Design and Fabrication of Tool Magazine for CNC Machines Using Geneva Mechanism

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Abstract – *An Automatic Tool Changer or ATC is used in computerized numerical control (CNC) machine tool to improve the production and tool carrying capacity of the machine. The project focuses on the development of tool magazine used in CNC machines based on Geneva mechanism driven by a DC motor system.*

The project aims to cut down CNC tool changer costs by replacing the stepper motor used in the existing machines with cheap and simple DC motor. The motor system is coupled with the Geneva mechanism to convert the continuous motion into an intermittent motion.

Key Words: Automatic tool changer, Geneva mechanism

1.INTRODUCTION

Nowadays, computerized numerical control (CNC) machines are very common and important in the engineering field. So any relevant changes in the CNC machine will help the engineering field. Simple CNC machines work with a single tool. But if even more tools are required, then automatic tool changer (ATC) is provided. The tools are stored on a magazine. It allows the machine to work with a large number of tools without an operator. ATC is used in CNC machine tools to improve the production and tool carrying capacity of the machine. ATC changes the tool very quickly, reducing the non-productive time. The existing tool magazines in CNC machines make use of stepper motors. But stepper motors have a complex control system for operation, thus making them costly and complex in operation. By the replacement of stepper motor by the combination of DC motor and geneva mechanism , a low cost and simple mechanism can be obtained.

1.1 Geneva Mechanism

The Geneva drive or Maltese cross is a gear mechanism that translates a continuous rotation movement into intermittent rotary motion.

The rotating drive wheel is usually equipped with a pin that reaches into a slot located in the other wheel (driven wheel) that advances it by one step at a time. The main also has an elevated circular blocking disc that "locks" the rotating driven wheel in position between steps. In most common arrangement of Geneva drive, the client wheel has four slots and thus advances the drive by one step at a time (each step being 90 degrees) for each full rotation of the master wheel. If the steered wheel has *n* slots, it advances by 360°/*n* per full rotation of the propeller wheel.

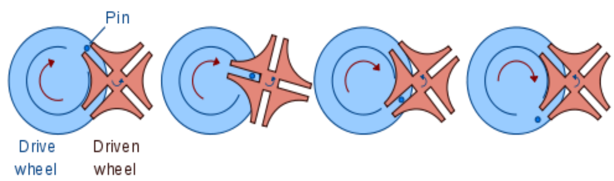

Fig-1: Geneva mechanism

One application of the Geneva drive is in film movie projectors and movie cameras, where the film is pulled through an exposure gate with periodic starts and stops. Geneva wheels having the form of the driven wheel were also used in mechanical watches. If one of the slots of the driven wheel is occluded, the number of rotations the drive wheel can make is limited. Other applications of the Geneva drive include the pen change mechanism in plotters, automated sampling devices, banknote counting machines. The iron ring clock uses a Geneva mechanism to provide intermittent motion to one of its rings.

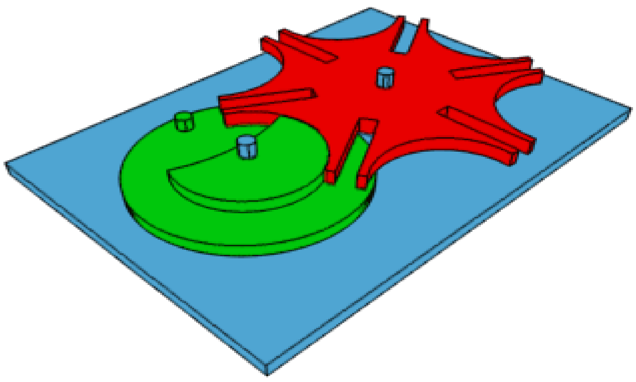

Fig-2: Animation of Geneva mechanism

1.2 Methodology

We studied the parts and working of a CNC machine. We were able to get an idea about the size and specifications of tool magazine. Then the design calculations were done according to the specifications of CNC machine. For the successful design of our project, factors such as materials used, surface finish, tolerance, loads, indexing accuracy, etc have to be considered. The primary design approach will be to reduce wear by altering the geometry of the Geneva wheel to reduce the contact stress. Based on the design calculations a 3D model of the project was created using Solid Works 2014. Our design should be able to keep the wear to the minimum to reduce the contact stress by maintaining acceptable stress levels in other regions of the wheel. So using ANSYS workbench 14.5 we did a stress analysis. The results show that maximum stress will be at pin. So consideration was given to two additional dimensions (pin diameter and pin thickness) on the wear stress. After making required changes in our calculations we proceeded to the fabrication process.

