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Design and analysis of CNC rotary table for horizontal machining centre

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Abstract

CNC rotary table is an important accessory employed to enhance the productivity of a CNC machining centre. It is a work holding device on a machining centre used to position the components in any desired position to carry out machining on different faces of the component. A CNC rotary table of size 500 x 500 mm has to be designed to support and hold components weighing up to 8000 N for machining. The rotary table should be designed with positional accuracy of ±10 seconds with a rotational speed of 30 rpm. This work focus on the design and selection of critical components like servomotor, worm gear mechanism, worm gear support bearings, bellow coupling, table support bearings, angle encoder and lock nut for preloading the bearings to meet the requirements of the rotary table. Existing geometry such as housing and pallet supporting components are modified with weldment structure for housing component and ribbed structure for pallet. Structural static analysis of these components carried out with ANSYS 12 finite element software.

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Keywords: *CNC rotary table* **,** *static analysis , servomotor ANSYS* **.**

1. Introduction

Rotary tables are used to index parts and components in defined, angular increments so that they can be machined, worked, or assembled in multiple operations. Tables consist of a circular steel plate, one or more spindles, a drive system, and pins that hold parts and components in place. Rotary tables have either fixed or adjustable indexing angles. During each revolution, the table stops for a specified period of time so that an operation can be performed at each station. The bearings that support rotary tables determine both the load capacity and accuracy. Angular contact bearings are more expensive than re circulating ball bearings, but provide better load capacity and axial stiffness. Cross-roller bearings are also commonly available. For a large sized table with high load capacity, the practice of using hydrostatic bearings is now observed.

Rotary tables are powered by pneumatic and electric motors, hydraulic drives, and manual actuation. Drive mechanisms can be located above, below, behind, or to the side of the table surface. Pneumatic rotary tables are suitable for small and medium loads. They are powered by one of more pneumatic cylinders, each of which represents an index. During the return stroke, a pawl locks the table in place. With some devices, the pawl can be adjusted to change the number of indexes. Electrically-powered tables are generally faster than pneumatic devices and can handle heavier loads. Tables that are powered by hydraulic drives use a pressurized fluid that transfers rotational kinetic energy. Manually-actuated rotary tables often include a hand crank or are loosened, turned, and adjusted by hand. For the larger sized tables drive motor (servo motor) in combination with reduction gear box and reduction pinion and gear ring .

