DESIGN AND MANUFACTURE OF A HYDRAULIC EXPANDING MANDREL

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Abstract

The present scenario in the mechanical manufacturing industries is, the conventional machine tools are being given a go by and more and more small as well as medium scale industries have switched over to CNC Machine tools. The CNC Machine tools basically with their higher accuracies and higher rates of production need to utilize more precision component location and clamping systems. Our Prime Ministers recent policy guideline "MAKE IN INDIA" makes it all the more important that in order to compete with international manufacturers, the manufacturing Industry should achieve component location and clamping elements of much higher accuracy.

The present work involves the Design and Manufacture of a Hydraulic Expansion Mandrel. Hydraulic Expansion Mandrels and chucks are high precision work or tool holding devices for true running of work piece for further machining operations, or inspection of concentricity. In case of tool holding, they increase the tool life by about 15 to 20% due to true running. Typically, the run out is less than 0.005mm Total Indicator Reading (TIR) in expanded condition. The Hydraulic medium used is a solid Hydro-Plastic Jelly and the mandrel expands with 1 or 2 rotations of a set screw. No external power pack is required. The Hydraulic Medium being solid, the leakages are very low. If the length to diameter ratio is in the range of 2 to 3, very high clamping forces can also be achieved. As a sample case, a 32mm diameter Hydraulic Expanding Mandrel is designed and manufactured to locate and clamp components with a bore size of 32.00H7.

Keywords: *CNC Machine, Hydraulic Expansion, Mandrel, Chucks , Sleeve, Actuator, Refil adaptor, Butting ring.*

1. INTRODUCTION

32mmDiameter Hydraulic Expanding Mandrel

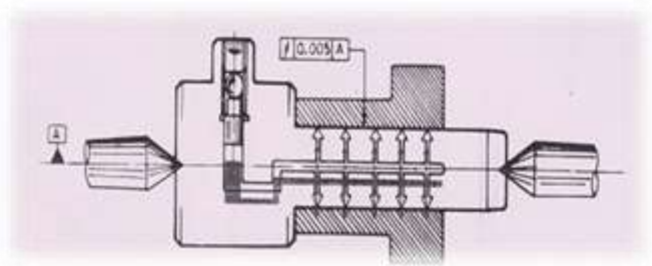
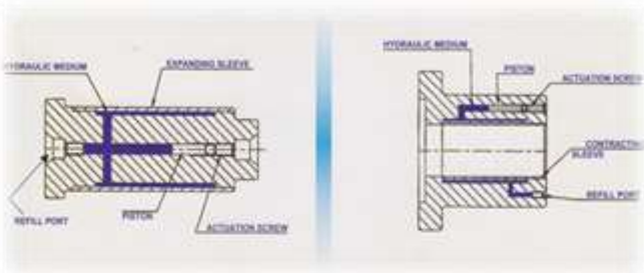


Fig 1.1(a) Hydraulic Expanding Fixture in Clamped Condition

Hydraulic Expanding Mandrels and chucks work on the principle of Expansion of thin walled cylinders under high pressure. Shown below are the schematic diagrams of an Expanding Mandrel and a contracting chuck. The mandrel/chuck has a hydraulic chamber below the thin walled sleeve and is fitted with a solid hydraulic medium. The in-ward movement of the piston by means of manual rotation of the actuating screw or power assisted movement through a drawbar causes a uniform radial expansion/contracting, resulting in accurate location and uniform clamping of the workpiece. Retraction of the piston causes return of the sleeve to original diameter facilitating easy un-loading of the workpiece.



2. Design of Hydraulic Expanding Mandrel

2.1) Basic Principle of Working:

Hydraulic Expanding Mandrels and Chucks work on the principle of expansion of thin walled cylinders under hydraulic pressure. An extremely thin walled cylinder manufactured from Chrome Vanadium Steel heat treated to a tensile strength of 1300N/mm^2(40 Hardness Rockwell C Scale).The sleeve is ground to close tolerances. To further increase the service life of the mandrel, the sleeve can be hard chrome plated before finish grinding in assembly.

The sleeve is shrunk fit on the Mandrel Body (Mandrel body ground to p5 tolerance and shrink fitting bore ground to H6 tolerance).The shrink fitting ensures that the sleeve can transmit torque from mandrel body to the component, at the same time without losing locational accuracy.

The Hydraulic Medium is Solid Hydro Plastic Jelly, a special formulation. The jelly can transmit pressure like hydraulic oil but with lower leakage rates.

