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Design and Manufacturing of Single sided expanding collet for Rotary VMC Fixture

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ABSTRACT

Expanding Collets are extensively used to hold the workpieces with circular features. Due to the shape and narrow tolerances, designs of such collets are always challenging. The paper represents process of dimensional design of a single sided expanding collet. This collet is for rotary VMC fixture. The collet not only just designed but also manufactured. The paper shows implementation of technological concepts for a live industry component which will really help a collet designer to design such kind of collets. The design is carried out using PTC Creo Parametric 3.0 and AutoCAD 2016. Finite element Analysis is carried out with Creo Simulation.

SUMMARY

Design and manufacturing of expanding workholding collet for a rotary VMC fixture to be used in the industry.

Keywords: Expanding collet, Mandrel, Fixture

INTRODUCTION

Collets is one of the best clamping device used to fix circular workpiece. Collets hold the workpiece by expanding externally or internally. When the workpiece is fixed by clamping its outer surface, it is called external collet, otherwise it is internally expanding collet. Internal expanding collets are further classified according to its side of operation. As shown in the Fig. *1*, single sided collets have open slots to one end only.

These kind of collets are easy to manufacture and hence is cheaper than double sided collets, but used for comparatively low clamping force. This paper shows a dimensional design process to design single sided expanding collet for a rotary CNC VMC fixture.

BACKGROUND

Collets are extensively used as fixture clamping elements. Shyr-long Jeng, Long-gwai Chen And Wei-hua Chieng*(1)* have found minimum clamping force for the stability of the workpiece while machining for different fixturing conditions. Excessive clamping force may deform the workpiece and less clamping force may not withstand the cutting load. Fixture clamping sequence is also has a major role to achieve the required accuracy. Anand Raghu, Shreyes N. Melkote*(2)* expressed that poor part location error leads to part location errors. The authors also refer that "In addition to typical error sources, such as fixture geometric error and elastic deformation of the fixture and part due to clamping forces, the clamping sequence used can also influence part position and orientation.". They have found influence of clamping sequence on part location errors by analytical model and experiments. J.H. Yehand F.W. Liou*(3)* have found identification of insufficient clamping force by analytical FEA model. Prediction of workpiece deformation helps the fixture designer to decide various parameters. Y. Wang, X. Chen and N. Gindy*(4)* have done deformation analysis between complicatedly shaped components and fixture elements. The verified FE analysis is used to predict surface error arising from deformations, and to evaluate the deformation distributions from fixture elements and work piece. K. Siva Kumar, and G. Paulraj*(5)* present the optimization of the locations of active (clamp) and passive (locator/support) elements in the workpiece-fixture system using genetic algorithm (GA) with ANSYS parametric design language (APDL) of finite element analysis. These authors have successfully developed a systematic procedure to optimise the locators and clamping positions to minimise the workpiece deformation using GA and FEA. Shane P. Siebenaler, Shreyes N. Melkote*(6)* studied various factors influencing the prediction of workpiece deformation with FEA. Prediction of deformations and locator reaction forces are also checked by experimental setup.

Traian Lucian SEVERIN and Vasile RATA*(7)* have studied on clenching mechanism for chuck model. The authors have expressed a mathematical model for chuck collet mechanism using theory of friction. Validation is also carried out by experimental setup. Stress model given by the authors can be used in the design of collet.

Thus, many researchers have worked for the analysis and design of fixtures, some on collets as well. Their findings individually have really helped the fixture design process and hence collet design process. But there are very less researchers who have designed and manufactured actual fixtures with collets which are to be used for industry purpose. The present paper gives design of expanding collet which is really to be used in the industry.

WORKING OF EXPANDING COLLET

Consider **Error! Reference source not found.**. The workpiece is kept in such a way, so that it touches the resting block. Taper surface of Mandrel and collet should match. Mandrel along with pull rod when joined using threads behaves like a single rigid bar. Puller rod when pulled downward, will push the taper contact surface of collet to expand outward and thus the workpiece is firmly clamped. To declamp the workpiece, the puller rod is again put to the original place.

STATEMENT OF PROBLEM

To design single sided expanding collet to hold workpiece for machining on VMC with 4^{th} axis(Rotary table with face plate support).

