Development of Automatic CTC Roller Chasing Machine

U.Datta[1]*, R.Lanjewar[1], G Balamurugan[1], A J Banerjee[1] P.Saha[1], S.Sen[1]

[1] Central Mechanical Engineering Research Institute,
Durgapur (WB) -713 209. (India)
enc@cmeri.res.in, uma_datta@hotmail.com

Abstract:

The tea produced by the process of crushing, tearing and curling (CTC) of tea leaf is commonly known as CTC tea and the processing unit as CTC machine. The preprocessed tea leaves are fed into CTC machine wherein a pair of rollers called CTC rollers, having uniform teeth along the circumference, is running in close proximity at different speeds to make CTC tea as final product. Combination of annular concentric grooves and helical grooves result in the formation of the CTC roller teeth. The circular grooves are machined on the rollers with a chaser tool on a special purpose lathe and helical grooves are milled on a special purpose milling machine. After continuous use, the teeth of the rollers undergo wear and deformity and therefore, they need to be reconditioned / resharpened

At present, chasing operation on CTC tea rollers are done on machines which are operated manually. Thus accuracy of chasing is not satisfactory. The accuracy of the teeth on the rollers has a great effect on the quality of tea leaves. Improved accuracy and productivity can be achieved by introducing automatic control. This paper describes development of control system of an automatic chasing machine of CTC Rollers.

Keywords: CTC Machine, Chasing, Tea rollers, Automation, Control, Cutting forces.

1.0 Introduction

Tea is produced mainly in two varieties namely Orthodox and CTC. The latter has the largest share about 80% of the total world market. The CTC tea is produced by the process of crushing, tearing and curling when withered leaves are fed in-between a pair of rotating rollers having accurately spaced teeth on their cylindrical surfaces. The machining accuracy of the teeth on the rollers has a great effect on the quality of tea Leaves. CTC rollers are formed by the combination of chasing and milling operation. Equal spaced concentric circular grooves are formed by chasing operation and helical grooves are formed by milling operation. The pitch accuracy of the annular concentric circular grooves has a large bearing on the quality of CTC tea. The developed machine provides a low cost solution to enhance the accuracy of chasing operation by automatic control using electrical drives and feedback devices with a programmable logic controller.

1. 1 CTC Process:

The process of crushing, tearing and curling (CTC) of tea leaf is commonly known as CTC tea and the processing unit as CTC machine. The preprocessed tea leaves are fed into CTC machine wherein a pair of rollers called CTC rollers, having uniform teeth along the circumference, is running in close proximity at different speeds to make CTC tea as final product. The CTC process is accomplished by meshing of teeth on the pair CTC rollers, rotating in opposite directions at different speeds. Tea leaves are fed between the rollers in the gap of the teeth, which is about 0.05 mm (0.002 Inch). The sharp edges of the teeth cut and tear up the leaves while they are crushed between the shoulders of teeth of the matched grooves, and curled due to rubbing action between the flanks of the teeth. The processed leaves are discharged on to a moving conveyor belt, which carries the leaves to the next CTC unit for forming finer CTC tea as required. Generally 2 to 3 stages of CTC process is applied on leaves to get the desired grade of tea.

Sharpening of rollers to accurate specification and proper meshing has a great influence on the quality of CTC tea. Tearing action is related to closeness of setting and the speed ratio. Closer the setting and higher the speed ratio more are the smaller grades. Curling and Crushing - the two simultaneous processes depend on the available surface area on the teeth, closeness of setting and linear differential speed.

1.2 Chasing of Circumferential Grooves on CTC Roller:

The CTC roller is made up of a cylindrical steel mandrel with concentrically machined outer surface as well as the bearing and pulley / coupling journal spaces in the mandrel arbor at both ends. Roller comprises of stainless steel segments 2” width and outside diameter 8.5” or 13”, snugly fitted on the mandrel side by side for the entire length3. Chasing operation on a CTC roller is cutting number of annular concentric grooves of “whit worth” specifications3 of normally 8 or 10 grooves per inch, irrespective, of the diameter of the rollers, on a special purpose lathe machine. The profile of the chased grooves can be either `V’ or `U’ shape as per choice of the user3. The profile angle of ‘U’ –chaser can be of either 45° or 55° by choice but in case of the `V’ –chaser the angle used universally is 55° only3.