Pressure is applied on the jelly through a close fitting Piston and Bush arrangement (the clearance being about 2 to 3μm).The piston is actuated manually by using an Allen key to rotate a set screw. However in case of flange mounted mandrels and chucks, the piston can be also be actuated through a hydraulic or pneumatic draw bar.

Once the inspection or machining operation on the component (or tool in the case of tool holding devices) is completed, the unscrewing of the set screw or withdrawal of the draw bar force, the pressure in the system falls. Since the sleeve is made of spring steel, it collapses to its unpressurized size, facilitating unloading of the component and reloading of the next component.

2.2) Why an Expanding Mandrel?

An Expanding Mandrel is basically a work holding device for precision component machining, i.e, is a tooling item.

The golden rule in tool design is 'Avoid combining location and clamping in a single unit'. This rule is always known to the tool designers but is often forgotten, till they face the problem of Geometrical Accuracies. Then, they look at the other options and finally conclude that an expanding mandrel is the answer. This is amply illustrated in the sketch in chapter I. The problem is more intense in hardened mandrels where the threaded portion and the locating diameter are not co-axial due to a possible bending in Heat Treatment.

3. Materials of Construction:

a) Mandrel Body: In all precision grinding or inspection work, the mandrel will be rotating on Tungsten Carbide dead centers. For a long service life, the female centers on the mandrel need to have good wear resistance property. As a natural choice, the mandrel body is made out of En 31(a High Carbon Chromium Manganese Steel) and heat treated to 58 -60 HRC.Turning and Drilling operations were carried out. Tapping operation were carried out for internal threads. After this operations the Mandrel was given for Heat Treatment to achieve Hardness of 55-60 RC. Then the cylindrical grinding operation was carried out to achieve the required tolerances.

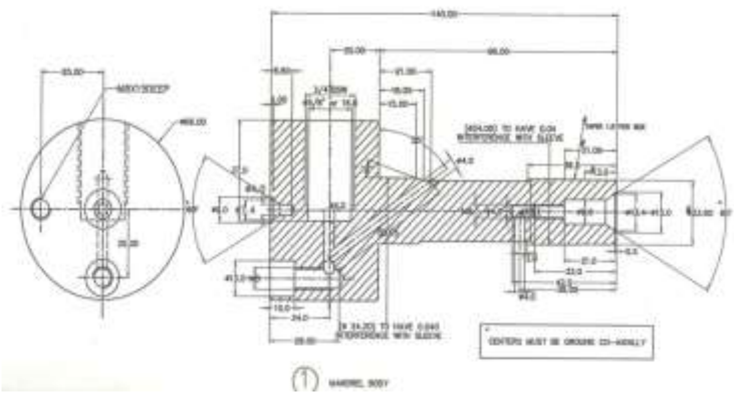
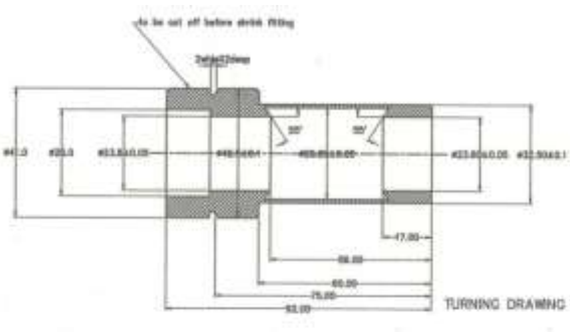


Fig 3.1. Mandrel Drawing

*b) Sleeve:*For the sleeve ,since it has to go through repeated expansion and contraction cycles, spring steel to En 47 specifications is chosen.The En 47, a Chrome Vanadium Steel is chosen for its excellent fatigue resistance properties. En 47 can be heat treated to 45 HRC, but at this hardness, the steel becomes extremely brittle. Hence after hardening, the sleeve is tempered to a hardness of 38-42 HRC. However, the sleeve is hard chromium plated to increase its wear resistance. But, Hard Chromium plating brings with it the problem of Hydrogen Embrittlement. Hydrogen Embrittlement is harmless in case of solid or thick walled materials, but can cause cracking of thin walled materials. Hence, it is imperative that the sleeve has to undergo Hydrogen De- Embrittlement Process.