Material of the workpiece is Aluminum A360 Die Casting Alloy. The operations to be carried out are drilling and tapping. The fixture is rotary (4 axis) which is to be used with VMC machine. Fig. 3 shows orthographic views of the workpiece. As shown in the **Error! Reference source not found.**, the reference dimension of the internal hole is 23.875 mm with symmetric tolerance of 0.125 mm. This diameter is to be used to hold the workpiece using expanding collet. Thus the collet should hold the workpiece using this hole with consideration of the tolerance. Operations to be carried out are drilling and tapping on two sides of the workpiece as shown in **Error! Reference source not found.** and **Error! Reference source not found.**.

As the fixture is rotary in nature, each side will be machined by rotating respectively. At zero degree (Fig. 5), two tapping holes of M2.5 is to be done. At 90 degree rotation (Fig. 4), 3 holes of M3.5 and two tapping of M5 is to be done. Maximum cutting force is expected to be 1.25 kN. The clamping force should be about 1.5 times against the cutting force to avoid any undue situations. Workpiece material is A360 and has comparatively small depth of cut, single angle collet will be a good choice as it has less manufacturing cost. Clamping and declamping is suggested as hydraulic.

COLLET DESIGN PROCESS

Error! Reference source not found. shows concept design for collet. As shown here, the collet will remain vertical which will hold the workpiece from the inside diameter. This diameter is to be taken as reference. While designing collets, the reference diameter has greater importance. This diameter should be having higher surface finish and dimensional tolerance. Here the reference diameter has a surface roughness of 1.6 Ra and a symmetric tolerance of 0.125 mm which allows this diameter to be used as reference diameter using which the collet will hold the workpiece.

As shown in **Error! Reference source not found.**, the reference diameter is not even throughout the length but is has surface irregularities in term of steps. So, the collet cannot use the entire length of the reference diameter but it can use maximum of (5.7 + 2.3)8 mm for clamping.

The reference diameter has a symmetric tolerance of ±0.125 mm. Considering the worst condition, the minimum diameter of the workpiece can be 23.875 – 0.125 = 23.750 mm. The collet should be able to hold the workpiece for the entire range of the workpiece diameter. Clearance between the workpiece and normal diameter of the collet (without expansion) is taken as 0.020 mm on diameter. So, the collet diameter should be 23.730 mm. And it should expand to clamp the workpiece with maximum diameter of 23.875 + 0.125 = 24.000. The collet should be able to expand by 0.020 + 0.125 = 0.125 = 0.270 mm. Consider **Error! Reference source not found.**. As per an empirical relation, the collet should be 2 mm above at the initial state. As earlier stated, the collet diameter is to be taken as 23.750 which is closer to 24 by randomizing. To take 2 mm of collet thickness, internal diameter of the collet should be 20 mm. Considering taper angle to be 5^0 and extending the taper surface almost at the middle of the reference-diameter length, the taper surface should end at 24 mm from top surface. Then a step is provided to weaken the strength and thus to increase the stress concentration. This phenomenon helps the collet to expand evenly with respect to free end. The width of this section should be same as collet minimum thickness and the length should be according to length of the workpiece reference-diameter plus some clearance which is taken here as 5 mm. Workpiece resting is of 20 mm and collet flange is taken as 14 mm. As per these empirical relations remaining length of the collet is 39 mm. Collet thus designed is shown in **Error! Reference source not found.** by putting all other required dimensions as per need and experience. This collet will be firmly bolted with main fixture plate using 3 M6 bolts. **Error! Reference source not found.** shows complete collet assembly along with hydraulic cylinder.

FORCE CALCULATION

Depending upon the prevailing cutting condition, maximum cutting force will be 1.25 kN. This cutting force is given by the vendor, so here calculation for the cutting force is not necessary.

As the clamping force should be 1.5 times the cutting force,

Clamping force = Cutting Force X 1.5

$\therefore$ Clamping force = 1.25 X 1.5 = 1.875 kN which is randomize as 2 kN.

This force is to be generated by applying force on the entire taper surface of the collet by taper Mandrel. This Mandrel is pulled by puller rod and puller rod is connected with hydraulic actuating cylinder. Hydraulic cylinder has reciprocating piston which in term pulls the push rod. There should be enough amount of pressure inside the cylinder. To find intensity of the cylinder pressure, following procedure is carried out.