2. WORKING

The driving shaft is connected to the DC motor, which in turn is connected to the power supply, in this case, a battery. The Geneva wheel is mounted on a shaft. The locking mechanism consists of a cam connected with a lock pin. The cam is designed in such a way that the lock pin enters the slot of the Geneva wheel, after the crank pin leaves the slot and retracts during the rotation of the Geneva wheel. The rotation of the crank pin is controlled by a controller circuit consisting of an Arduino, relay circuit and controller circuit. The controller has 6 switches each for each position of the tool.

Initially the power supply is turned on. The controller switch is pressed to choose the required tool number from the marked positions on the Geneva wheel. After giving the tool position required, the program starts and the crank pin starts to rotate. The crank pin enters the slot of the Geneva wheel and forces the Geneva wheel to rotate. Each rotation is confirmed by the help of the proximity sensor. After the program detects, the required number of rotations are completed from the input of the proximity sensor, the DC motor supply is cut-off. So, the new required tool is brought to the position. This tool is picked from the position by a tool picker and taken to the spindle for machining.

3. COMOPONENTS

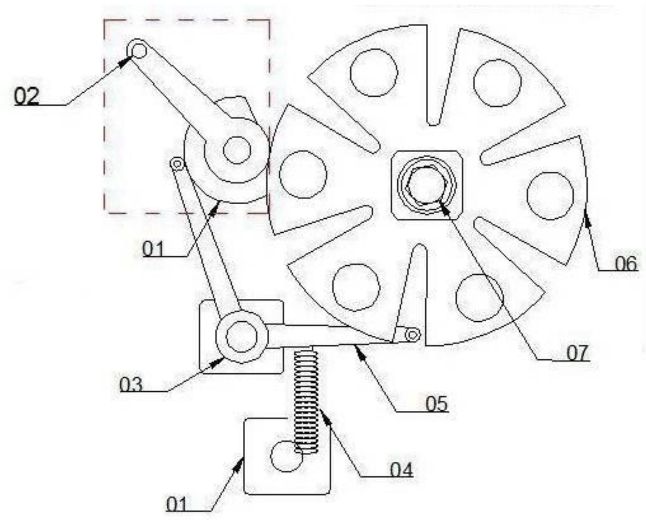

Fig-3: 2D model of detailed structure

The main components of the structure are tabled below.

Table-1: Main parts of the system

Part Number	Part Name
01	Cam
02	Cam pin
03	L-block shaft
04	Spring
05	Pin
06	Geneva Wheel
07	Tool magazine shaft

4. DESIGN

4.1 Geneva Wheel Design

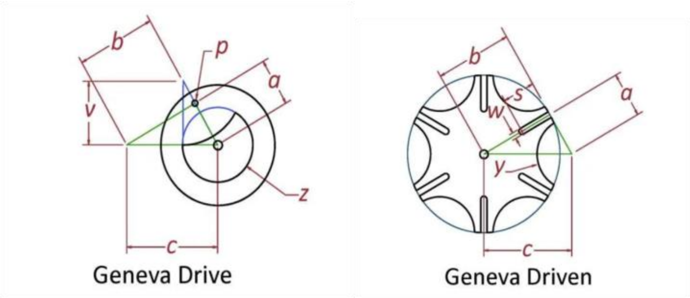

Fig-4: Dimensions of Geneva mechanism

Assume Geneva wheel radius, b = 125 mm

Driven slot quantity, n = 6

Pin drive diameter, p = 20 mm

Allowed clearance, t = 5 mm

Slot width, w = p + t = 25 mm

Centre distance, c = b/Cos (180/n) = 288.675 mm

Drive crank radius, a = $\sqrt{(c^2-b^2)}$ = 144.3376 mm

Slot length, s = a + b - c = 105.6624 mm

Stop arc radius, y = a-p*1.5 = 143.9626 mm

4.2 Motor Design

Torque Required

Torque, T = I x α

Where,

I = mass moment of inertia

m = mass of Geneva wheel = density x volume

Density = 7800 kg/m^3 for structural steel

Volume of Geneva wheel = (3.14/4)xd^2

d = diameter of Geneva wheel = 250 mm

α = angular acceleration of wheel

Torque is found to be 99.91 Nmm

Power required

Power = T x ω

Where,

ω = angular velocity = (2 x 3.14 x N)/60

N = speed in rpm = 30

Power required is found to be 1.18 W

Battery voltage = 12 V

DC motor with the required power and rpm is purchased

DC motor – specifications

Speed, N = 30 RPM

Voltage, V = 12 Volt

Current, I = 0.3 A (loading condition)