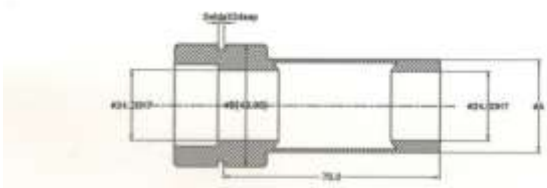


Fig. 3.2. Sleeve Drawing

c) Actuator: Actuator houses the piston-bush sub assembly. The bush is fixed to the actuator using Epoxy Adhesive (Araldite).The set screw through a steel ball pushes the piston to compress the hydro plastic jelly. The actuator is not a major wear part and so is manufactured from medium carbon steel (En8).

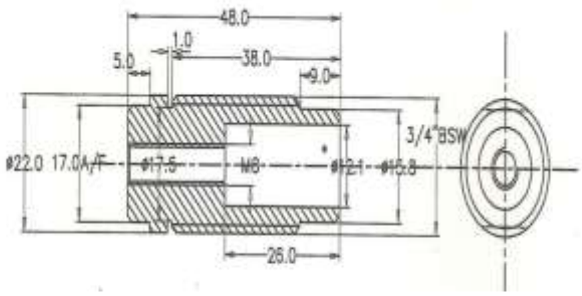


Fig 3.3. Actuator Drawing

d) Refill Adapter: The Refill Adapter is manufactured out of a standard 19mmA/F hexagonal rod. The hexagonal rod is turned according to the part drawing to the required dimensions. At the larger end of the adapter, threads are tapped to a depth of 68 mm using a long tap. At the smaller end of the adapter,M8 external threads are cut. These threads are used to fit the adapter in the mandrel body during Jelly filling. Both the internal and external threads are properly cleaned to ensure correct fit during Jelly filling

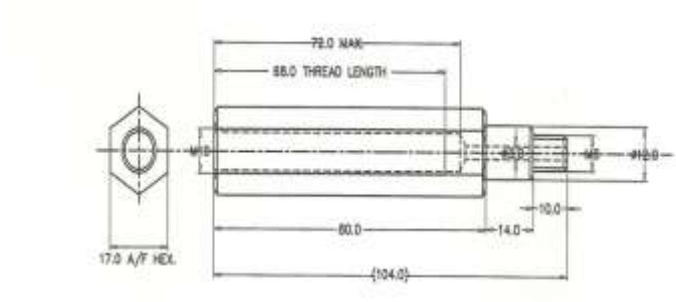


Fig 3.4. Refill Adapter Drawing

e) Jelly Refill Adapter: In spite of careful filling of jelly into the annular space between sleeve and mandrel body as well as below the piston and bush and the connecting paths, there is every chance of air entrapment in the annular area. This air will escape during a number of expanding and contracting cycles. Also because of high pressure that builds up in the system, there can be marginal leakage of the jelly through the small clearance between the piston and bush. To make good this leakage, the jelly has to be topped up in the initial days of use and occasionally thereafter. To facilitate the topping up, a jelly refill adapter is designed and manufactured. Since it is neither a pressure part nor a load bearing part, it is made out of low carbon steel, usually a mild steel hexagonal bar.

f) Hydro-plastic Jelly : The Jelly is the Hydraulic Medium.It Transmits the force from the screw to the sleeve.The Jelly is in Semi-Solid Condition under pressure.

Fig.3.5 Hydro plastic jelly

*f) Butting Ring:*The Butting Ring is machined from 20MnCr5 or equivalent round bar stock.The Rod is turned according to the part drawing and the required bore is made in it.The butting ring is case hardened to RC 55-60.The bore in the Butting Ring is fine ground to get the required finish dimension.The Butting ring is then ready for shrink fitting and further operations.After shrink fitting and final assembly, the butting ring is finish ground for aesthetics.

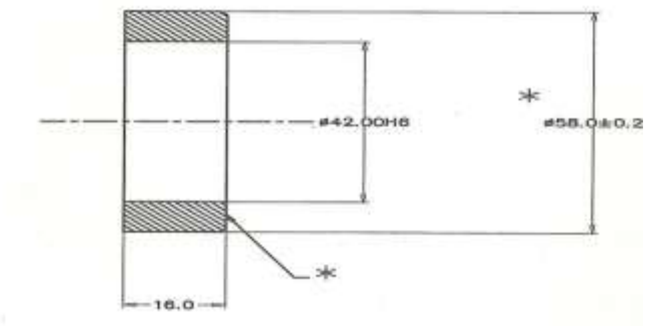
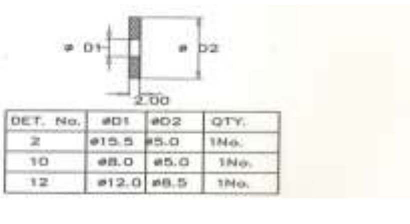


Fig 3.6 Butting ring Drawing

g) Washers: The required Copper Washers are not standard washers. Hence they have to be manufactured using the appropriate copper rods. The Copper rods are turned on the Lathe to obtain the required dimensions. Then the required length is cut off from the copper rods to obtain the required washers.