To achieve clamping force of 2 kN, pulling force required should be around 5.5 kN. Hydraulic cylinder is to be taken as standard element. Here, KOSMEK brand hydraulic cylinder is selected *(10)*. Looking to the specifications given, for various cylinders, LLR0400 will be a suitable choice. Fig. 11 shows specification of Hydraulic Compact Cylinder. The workpiece is clamped here when there is a pulling action in the cylinder. As shown in Fig. 11,

Pulling force or Cylinder force = P X 0.28

Assuming cylinder pressure P to be 20 MPa.
$\therefore$ Pulling force = 20 X 0.28 = 5.6 kN which is closer to pulling force required (5.5 kN).

FINITE ELEMENT ANALYSIS

The above design is a dimensional design and carried out using knowledge base and empirical relations. Dimensions thus achieved must be checked using FEA software. As most critical part in the entire assembly is collet, FEA is carried out for this component as below. Creo Simulation 3.0 is used to carry out FEA. Here assembly of mandrel and collet is considered and contact stress analysis has been carried out. The assembly is restricted at the either end of taper end. Pulling force is applied at the end of puller rod. Mesh size is restricted to maximum size of 5 mm.

The result (Fig. 11) shows that maximum stress produced is 290 MPa. The collet is made from EN24 for which tensile and yield stress is 850 N/mm^2 and 650 N/mm^2 *(8)* respectively. Taper Mandrel is made of EN31 which has Tensile Strength as 750 N/mm^2 and Yield Stress 450 N/mm^2*(9)*.

FEA result shows that the collet and mandrel are well within allowable stresses.

MANUFACTURING

The collet thus designed is manufactured also using the achieved dimensions. Table 1 shows manufacturing process plan for manufacturing of collet. Fig. 12 shows manufactured collet without component. Fig. 13 shows manufactured collet with component.

CONCLUSION

The paper presents a dimensional design of single sided expanding collet for fixture. This design achieves all the requirements needed for actual working. Manufacturing of the component has also been carried out. The component thus manufactured has been checked and is found within specified tolerances.

Many parameters are assumed here from past experiences. This design can be over safe and may use higher dimensions than what really are required. To get optimized dimension, the design should also be checked analytically.