The width of the chaser tool is 25.4 mm (1 Inch) with 8-TPI, which is conventionally used in manual operation3. After each grooving operation, the chaser tool is axially advanced by one or two teeth every time from tailstock to headstock end, by manual turning of an indexing wheel until the last groove is cut. The commonly accepted practice in chasing operation is taking reference from the previously chased grooves. This method depends on the skill of the operator. Accurate axial advance of the chaser tool is the most important in the chasing operation. Incorrect pitch of the circular grooves will result in improper meshing of the rollers. This would cause metal to metal contact between some of the meshed grooves of the pair of rollers on the CTC machine. As a result there will be consumption of more power, quick wear, tear of CTC rollers and improper cut of CTC tea.

2.0 Automation approach:

The features of the proposed automation on the existing manually operated chasing lathe are:

(1) Automatic axial positioning of the chaser tool.
(2) Automatic tool feeding for depth of cut.
(3) Inclusion of speed control in roller drive (for finding out the optimum speed of roller).

All the above motions in serial no. 1 & 2 are provided by means of two separate stepper motor drives with electro-magnetic clutches through feedback arrangement using encoder and PLC. The machine comprises of a main frame mounted headstock, tailstock, AC drive assembly, chaser tool holding attachments, electro-magnetic clutches, stepper motors, proximity switches, and electronic control unit having programmable logic controller (PLC). The AC drive assembly, which is a subassembly of the total machine, provides the required rotational motion to the job (CTC roller). Stepper drive assembly provides rotation to the main lead screw for forward intermittent movement to provide accurate longitudinal motion of saddle in chasing operation and non-cutting rapid return of the saddle after completion of particular machining cycle. The other stepper motor provides movement of saddle for depth of cut during chasing operation. This results increased productivity and increased accuracy in machining. The photographs of developed prototype is shown in Figure 1 (a) and Figure 1 (b).

2.1 Selection of Motors:

Estimation of power of the motor for rotation of roller during chasing:

Power required for rotation of roller against the tangential cutting force[2] during chasing is given by (considering one tooth at a time)

$P_{roll} = P_Z * V$ - (1)

P_Z = tangential cutting force & V = linear speed of the roller.

Power of the motor for rotation of the roller

$P_{mot} = P_{roll} / r_1 * r_2 * \eta_1 * \eta_2 * \eta_3$ - (2)

r_1, r_2 = Ratio of belt pulley, ratio of worm and worm wheel

η_1, η_2, η_3 = efficiency of belt pulley, worm and worm wheel & Motor.

The tangential cutting force (P_z) can be calculated by the following empirical relation[2] in which the influences of various important factors are considered:

$P_z = K_s * A_C$ - (3)

A_C = chip cross sectional area,

K_s = specific cutting resistance at the considered chip thickness.

The chip cross sectional area is increasing with each revolution of the roller during feed for depth of cut as shown in Figure 2. The maximum chip cross section will occur in the last revolution of the roller.

In chasing the given data are:

(1) Total depth of cut = 2.286 mm (0.09Inch)[3]
(2) Angle of 'V' groove = 55°[3]
(3) Hardness of the CTC roller (AISI 201) = 95 RB i.e 206 HB[3]
(4) Tensile strength of the material σ_t = 73 Kgf /mm²[2]
(5) V = linear speed of the roller in meter/sec

From the calculated value of A_C (chip cross sectional area) in the last revolution and from the value of K_s^2, The tangential cutting force (P_z) can be obtained from equation (3).

Estimation of the torque of stepper motor for linear indexing of the main lead screw :

Frictional resistive force for the saddle P_f(Kg-f) = total weight to be moved *μ - (4)

Coefficient of friction, μ= 0.3

Total resistive force acting on the main lead screw(P) = P_f (Kg-f.)

If T is the torque required for rotation of the lead screw, then $T = P * p / 2\pi\eta$ - (5)

p = pitch of the lead screw and η = efficiency of lead screw.

Torque required for the motor for rotation of the main lead screw $T_{ml} = T / (r_l * \eta_1 * \eta_2 * \eta_3)$ - (6)

r_l = Ratio of gear box & η_1, η_2, η_3 = efficiency of electromagnetic clutch, gear box, motor.

