Design and Fabrication of Multi-speed Bicycle Sprocket on CNC Milling Machine

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Abstract
Now a day's cycling is a passion for the young generation of Bangladesh. Multi-speed bicycles are most preferable to them as it allows gear selection to suit the circumstances: a cyclist could use a high gear when cycling downhill, a medium gear when cycling on a flat road, and a low gear when cycling uphill. On a Multi-speed bicycle, the cogset or cluster is the set of multiple sprockets that attaches to the hub on the rear wheel to provide multiple gear ratios to the rider. Manufacturing of sprocket in an accurate dimension is a challenge to the cycle manufacturing industry. Generally in Bangladesh, sprocket teeth are cast or flame cut of sheet metal which is almost as accurately as manufactured in Milling, shaper, or even CNC Hobbing Machine. This paper aims to show a systematic way to cut sprocket teeth in 3 Axis CNC Milling Machine. For this purpose, at first, a 14 teeth sprocket is designed as ASME B29 standard. Then a CAD model is generated on Solid works according to the designed dimension. Thereafter, the G-code for milling operation is generated and simulation of the manufacturing process is investigated by Master Cam software. Then the G-code is transferred to the CNC Milling machine and the operation is done sequentially. It has observed that cutting sprocket teeth on CNC Milling is suitable for industrial production as various dimensions measured after manufacturing are found almost as accurate as of the theoretical one.

Keywords — *Cogset, Sprocket, CNC Milling Machine, Master Cam*

I. INTRODUCTION

Cogsets come in two varieties, cassettes or freewheels, of which cassettes are a newer development. Although cassettes and freewheels perform the same function and look almost the same when installed, they have important mechanical differences and are not interchangeable.[1]

A freewheel consists of either a single sprocket or a set of sprockets mounted on a body which contains an internal ratcheting mechanism and mounts on a threaded hub. Threaded rear hubs were available in different thread patterns depending on the country of manufacture, French and British threads being the most common. British CEI (Cycle Engineers Institute) thread was adopted as the international standard and is now known as B.S.C. - British Standard Cycle and is a standardized right-hand thread (1.375 x 24 TPI) onto which a standard freewheel is screwed. This allows different brands of freewheels to be mounted on different brands of hubs.

Cassettes are distinguished from freewheels in that a cassette has a series of straight splines that form the mechanical connection between the sprockets and the cassette compatible hub, called a freehub, which contains the ratcheting mechanism. The entire cassette is held on the hub using a threaded locking. Some cassette systems from the late 1980s and early 1990s use a threaded small sprocket to hold on the larger splined sprockets, the entire set referred to as a cluster. Cassettes resemble freewheels when installed, but are different when removed as they do not contain a free wheel's internal ratcheting mechanism.

Fig. 1: Freewheel threaded hub

Fig. 2: Cassette and freehub

The sprockets in a cassette are usually held together by three small bolts or rivets for ease of installation. These keep the sprockets and spacers in the correct order and position when they are removed from the freehub body.

There are many ways to produce sprocket teeth, and the actual teeth form may not exactly match the theoretical tooth form. Cast, power metal, or molded plastic teeth may vary from the theoretical tooth form in various ways depending on how the pattern, die, or mold is made. [5]

Sprockets, on the other hand, are formed in the same way as gears, through cutting techniques such as hobbing, so that they can withstand harsh and repetitive use. Sprocket hobbing is the process of using a broaching machine to cut the grooves, known as teeth, into a component. Cutting sprockets with different numbers and varying sizes of teeth, these processes are used to make teeth for many different kinds of sprockets. Additional machining processes are used, to ensure the best teeth and closest tolerances. Secondary service including heat treating and hand-finishing can be used to provide additional strength and quality. It should be stressed that a significant inconvenience of this method consists of the fact that the manufacturing process of particular tool cutting – sprocket hob, to produce each new benchmark, increase the main cost of the product. [3]

Again toothing chain sprocket by mortising with knife-wheel is based on generating the profiles with gearwheel generating. Knife-wheel is of form conjugate gearwheels with gearwheel processed, having a particular geometry of toothing, which shouldn't allow machining trough cutting.[4] Themselves meets and here the same inconvenience as at sprocket, the necessity to manufacture a new knife-wheel to every new benchmark.

By the way in developing countries like Bangladesh, sprockets manufacturing industry cannot afford hobbing machines particularly for a single operation. Rather industries are using such multifunctional machines like CNC milling machines. A typical CNC milling machine has three axes of movement, X, Y & Z; which is these same points as the Cartesian coordinate system. CNC milling machines are capable of various tasks and operations. A machine can be scaled down for use on individual parts, or it can be scaled up to be used as huge heavy-duty operational machinery. As a result of this, CNC milling machines are so commonly used in machine shops and industrial factories; and are a popular choice for cutting parts to very precise shapes and sizes.

In this paper, a systematic way to cut sprocket teeth on the CNC Milling machine is discussed.