Current, I = 0.06 A (No Load Condition)

Power, P =V x I=12x0.3 = 3.6 W

Motor Efficiency = 36%

Therefore,

Output power of purchased motor = 0.36 x 3.6 = 1.26 W
So the purchased motor is suitable for the purpose.

5. ANSYS ANALYSIS

Fig-5: 3D model of the structure created in Solid Works 2014

5.1 Meshing

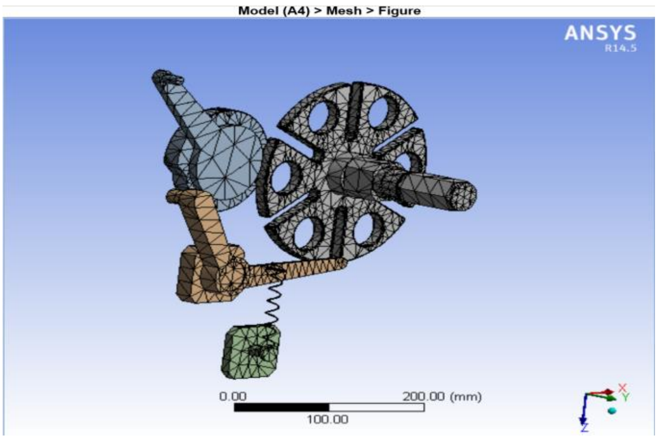

Fig-6: Mesh analysis of the structure

Here we done were tetragonal element analysis.
Number of nodes = 28186
Number of elements =14851
Minimum edge length = 0.163640 mm

5.2 Application of Moment

The driving shaft is fixed and moment is applied to the wheel to analyse for stresses and strains. The applied moment is the maximum value of moment the crank pin can exert on the Geneva wheel based on torque calculations.

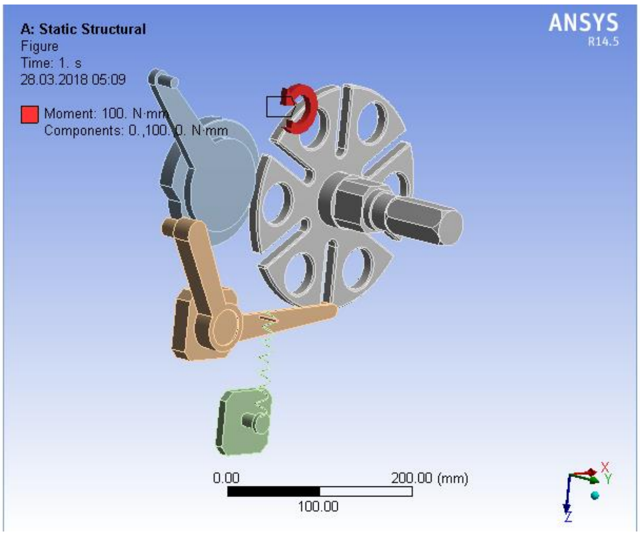

Fig-7: Moment application

5.3 Total Deformation Analysis

After the application of the moment, the program was used to solve for total deformation. The deformation for the given moment was found to be maximum at the crank pin and the value is found to be within the safe limit of the material of the pin. Hence the design is safe under total deformation criteria.