Estimation for the torque of stepper motor for rotation of the cross lead screw to impart depth of cut:

Tangential cutting force for cutting one groove = Pz Kg-f.

Assuming, Radial cutting force (P_r) = 70 % of tangential cutting force

Therefore, $P_r = 0.7 * P_z$ Kg-f. -(7)

Frictional resistive force P_f Kg-f = total wt to be moved *μ … (μ=0.3) -(8)

Total resistive force acting on the cross lead screw (P) =($P_r + P_f$) Kg-f. -(9)

If T_c is the torque required for rotation of the cross lead screw, then $T_c = P * p / 2\Pi \eta$, -(10)

Where p = pitch of the lead screw and η = efficiency of lead screw.

Torque required for the motor for rotation of the cross lead screw, $T_{mc} = T/(r_c * \eta_1 * \eta_2 * \eta_3)$ -(11)

r_c = ratio of gear box and η_1, η_2, η_3 = efficiency of electromagnetic clutch, gear box, stepper motor.

The above equations are used for the selection of motors to be used in prototype machine and the higher available motor size is selected for implementation. The specifications of the selected motors and drives for the prototype are shown in Table 1.

3.0 Development of the Prototype:

For development of the prototype, the basic lathe machine without screw cutting arrangement is used with specially designed attachments to implement automation. The attachments are used for providing automated controlled drive to the main lead screw and cross lead screw through independent set of stepper motor, gearbox, and electromagnetic clutch.

The rotation of roller is provided with 3 phase induction motor through variable frequency drive. Belt drive is used to impart rotation to roller from the motor. Following are the major considerations for the development of prototype

1. Controlled motion to main lead screw for longitudinal movement.
2. Controlled motion to Cross lead screw for depth of cut.
3. Accurate indexing of chaser tool between grooves.
4. Accurate control over depth of cut during chasing.
5. Electronic controller.

The following equipments are used in the prototype to achieve the above objectives.

Equipment	General Specifications	Remark
Stepper Motor (1)	Torque-125 Kg cm	For main lead screw
Reduction Gear Box (1)	Reduction; type: worm and worm wheel Ratio- 1:10	For main lead screw
Electromagnetic Clutch (1)	24V DC	For main lead screw
Stepper Motor (2)	Torque-75 Kg cm	For cross lead screw
Reduction Gear Box (2)	Reduction; type: worm and worm wheel Ratio- 1:10	For cross lead screw
Electromagnetic Clutch (2)	24V DC	For cross lead screw
Encoder	5000PPR	For indexing of chasing grooves Feedback
Proximity switches	Magnetic types	For depth of chasing
GE-Fanuc make micro-PLC	28 input / output with two analog output modules	For control of the system & for automatic cycle operation.

3.1 Description of Electronic Controller

The electronic controller is based on GE-Fanuc make micro-PLC (28 input/output). Analog output modules are used for varying the speed of the two stepper motors used in the prototype:

1. Intermittent forward movement of the saddle in longitudinal (x) direction for indexing and rapid return after completion of machining,
2. Slow forward movement of the tool holder along y direction to impart depth of cut, maintained by one proximity switch and rapid return to the cross home position maintained by another proximity switch.

Encoder (5000PPR) along with high speed counter module of PLC is used for accurate longitudinal indexing of the saddle along x direction after making each groove. Longitudinal home proximity switch is used to stop the motion after completion of job.

Switches which are used in the Electronic Controller are listed:

- 'Run / Stop' : To make the system run or stop as and when required,
- 'Reset' : To reset the system at starting of operation.
- 'Length Selection': To select two different standard length of roller, hence total number of concentric circular grooves.

The schematic of the controller is shown in fig.3 and the flow chart of the chasing operation is shown in fig. 4.

4. 0 Experimentations and findings:

The proposed automation system has been installed on the existing chasing lathe with necessary modifications as described above and tested at CMERI. The machine works satisfactorily to meet the required criterion and design objectives.

Machining experiments were carried out on the prototype. The following are the brief description of experiments and observations.

Due to the corrosive environment of machining process involved in CTC tea making, CTC rollers made of Austenitic Stainless Steel AISI 304 are commonly used. Austenitic stainless steels are characterized by their high work hardening rate and low thermal conductivity, are greatly regarded as more difficult to machine steels than carbon and low alloy steels.