DET. No.	øD1	øD2	QTY.
2	ø15.5	ø5.0	1No.
10	ø8.0	ø5.0	1No.
12	ø12.0	ø8.5	1No.

Fig 3.7 Washers

h) Set Screw nd allen keys: Screws are standard high tensile fasteners bought off the shelf. The required Set Screws and their corresponding Allen Keys are Standard components and are thus bought directly off the shelf.

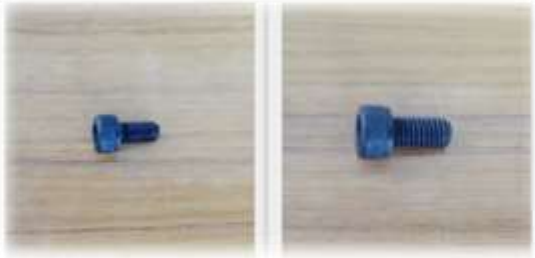


Fig 3.8. Set Screws

Fig 3.9. Parts of the Hydraulic Expanding Mandrel

4. Final Assembly

i. The Sleeve is kept in a furnace at a temperature of 400^0C. Heating is done till required expansion of the Sleeve is achieved.

ii. On achieving required expansion, the Sleeve is placed on the Mandrel Body using a pair of Gloves. Then the whole setup is placed in the furnace at a temperature of 180deg.C for 4 hours for stress relieving as thermal stresses are developed in the sleeve during shrink fitting.

iii. Then the Actuator along with the piston and bush assembly is tightened in the actuator hole in the mandrel body along with the washer.

iv. Then the refill adapter is tightened in the jelly filling hole and jelly is passed into it and a grub screw is tightened on it. This causes the jelly to fill in the Mandrel body and the clearance between the body and the sleeve. This process is repeated till complete assembly is filled with the jelly.

v. After completion of jelly filling, the screws are tightened in the air vent hole and the jelly filling hole along with the washers to make it completely leak proof.

vi. After completing all these operations, the butting ring is then again shrink fitted on Sleeve Collar. The actuator assembly is removed to facilitate cylindrical grinding.

vii. Then the complete assembly is finish ground between centers to Dia 32.00h6 tolerance.Other diameters and faces are also ground for aesthetics.

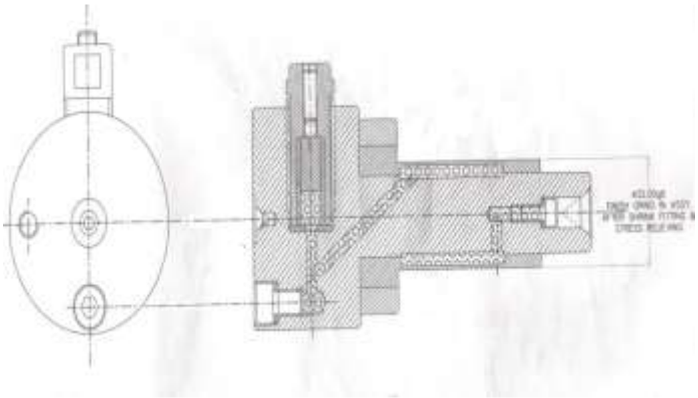


Fig 4.1 Final Assembly Drawing

Fig 4.2. Final Assembly

5. Design Calculations

Since sufficient Data on the wall thickness required for Hydraulic Expansion Mandrel is not available the mandrel has been tried out with different wall thicknesses for the expansion sleeve.

The desired Expansion required for precision component location clamping is a maximum of 0.3% of the expanding diameter.

a) Similarly on an experimental basis another Mandrel with the same dimensions has been manufactured using Bharat Hydrol 220 Hydraulic oil after expansion up to 0.035mm the Mandrel functioned normally. But at Higher pressures it needed for further expansion , the oil started leaking between the piston and the bush.The Mandrel was tried by adding a polyurethane seal on the piston but the oil started leaking at an Expansion value of 0.04mm.In view of the above results it has been decided to retain the Hydro Plastic Jelly as the Hydraulic Medium.

b) In order to give a good shrink fit between the expanding sleeve and the Mandrel Body as per the Design Standards a fit of H6p5 has been decided. This works out to 0.040mm interference on the mating dimensions between the Mandrel and the Sleeve.