II. DESIGN OF A 14 TEETH SPROCKET

Chain sprocket interaction is very complex in theory. It can be even more so when the effects of wear and elastic deformation of the chain and sprocket under load are considered. As the main function of a sprocket is to transmit torque, the following consideration should be taken:

- The sprocket teeth must transfer the tension load to the chain or absorb the tension load from the chain.
- The sprocket should engage the chain as smoothly and consistently as possible.
- The sprocket should distribute the tension so that each tooth in engagement caries a share the load
- The sprocket must accommodate a reasonable amount of wear.

Figure: 3. shows the important diameters of roller chain sprockets. Chain Pitch P and Roller diameter Dr are standard dimensions and can be obtained from Table 1. The Number of teeth, N must be supplied by the sprocket designer.

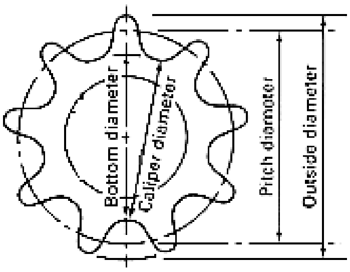

Fig.3: Roller chain Sprocket diameters

TABLEI
Standard Dimension

Chain Number	Pitch	Max Roller Diameter
25	¼	0.130
35	3/8	0.200
41	½	0.306
40	½	5/16

Pitch Diameter: The diameter of the pitch circle through the chain roller centers as the chain wraps the sprocket. But chain pitch is measured on a straight line between centers of adjacent rollers, so the chain pitch lines form a series of chords of the pitch circle.

$$\text{Pitch diameter, } PD = \frac{p}{\sin\frac{180^\circ}{N}} \ldots\ldots\ldots\ldots\ldots(1)$$

Bottom Diameter (BD): The diameter of a circle that is tangent to the curve at the bottom of the tooth gap

$$BD = PD - D_r \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (2)$$

Caliper Diameter (CD): For a sprocket with an even number of teeth, the caliper diameter is the same as the bottom diameter. For a sprocket with an odd number of teeth, the caliper diameter is the distance from the bottom of one tooth gap to the bottom of the nearest opposite tooth gap.

$$CD = PD\left(\cos\frac{90^{\circ}}{N}\right) - D_r \quad \ldots\ldots\ldots\ldots(3)$$

Outside Diameter (OD): The diameter over the tips of the sprocket teeth.

$$OD = P\,(0.6 + \cot\frac{180^{\circ}}{N}) \quad \ldots\ldots\ldots\ldots(4)$$

Tooth form: The outline of the working surfaces of the tooth that transfer forces to or absorb forces from the rollers of the chain.

Tooth Profile: The outline of the tooth section that is projected on a plane through the sprocket axis and the center of the tooth.

Groove Diameter (GD): The diameter of the grooves in a multiple-strand sprocket. The maximum groove diameter is the largest groove diameter that will clear the roller link plates in the chain.

$$GD = P\left(\cot\frac{180^{\circ}}{N} - 1\right) - 0.030 \ldots\ldots(5)$$

III. GENERATING CAD MODEL

The tooth form of a sprocket is derived from the geometric path described by the chain roller as it moves through the pitch line, and pitch circle for a given sprocket and chain pitch. The shape of the tooth form is mathematically related to the Chain Pitch (P), the Number of Teeth on the Sprocket (N), and the Diameter of the Roller (D_r). Here for a 14 teeth sprocket and chain pitch (P) ½, the diameter of the Roller (D_r) is 5/16 From Table 1. The formulas for the seating curve, radius R, and the topping curve radius F include the clearances necessary to allow smooth engagement between the chain rollers and sprocket teeth. The formulas are taken from the American Chain Association Chains for Power Transmission and Material Handling handbook, and they represent the industry standards for the development of sprocket tooth forms. [5] With the calculated values sprocket is first designed in Solid Works. For simplicity, a hexagonal shaped hub is designed. A Cad model of the desired sprocket is shown below.

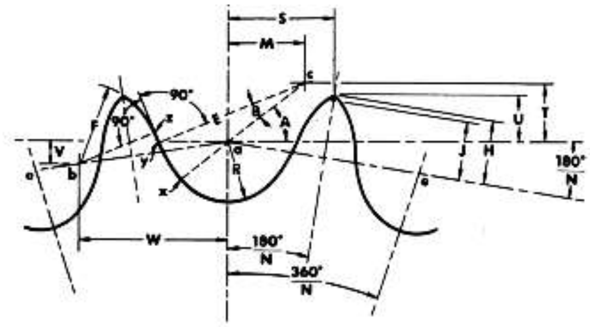

Fig. 4: Sprocket Tooth Geometry

Fig. 5: Cad Model of the Sprocket

IV. GENERATING G- CODE & SIMULATION

As CNC milling machine is controlled by the use of a computer; more specifically, a computer-aided program it is vital to create operational coordinates using a program that converts a CAD design/drawing into the G-Code. Using the computer program, a list of very specific step-by-step instructions are made, which will describe to the CNC milling machine how to physically turn the working material into a sprocket. Here G-Code is generated using Master Cam Software.