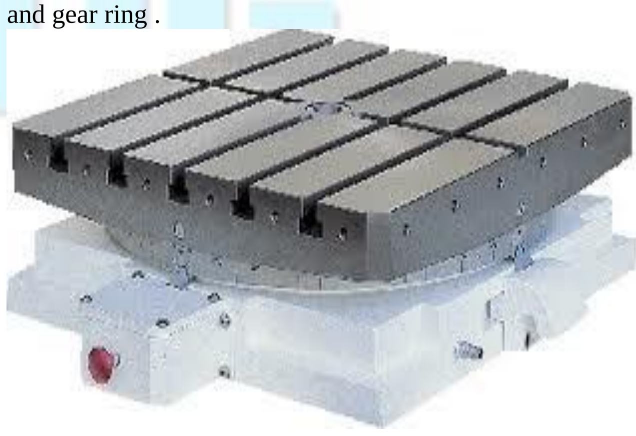

Fig1 CNC Rotary Table

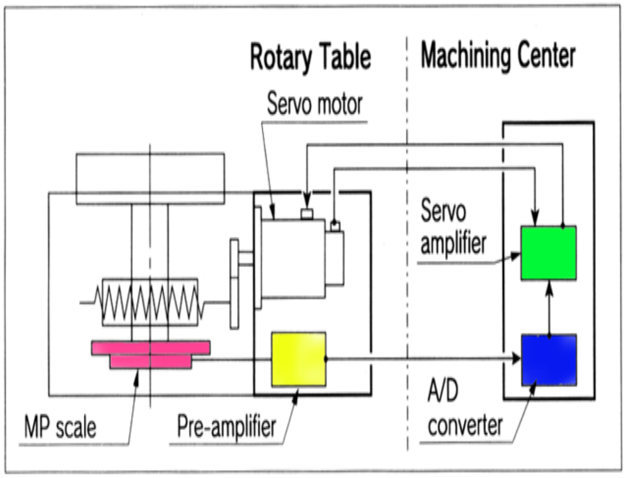

Fig2. Operation of CNC Rotary table

2. Design of CNC Rotary Table

2.1 Calculation of machining force

Average chip thickness, as = 57.3SZ x Sinx (cosΨ1-cosΨ2) /Ψs° = 0.35073mm,Power of the spindle, N = UkhKγQ = 6.04296 KW,Efficiency of transmission, E = 0.9%,Power of the motor, Nel = N/E = 6.7144KW, Tangential cutting force, Pz = 6120N) ÷V = 106.5 Kgf
The machining force on the Rotary table will be 1020 N will be considered.

2.2 Design of Worm &Worm wheel for Rotary Table

Where T2, T1 is the torques acting on the worm and the worm gear, i: velocity ration η is the efficiency of worm gearing, Tngential force on worm (F_{t1}) = axial force on worm wheel Ft1 = 2.M_1 / d_1 Axial force on worm (Fa1) = Tangential force on gear

$$Fa1 = Ft1\left(\frac{\cos(\alpha_n).\cos(\gamma) - \mu\sin(\gamma)}{\cos(\alpha_n).\sin(\gamma) + \mu\cos(\gamma)}\right)$$

Output torque = Tangential force on worm wheel x Worm wheel reference diameter /2, M_2 = Fg1 x d_2 / 2,Relationship between the Worm Tangential Force Ft1 and the Gear Tangential force

$$Ft1 = Fg1\left(\frac{\cos(\alpha_n).\sin(\gamma) + \mu\cos(\gamma)}{\cos(\alpha_n).\cos(\gamma) - \mu\sin(\gamma)}\right)$$

Relationship between the output torque M_2 and the input torque M_1, M_2 = (M_1. D_2/d_1). [(cos α_n – μ tan γ) / (cos α_n. tan (γ + μ))], Separating Force on worm-gearwheel (F_s)

$$Fs = Ft1\left(\frac{\sin(\alpha_n)}{\cos(\alpha_n).\sin(\gamma) + \mu\cos(\gamma)}\right)$$

Tangential load by Lewis, WT = (σ0cv)bπmy = 3926.808 Mpa, Dynamic load, WD = WT ÷ CV = 4090.425 Mpa, Static or Endurance strength, WS = σebπmy, = 8180.85 Mpa, Wear load, Ww = d2bk , = 4226.798 Mpa, Efficiency, η = Tan λ÷tanλ+φ1 = 0.878788 %,Tangential Force on worm, Ft1 = 2Tgear ÷ 60 = 0.363657 KN, Axial Force on worm , Fa1 = Ft ((cos α cosγ - μsinY) / (cosαsinγ + μcosY)) , = 1.068099 KN, Radial force on worm, Fr1 = Ft (sinα ÷ cosαsinγ+μcosγ) = 0.248271 KN,Bending moment by Radial force, Bm1 = Fr1 x d2/4, = 14.89624 N-m,Bending moment by axial force, Bm2 = Fa1 x d1 / 4 = 10.68099 N-m,Total bending moment (vertical plane), M1 = Bm1+Bm2 = 25.57723 N-m

Bending moment due to tangential force, M2 = Ft1 x d1/4 = 3.636574 N-m

2.3 Angle Encoder / Positioning System with Servo Motor

The design and mounting of the stator coupling it absorbs the torque which is caused by the friction in the bearing during angular acceleration of the shaft,The **RCN, RON & RPN** angle encoder there for provide the excellent dynamic performance with an integrated stator coupling

Encoder Specification

- Series ERN 200
- System accuracy ± 10 sec
- Recommended mean step 0.001°
- Speed limit 3000 rpm

2.4.Selection of locknut:

Lock nut is selected depending upon the tightening torque:

Tightening torque $M = fa \text{ x } (f \text{ x } \frac{Dm}{2} + F1 \text{ X } \frac{Dt}{2}) \text{ x } 10^{-3}$

M=143.5 (0.3x $\left(\frac{30}{2}\right) + 0.14 \text{ x } \left(\frac{30}{2}\right)$)x 10^{-3}

M =1.9122 Nm,Then Select the model ,**MKR 30 x1.5L**

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MKR series is the axial locking. ,30 is the thread diameter.