Traditionally the tea industry uses a HSS tool for sharpening of CTC roller on conventional lathe. As the machine developed by CMERI is an automatic CTC sharpening machine, it was necessary to standardize the tool material and process parameters for automatic cycle operation and ease of changing worn out tools without disturbing the tool setup. Thus, to investigate the use of different tool materials and process parameters for low machining vibrations and minimum machining forces for selected parameter range study was carried out. Comparative studies are made to select the process parameters for chasing operation on CTC roller by measuring cutting forces and vibration of the machine during machining. The goal of this study is to find better alternative machining parameters like tool geometry, single or double tipped roughening process, tool materials, feed value and cutting speed for minimum vibrations and cutting forces.

Taguchi parameter optimization method was used to evaluate the best possible combination for minimum cutting force and minimum vibrations during grooving on the CTC roller.

The developed machine has limitation of Roller RPM as 20 to 30 rpm because of the structure of the machine. Considering the above limitations, roller rpm of 22, 25 & 28 rpm are selected for corresponding cutting speeds of 14.37, 16.33 & 18.29 m/min respectively. The total depth of groove is 2.59mm [0.102 Inch] and the depth of cut is imparted continuously while chasing operation form engagement of tool with work piece [roller] to the total depth of cut. The feed of 1.219, 1.602, and 1.905 mm/min were selected to impart depth of cut according to the existing industry practices.

The tool material selected in this study is HSS inserts, CVD coated inserts, and Carbide inserts. As the U-type chaser tool is primarily used for rough machining on the CTC roller, it was decided to explore the single teeth and double teeth configuration of U –type tool to reduce the rough machining time.

Radial force (Py) and tangential force (Pz) are recorded through Piezoelectric force dynamometer (Kistler- 9272).

Vibration analyzer (type IRD- 880) along with Accelerometer (IRD-970) was employed to measure the tool Vibrations during chasing. The accelerometer used has resonant frequency of 27 Khz and nominal sensitivity of 50 mV/g.

The following table shows the parameters selected and output results for experiments on the prototype.

Table1:- Input parameters

Process parameter	Parameter designation	Levels		
		L1	L2	L3
Tool shape	A	'U' Single teeth	'V' Single teeth	'U' Double teeth
Tool material	B	HSS	Carbide	Insert
Feed mm/min	C	1.219	1.602	1.905
Cutting sped m/min	D	14.37	16.33	18.29

Table2:-Results showing optimum parameter levels

Optimum machining parameter	Investigated Optimal parameter level	Predicted average value	Confirmation Experimental average values
Redial force Y	**A1, B2, C3, D3**	129 N	172 N
Tangential force Z	**A1, B2, C1, D3**	77.5 N	130 N
Tool vibrations	**A2, B2, C3, D2**	17 Micron	23 micron

The experimental results show the effect of selected parameters and their significance in chasing operation.

Pitch accuracy of the chasing grooves i.e. the spacing of the chasing grooves is the most critical output parameter which affects the final product and meshing of the rollers. Accuracy of longitudinal indexing was measured using Renishaw Calibration Interferometer System over a length of 895mm. Cumulative accuracy over that length was approximately 235 micron. The result is shown graphically in figure-5.

Accuracy of meshing of pair of rollers is also checked on Inspection Table, specially designed for this purpose, which is a general practice in Tea industry. In the inspection table, a pair of roller is mounted in bearing supports side by side with meshing of teeth to a minimum gap. The light source is placed underneath the rollers along the length. The matching of the rollers is verified by the uniform visibility of light through the length of mating rollers. Accuracy achieved with the rollers machined on the prototype is found to be superior to existing practice.

5. 0 Conclusion:

On the basis of experiments, following conclusions can be drawn

1. Accuracy in chasing operation is approximately three times higher in automatic operation than manual operation.
2. Time to complete chasing operation on a roller is marginally improved over manual operation.
3. The automation was developed on the available manually operated machine, not fully suitable to incorporate automation. It is observed that structure of the machine should be rigid to increase productivity with better quality of cutting using automation.