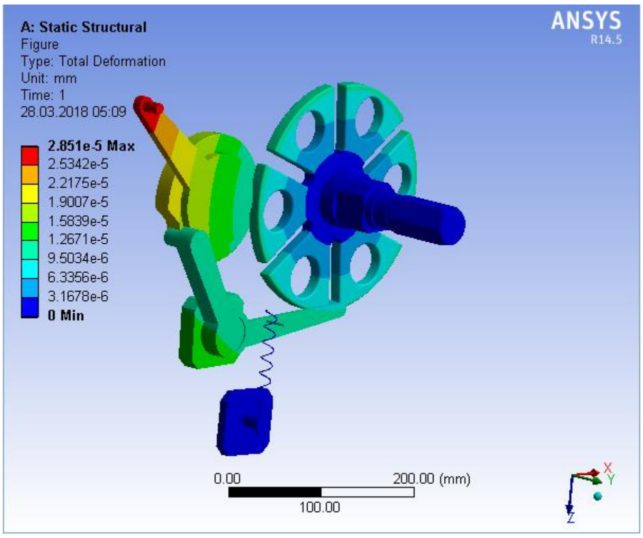

Fig-8: Total deformation analysis

5.4 Elastic Strain Analysis

After total deformation analysis, the model was analyzed for elastic strains and the maximum strain is found to occur in the starting points of the slots. But the value is within safe limit of material of Geneva wheel. Hence the design is safe under elastic strain analysis.

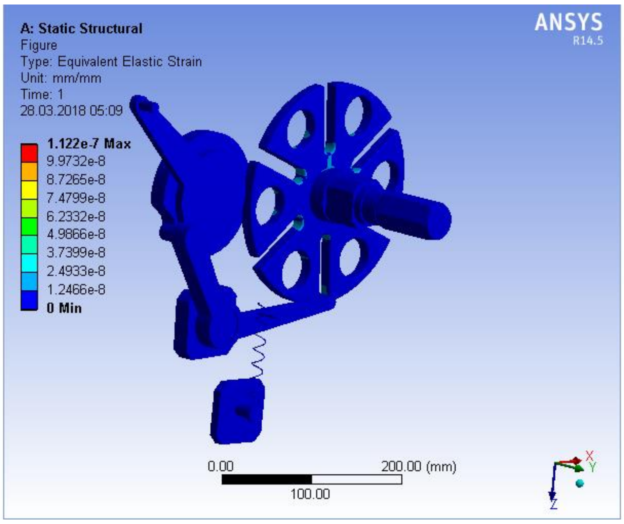

Fig-9: Elastic strain analysis

5.5 von-Mises Stress Analysis

For ductile bodies subjected to load in a single direction, von-Mises stress is the most suitable mode of stress calculation. Hence von-Mises analysis also is done.

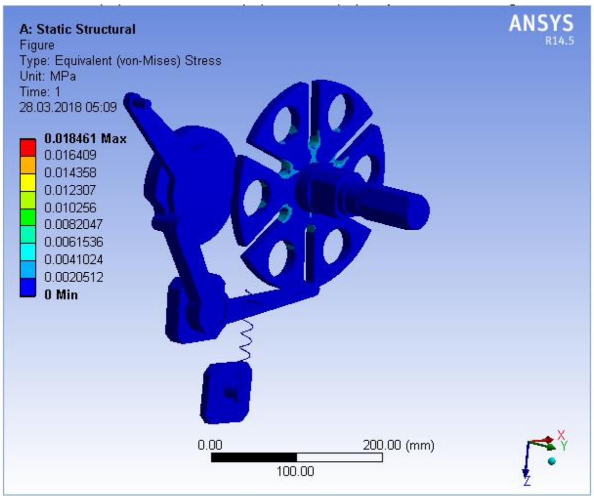

Fig-10: Von-Mises stress analysis

Von-Mises stress is maximum along the same points as that of maximum elastic strain. But the strain values are within the safe limits of the material used. Hence the design is safe under elastic strain criteria.

3. CONCLUSIONS

In this project, a CNC tool magazine prototype is designed and fabricated. The new mechanism is able to hold 6 tools in the magazine. Each tool is numbered from 1 to 6. The required tool number can be selected from controller in the control circuit.

The indexing accuracy can be increased by optimizing the speed of the crank. Non-machining time of the CNC machine can also be reduced by using the concepts of tool sharing and tool duplication. The number of indexing positions should not be greater than the number of cutting tools as it will always increase the non-machining time.

The current system uses DC motor instead of an indexed stepper motor. DC motor do not use any control system for its operation. The motor is controlled by the control circuit only. Hence, system is found to be cheaper than conventional tool magazines. But the tool changing time is found to be more than the average time. It could be improved by using a motor with higher rpm.

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