1.5 is the thread pitch diameter., is the left hand thread.

5 Finite Element Analysis

5.1Static analysis of Solid Pallet

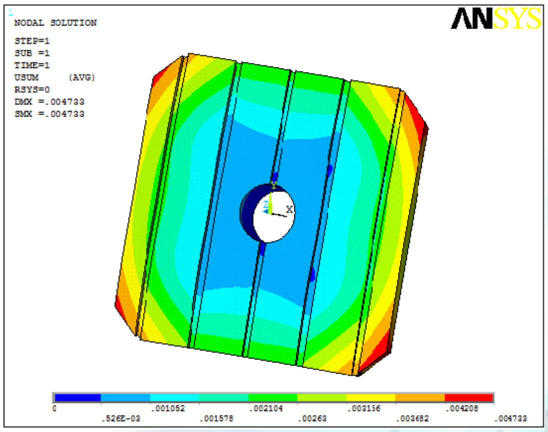

Fig 3 Deflection in FG300 Solid Pallet

it is evident that the deflection is 4.7 microns which is lesser than the allowable deflection of 10 microns (HMC machine accuracy).If factor of safety is 2 applied than also design is safe

Table 1: Comparison of Static Results of Pallets.

Model	Ribbing Pattern Pallet	Solid Pallet
Material	Grey cast iron (FG 300)	Grey cast iron (FG 300)
Weight	146 kg	118 kg
Total Deflection	0.004733 mm	0.004886 mm
Vonmises Stress	11.72 MPa	11.1MPa

5.2 Static analysis of Weldment Housing:

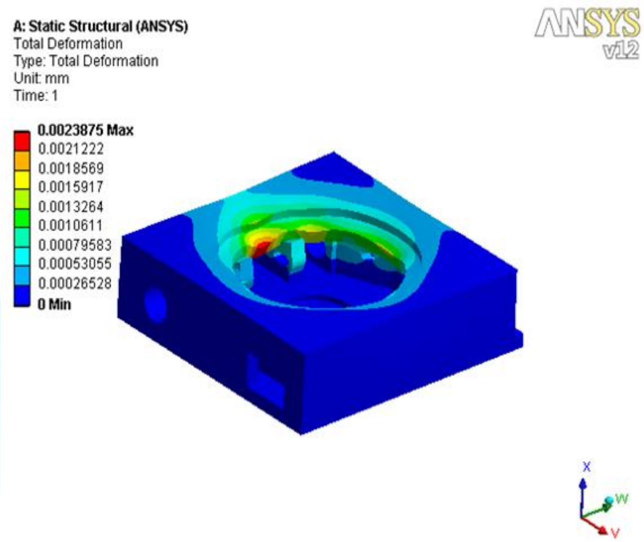

Figure 4: Deformation in Fe410 Weldment Housing

it is evident that the deflection is 2.38 microns which is lesser than the allowable deflection of 10 microns (HMC machine accuracy).If factor of safety is 2 applied than also design is safe