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Figure 1(a):- photograph of machine from operator side

Figure 1(b):- photograph of machine from rear side

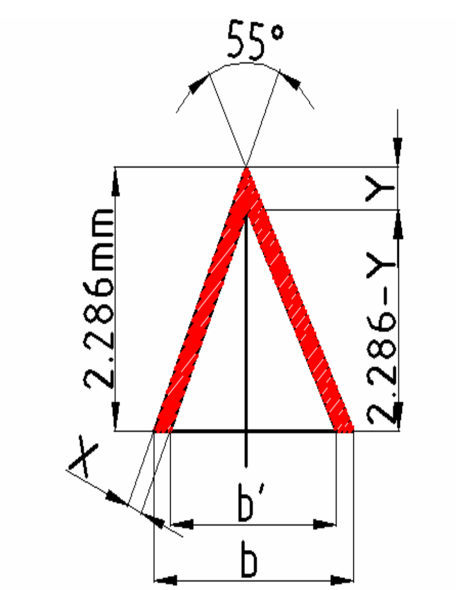

Figure 2:- chaser tool chip cross section

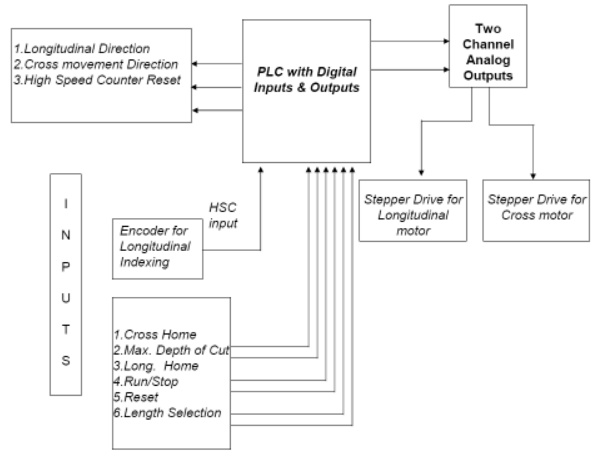

Fig. 3: Block Diagram of Electronic Controller

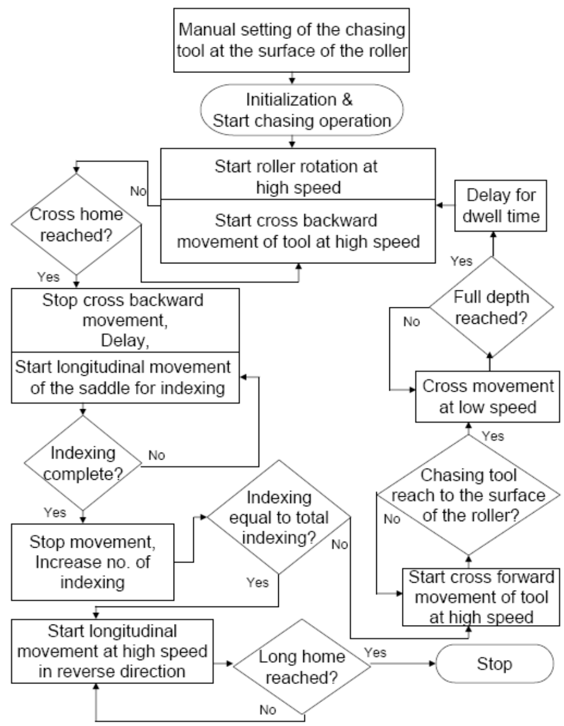

Fig.4: Flowchart of Chasing Operation

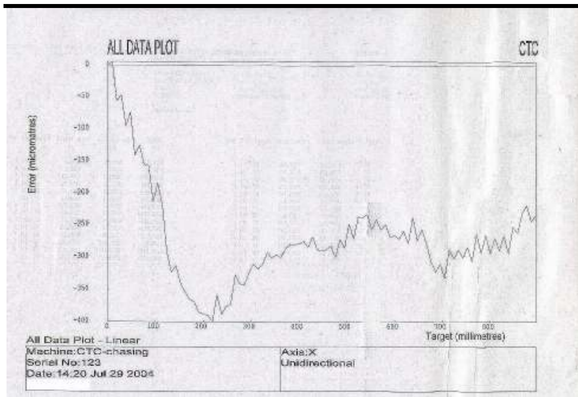

Fig.5: accuracy of longitudinal indexingusing Renishaw Calibration Interferometer System

Fig.6: Experiment on CTC roller