FIGURES

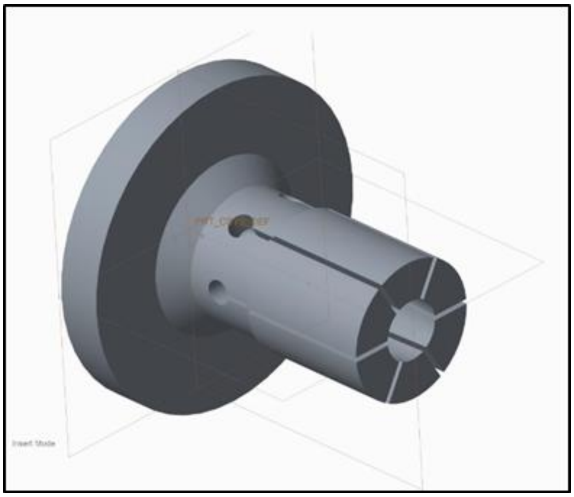


Fig. 1. Single Sided Expanding Collet

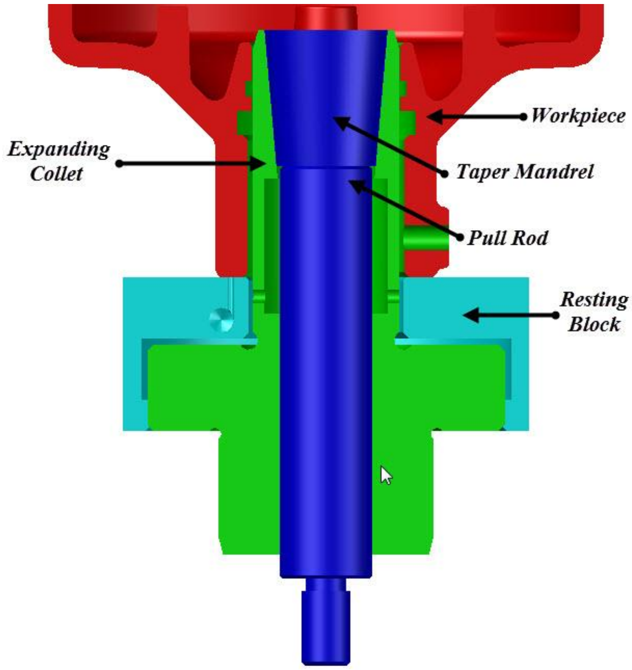
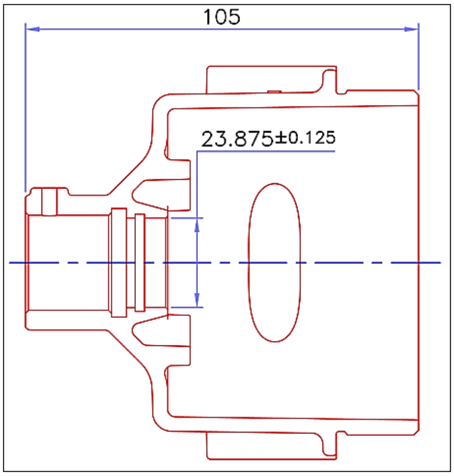
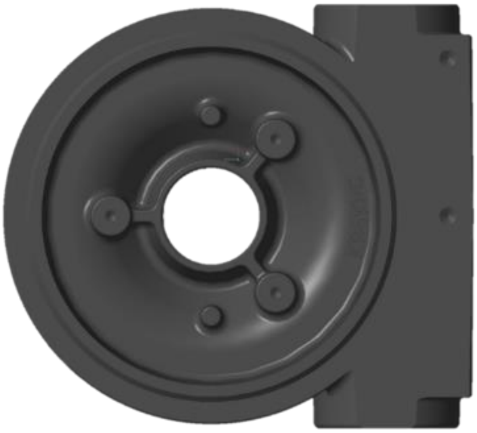