The Sleeve is made to expand by heating so that it can easily be slid onto the Mandrel body to facilitate this the 24.0 H7 bore has to increase by a minimum of 0.04mm on dia for achieving exactly identical dimensions of the Mandrel plus another 0.040mm on dia for ease of assembly.

To sum up the sleeve has to be heated to expand the bore by 0.080mm. To find out the temperature to which the sleeve is to be heated the following formula is used.

$E = \text{Diameter} \times e \times T$

Where,

E=Amount of Expansion.
e=co-efficient of linear Expansion for steel.
T=Temperature to which the sleeve is to be heated.

D=Internal Dia of the sleeve.

Applying the above formula and taking a value of 0.000014 for e

$E=0.080=24\times0.000014\times T$

$T=0.080/(24\times0.000014)$

T=238℃

By the time the sleeve is taken out of the furnace and slid onto the Mandrel the Sleeve is likely to loose at least 56-60 (Because of low wall thickness and consequently lower heat stored in the sleeve).

It has been decided to heat the sleeve to 238+60=298℃

Approximately 300℃

On a similar basis the butting ring is also heated to 250℃

c) For Piston

Volumetric Expansion of sleeve required= $(\pi/4)\times(D_1^2-D_2^2)\times L$

Where,

D_1 is the maximum Expanded Dia

D_2 is the collapsed Dia

L is the Expanding Length

Now, D_2=32.00mm

$D_1=D_2\times1.003=32\times1.003=32.096$

i.e., 0.3% of dia expansion

VolumetricExpansion=$(\pi/4)\times(32.096^2-32.0^2)\times56=270.06mm^3$.

Volumetric Displacement of piston required=270mm^3.

Dia of piston selected=8.5mm.

Volumetric displacement of piston=$(\pi/4)\times(8.5^2)\times(x)$ =270mm^3.

Where x is the stroke of piston requires.

Therefore $x=(270)/((8.5^2)\times(\pi/4))$ =4.76mm. Say 4.8mm.

Assuming the factor of safety of 1.5 for clamping force to be built-up.

Stroke required=1.5×4.8=7.2mm.

Providing another 2.8mm to compensate for possible leakage of jelly over a period in use,The final Stroke decided is **10.0mm**.

d) Pressure calculations

Pressure required for clamping

Assuming 2 numbers of bolts of ½" clamping force is equivalent to force applied by the 32 dia × 39 long Expanding Mandrel.

Clamping force=2×11200=22400 lbs.

i.e., 10163 kg.

Clamping surface=π×d×L

$=3.1416\times3.2\times4=40.192\ cm^2$.

Therefore pressure=(Force/Area)=(10163/40.212)=**252.73kg/cm**^{2}.

Applications

- **i.** Inspection
- **ii.** Cylindrical Grinding
- **iii.** Turning
- **iv.** Gear cutting
- **v.** Gear Shaping
- **vi.** Gear Hobbing
- **vii.** Gear Shaving
- **viii.** Gear Honning
- **ix.** Gear Grinding
- **x.** Milling & Drilling Operations

6. Advantages and Disadvantages

a) Advantages: High accuracy can be obtained. Better damping effect. Better Concentricity. Longer life with high accuracy than Conventional Mandrels.

b) Disadvantages: The Hydro Plastic Jelly has a higher co-efficient of volumetric expansion and hence any heavy machining should be done under copious flow of coolant. It can only be used for mass production.

7. **Result**

Fig 7.1 Checking the accuracy using Dial Gauge

i. Run out before Expansion 0.000mm
ii. TIR.Run out after Expansion by 0.064mm=0.001mm TIR. Since the acceptable run out limit for a Hydraulic Expanding Mandrel is 0.005 TIR the Mandrel is accepted without any further corrections.
iii. Also the Mandrel is to Dia 32.090mm and it was found that no permanent set or damage occurred.The Mandrel repeatedly collapsed to the original dimension each time the pressure is released.

8. Conclusion

A Hydraulic Expansion Mandrel was completely designed and manufactured.Each of its individual components and their complete manufacturing processes were studied and satisfactorily carried out.

A Mild Steel Bush was also manufactured and was used in the demonstration of the Hydraulic Expansion Mandrel.

The Mandrel was also mounted between centres on a lathe and a 2mm depth of cut was taken on the mild steel bush without any additional clamping.

References

[1] Tool Design by ZORKOV-MIR Publisher MOSCOW.

[2] “Machine Tool Design” by N. K. Mehta