First, the cad model is imported to the master cam software. Machine type and Model no is selected as availability. Bounding box type Stock is settled up. Chain and contour type with true spiral roughing is set up as tool path configuration for cutting of hexagonal-shaped hub. Again for sprocket teeth cutting Contour type tool path is selected. Ball mill cutter of 2 mm diameter is used as the cutting tool. Also for the smooth machining appropriate feed rate, spindle speed, depth of cut,etc. is selected. Flood type coolant flow is selected for smooth surface finish and to reduce wear.

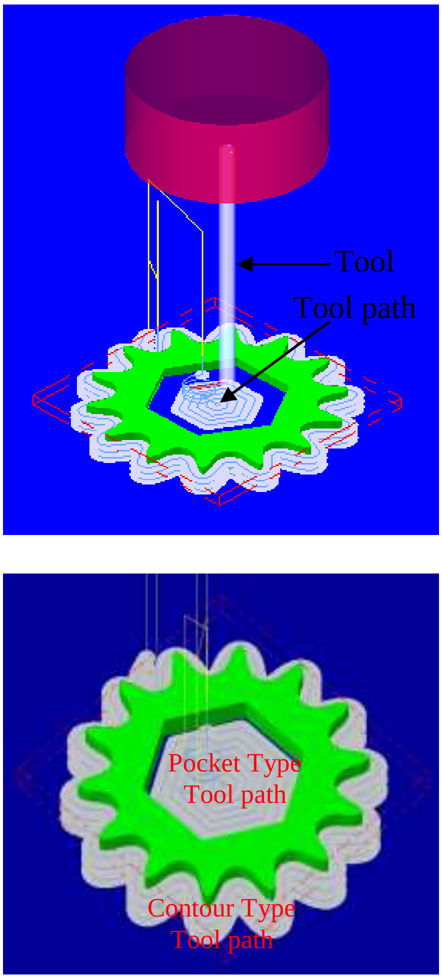

Fig. 6: Simulation of the cutting process on Master cam Software

V. MILLING OPERATION OF SPROCKET TEETH

Once the G-code is complete, with no errors; the CNC Milling Machine is ready for prep. First set the working material, the milling machine will be working on beforehand. Then placement of the working material on the CNC milling work surface/work table. The CNC milling machine used for the operation is manufactured by **HAAS AUTOMATION, INC. OXNARD, CA, U.S.A**, and the model is **HAAS VF-2**. The specification of the machine is given below.

TABLE II
Specification of CNC Milling Machine

Criteria	Specification
Voltage	360-480
Phase	3
Hertz	50/60
Full Load	40 Amps
Largest Load	70 Amps
Short Circuit interrupting capacity	10,000 Amps

Fig. 7: Machining on CNC Milling Machine

Then the machining is done with spindle speed 2000 rpm and feed rate 40. The machining process of cutting sprocket teeth is shown in Fig.7

VI. TEST OF THE SPROCKET

The pitch diameter probably is the most important diameter of the sprocket, but it cannot be measured directly. Thus manufacturers usually control the bottom diameter, or caliper diameter, in production. The tolerance on bottom diameter is always negative, to avoid chain binding.

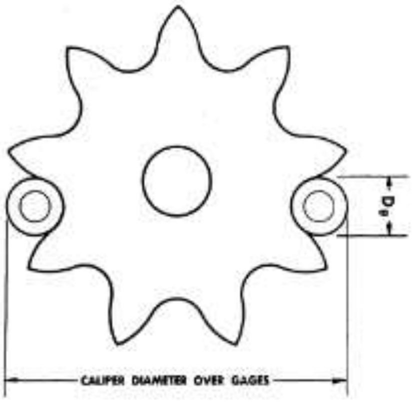

Fig. 8: Caliper diameter over gauge pin

Fig. 9: Test of Sprocket dimensions

Measuring the caliper diameter over two concave surfaces is also difficult. Measuring the caliper dimension over gauge pins is easier and more accurate. A gauge pin is put in two tooth gaps and the distance over the gauge pins is measured. The gauge pin diameter is equal to the maximum roller diameter of the chain.

VII. CONCLUSIONS

Using CAD / CAM / CAE minimizes the cost of temporary registration by the standard documentation as the design (building products), and the development of a single process. This paper works with the application of CAD for the production of sprockets by using a universal cutting tool - Ball mill. From an economic point of view, a departure from this special tool in the factory will create a significant reduction in the cost of parts. Implementation of the electronic document in the project process cycle a product is organizing an effective synchronous design and technology in enterprises, thereby enhancing the culture of production also.

ACKNOWLEDGMENT

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