Fig. 2. Working of expanding Collet



(a) Front View



(b) Side View - Shaded

(c) Side View - Shaded

Fig. 3. Orthographic Views of Workpiece

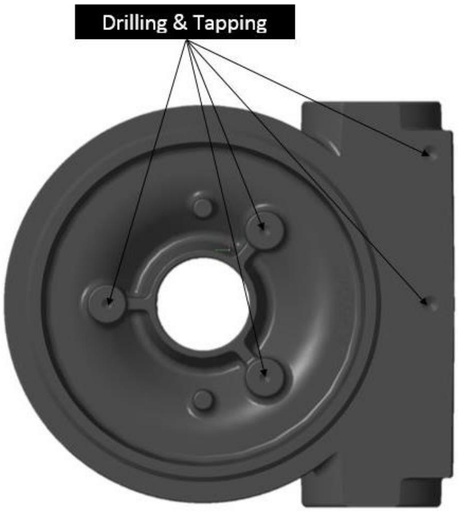


Fig. 4. Operations at 90^0

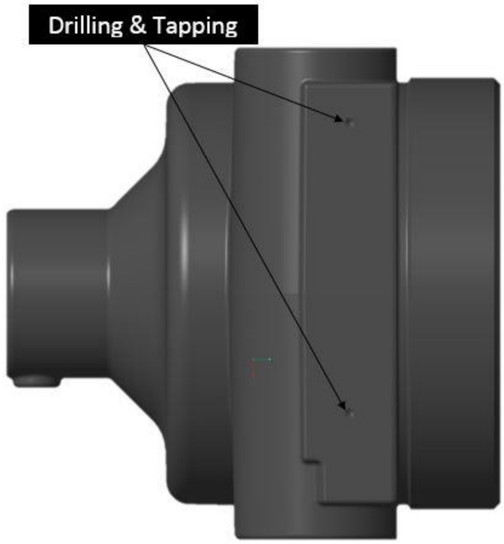


Fig. 5. Operations at 0^0

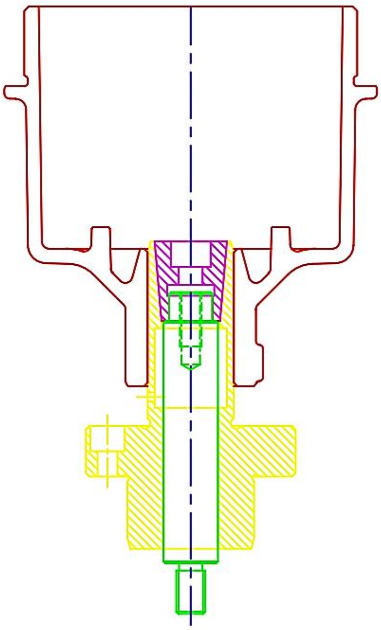


Fig. 6. Concept Design

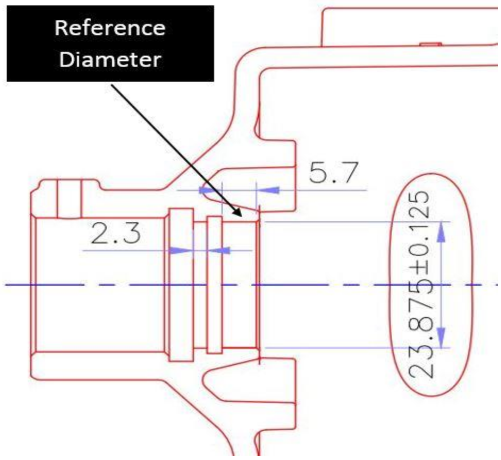


Fig. 7. Workpiece Reference Diameter

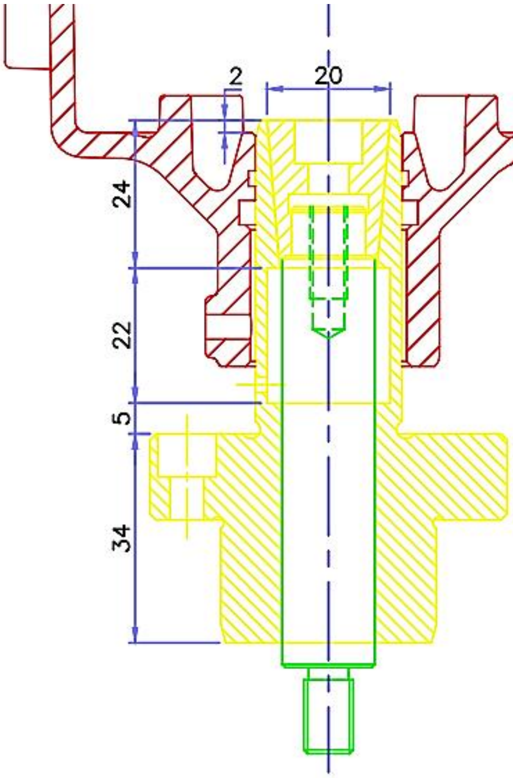


Fig. 8. Collet Design

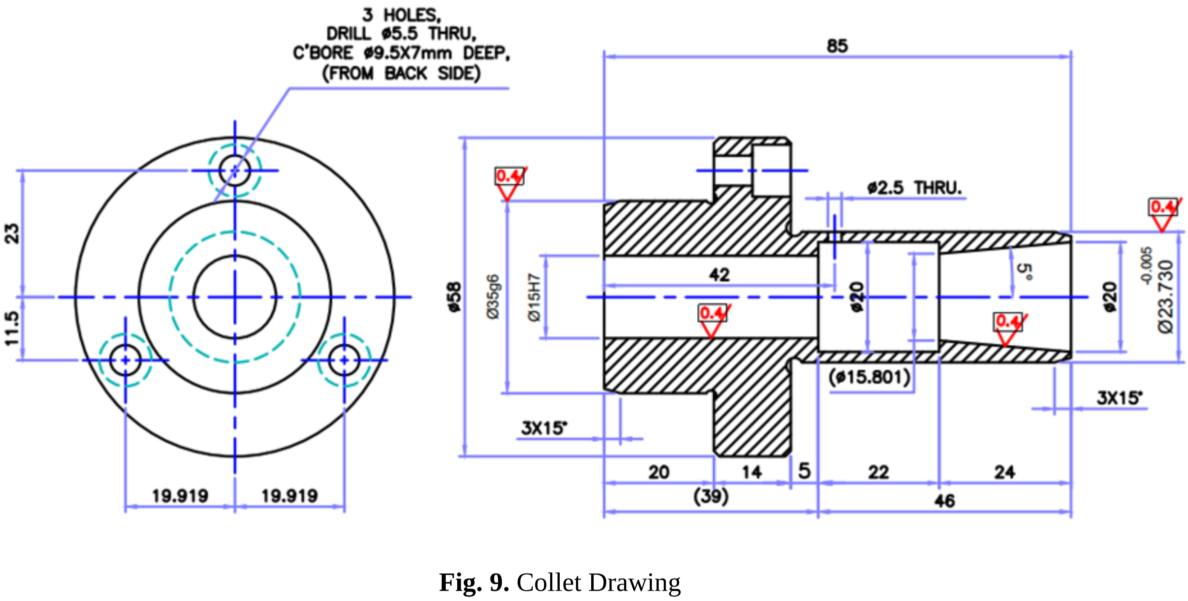


Fig. 9. Collet Drawing

Fig. 10. Exploded Collet-Assembly with Hydraulic cylinder

Specifications

Model No.		LLR0360-□□	LLR0400-□□
Full Stroke Y mm		Y : 1～50	
Cylinder Area cm^2	Push Side	4.5	5.3
	Retract (Pull) Side	2.5	2.8
Cylinder force (Calculation Formula) kN	Push Side	P×0.45	P×0.53
	Retract (Pull) Side	P×0.25	P×0.28