5.3 Static analysis of Casted Housing:

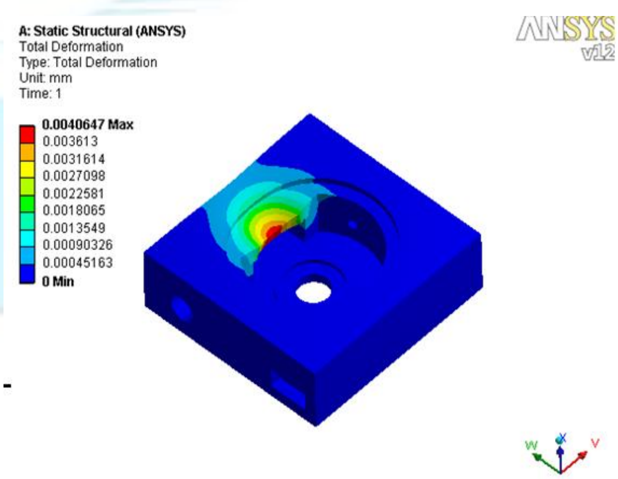

Fig 5 deformation in casting housing

Table 2: Comparison of Static Results of Housing

Model	Weldment Housing	Casted Housing
Material	Structural steel Fe 410	Grey cast iron (FG 300)
Weight	160 kg	206 kg
Total Deflection	0.00238 mm	0.00406 mm
Von-mises Stress	5.35 MPa	5.94 MPa

From the above result it is evident that, weight of the Weldment Housing is 46 kg less than the old design, and also design is safe (deflection less than 10 microns), hence we can use Weldment housing

5.4 Modal Analysis of Ribbing pattern Pallet

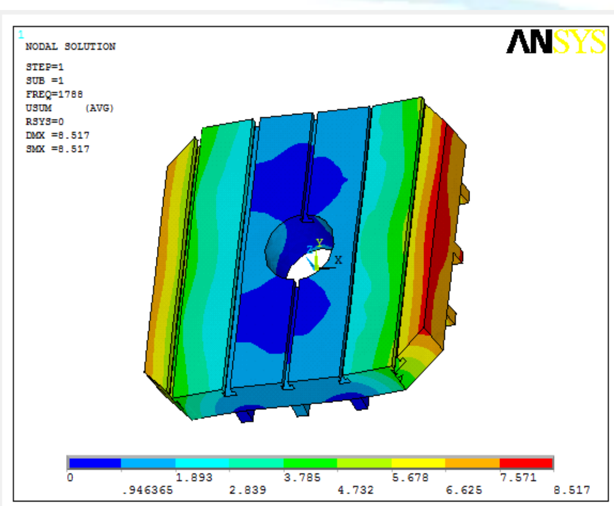

Fig 6 Nodal solutions for ribbing pallet

5.5 Modal Analysis of Solid Pallet

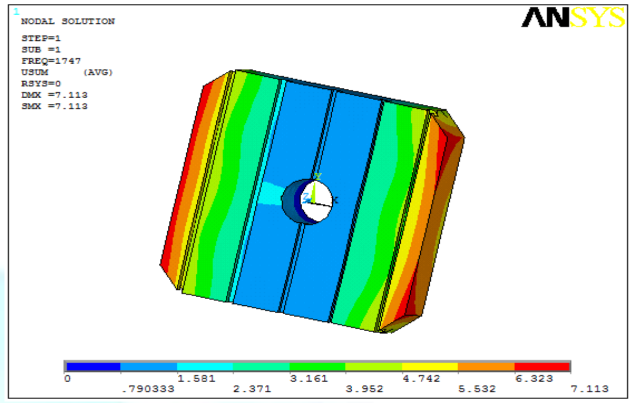

Figure 7. Solid Pallet Frequency 1747 Hz

6. Conclusions

With this proposed design we can develop the rotary table with an indexing step of 0.001°, position accuracy of ±10 sec and also height easily suit HMC machine for various machining operations. Indexing accuracy of the rotary table ±10 sec can be maintained by using the angle encoder of ERA 200 series & Servomotor.

Clamping mechanism in the Servomotor avoid the rotation of the table when static condition. Duplex worm gearing mechanism which greatly reduce the speed, hence desired speed of the table easily achieved, along with this backlash of the gearing easily eliminated by this gearing.

Table is supported by two four point angular contact ball bearing at the top and bottom of the table with this higher rigidity of the table is maintained while machining operations. Both sides of Worm shaft is supported by two taper roller bearing which takes the combined loads, while clockwise and anticlockwise rotation of the shaft and higher rigidity will be achieved.

Pallet is build with ribs and patterns with this there will be reduction in the weight of the pallet compared to the solid pallet. Housing of the rotary table is developed by Weldment using a structural steel plates, hence there will no any extra cost of mould and machining operations.

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