm^4$
For larger disk, $I_2 = \pi/32(D_o^4-D_i^4)$
$= 14371732.39\ mm^4$

Apply perpendicular axis theorem
$Ic = I_1 + I_2$
Ic = 23536416.63 mm4
Hence Ixx = 11768208.31 mm4
From loading diagram,
Moment at C = max. moment
= 20×49.15
= 983 N-mm
Thickness of plate = 4mm
y = distance of outermost fiber from neutral axis
y_{max} = 2mm
Using flexural formula,
M/I = (bending stress)/(y_{max})
983/11768208.31 = (bending stress)/2
Bending stress (Ϭ)outermost = 1.6706×10^{-4}Mpa
Hence the design is safe.
Similarly for face plate 2
For small disk, I1 = 532268.238 mm^4
For larger disk, I2 = 963463.635 mm^4
Hence Ixx = 747865.93 mm4
Max. Moment = 483 N-mm
Using flexural formula,
M/I = (bending stress)/(y_{max})
Bending stress (Ϭ) = 1.2916×10-3 Mpa
Hence the design is safe.
Similarly for face plate 3
For small disk, I1 = 155652.69 mm^4
For larger disk, I2 = 365932.712 mm^4
Hence Ixx = 260792.70 mm^4
Max. Moment = 356 N-mm
Using flexural formula,
M/I = (bending stress)/(y_{max})
Bending stress (Ϭ) = 2.7301×10-3 Mpa
Hence the design is safe.

IV. CONCLUSION

Elimination of the problem of Ovality in the manufacturing of valve seat is achieved by designing a holding fixture assembly to avoid the holding of job directly into the machine chuck as the main cause of Ovality was the deformation of material due to the hydraulic pressure of machine chuck. Methods used are derived from the previous researches done in the development of the fixture which includes Computer Aided fixture design, Feature Based fixture design, Flexible design fixture and the Computer aided mass balancing method. Analysis of the design is done on the Ansys software with the parameters as the working pressure of CNC Machine used in the Industry. The manufacturing of the prototype is done by additive manufacturing as to have a finished product for the physical experimentation with the mating of job and fixture. This project also deals with the reduction of the mounting time on the fixture and easy mounting of the workpiece.

REFERENCES

[1] Nirav P. Maniara,*,Dr. D. P. Vakhariab “Design & development of rotary fixture for CNC with computer aided mass balancing method as pre-mortem tool” , 2nd International Conference on Innovations in Automation and Mechatronics Engineering, ICIAME 2014.
[2] Li Hui, Chen Weifang, Shi Shengjie, “'Design and Application of Flexible Fixture”, 9th International Conference of Digital Enterprise Technology- DTE2016 – Intelligent Manufacturing in the Knowledge Economy Era China, 2016.
[3] 3.Iain Boyle, YimingRong , David C. Brown, “A Review and Analysis of current computer-aided fixture design approaches”,Robotic and computer integrated manufacturing 27 USA, 2011.
[4] N. P. Maniar, D. P. Vakharia, “Design & Development of Rotary Fixture for CNC”, International Journal of Engineering Science Invention India 2012.
[5] R. J. Menassa,W. R. DeVries, “Optimization Methods Applied toSelecting Support Positions inFixture Design” Department of Mechanical Engineering,Aeronautical Engineering and Mechanics,Rensselaer Polytechnic Institute,Troy, NY 12180-3590 1991.
[6] ParagVichare ,AydinNassehi& Stephen T. Newman, “Unified representation of fixtures:clamping, locating and

supportingelements in CNC manufacture"International Journal of Production Research, 49:16, 5017-5032, DOI:10.1080/00207543.2010.518992 2011.

[7] HuiWang,Yiming(Kevin)Rong,HuaLi,PriceShaunb, "Computer aided fixture design: Recent research and trends",0010-4485/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.DOI:10.1016/j.cad.2010.07.003 2010.

[8] Yunbo Zhou, Yingguang Li, Wei Wang, "A feature-based fixture design methodology for the manufacturing of aircraft structural parts"0736-5845/$ -seefrontmatter& 2011 ElsevierLtd.Allrightsreserved. DOI:10.1016/j.rcim.2011.05.002 2011.