Cylinder Capacity (Calculation Formula) cm^3	Push Side	Y×0.45	Y×0.53
	Retract (Pull) Side	Y×0.25	Y×0.28
Cylinder Inside Diameter mm		ϕ24	ϕ26
Rod Diameter mm		ϕ16	ϕ18

Fig. 11. Specification of Hydraulic Compact Cylinder*(10)*

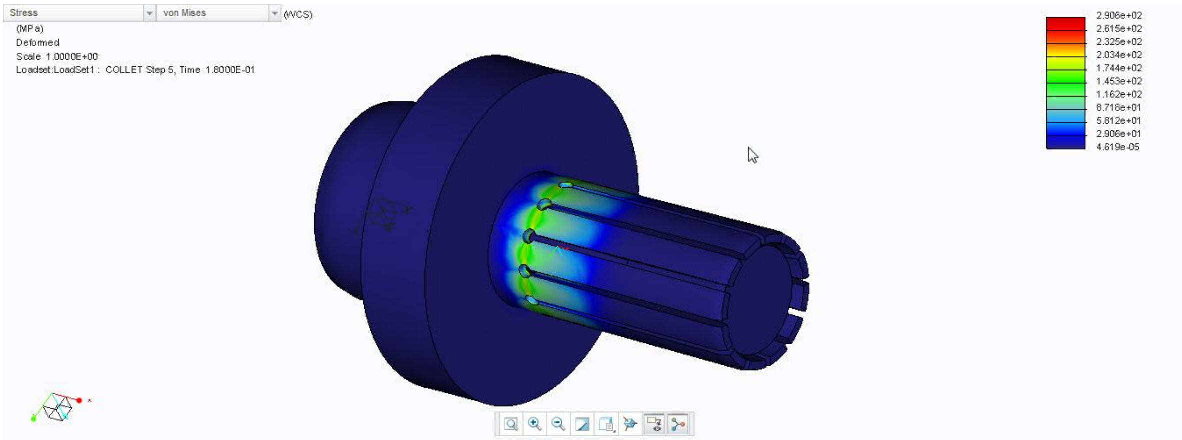


Fig. 12. FEA Stress Analysis Result

Fig. 13. Collet without Component

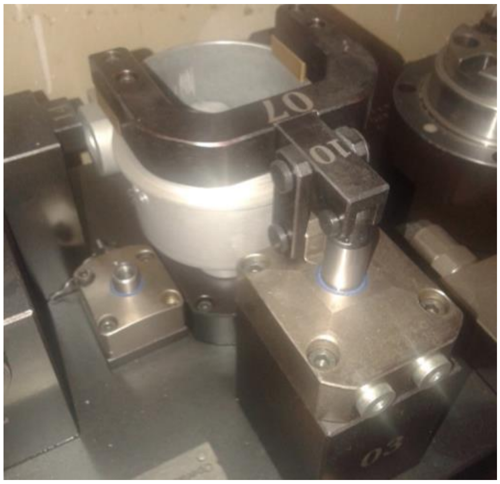


Fig. 14. Collet with Component

TABLES

Table 1. Manufacturing Process Sequence

Sr.NO.	Name of Operation	Machine
1.	Turning(Including taper surface)	CNC turning centre
2.	Hole on PCD	Jig Boring Machine
3.	Relieving Hole for slit cutting	Jig Boring Machine
4.	Heat Treatment	-
5.	I.D. and Face Grinder	Universal Grinding Machine
6.	O.D. Grinding	Universal Grinding Machine
7.	Slit Cutting	Wire Cut Machine

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