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# Evaluation of machining parameters for turning of AISI 304 austenitic stainless steel on auto sharpening machine

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This study evaluates optimum machining parameters like tool geometry, tool materials, single or double tithed machining process, feed and cutting speed for minimum vibrations and cutting forces for turning AISI 304 austenitic stainless steel on autosharpening machine. Taguchi's parameter optimization method is used to evaluate best possible combination for minimum cutting force and minimum vibrations during machining.

**Keywords:** CTC machine, CTC roller, Autosharpening, Chasing, Optimisation

## Introduction

Machines used by tea industries for processing tea leaves consists a pair of cylindrical rollers called 'CTC rollers' made of stainless steel, running with different speed in close proximity (meshing) to process withered leaf to form CTC (cut, torn and curled) tea. Traditionally, tea industry uses two separate manually operated machines, one for chasing and other for milling operation on CTC roller with special fitment and setting. In order to enhance productivity and saving of machine setting time, CMERI, Durgapur has developed an automatic machine for manufacturing and reconditioning of CTC rollers, where both chasing and milling operations can be performed on the same machine in the same setup (Fig. 1).

Austenitic stainless steel[1] (ASS) is used to fabricate chemical and food processing equipments as well as machinery parts requiring high corrosive resistance[2]. ASSs with high strength, low thermal conductivity and high work hardening tendency are more difficult to machine steels than carbon and low alloy steels[3,4]. Tea industry has been using 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 tool material and process parameters for automatic cycle operation and ease of changing worn out tools without disturbing the tool setup.

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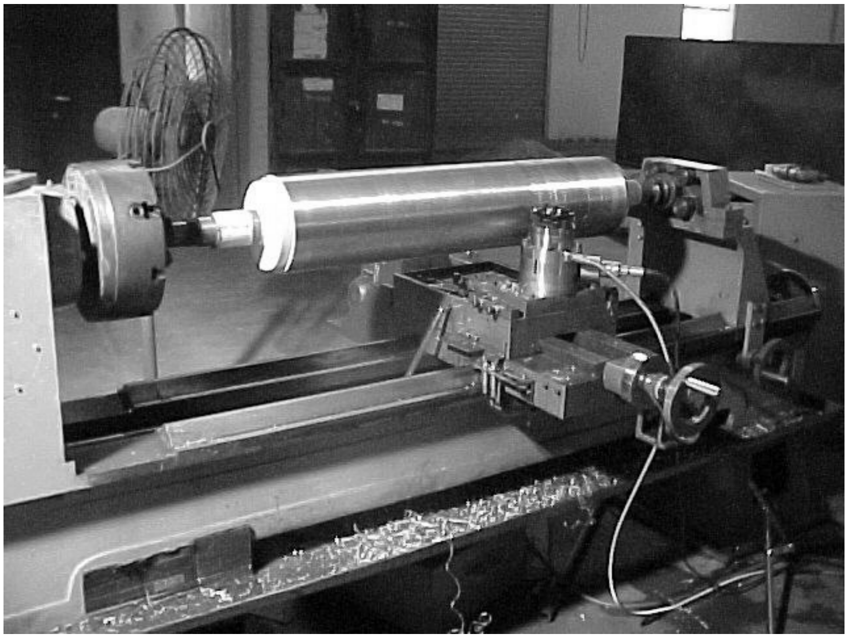
Present study investigates the use of different tool materials and process parameters for low machining vibrations and minimum machining forces for selected parameter range. Comparative studies are made to select the process parameters for chasing operation on CTC roller using cutting forces and vibration in order to find optimum machining parameters.

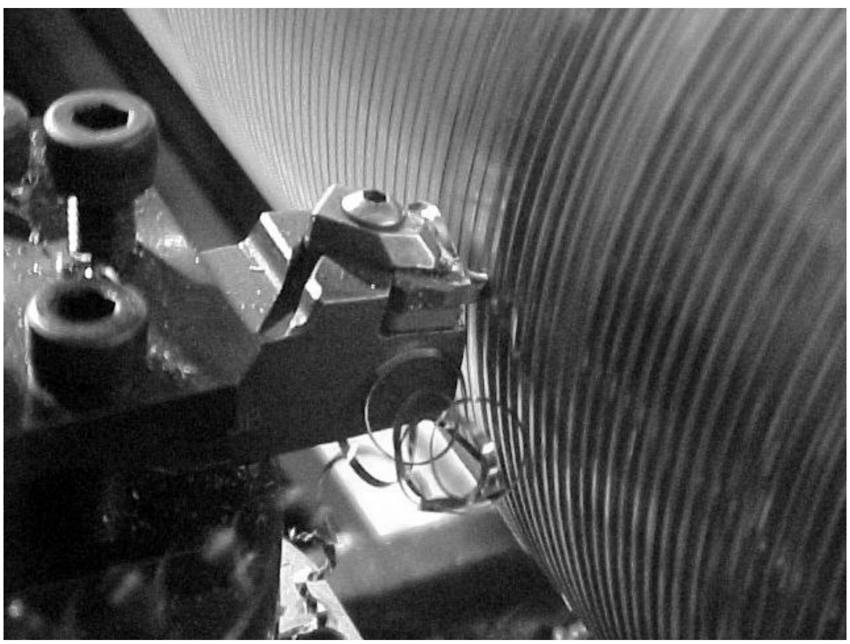
## Experimental Details

AISI 304 ASS, used in this study, consists of: Fe, 68.8; C, 0.08; P, 0.045; S, 0.03; Si, 1; Mn, 2; Cr, 18-20; and Ni, 8-10.5%. Machining tests were performed on a CTC roller made of 30 numbers of rings like segments (length 50.8 mm, outer diam 208 mm, inner diam 170 mm), snugly fitted on the rigid mandrel side by side (length 762 mm). Cutting speeds were selected by preliminary experiments conducted on the machine, cutting tool manufacturers recommendations and tea industry practice[5] (Table 1). Grooving tests were carried out on AISI 304 ASS to determine optimum machining parameters.

CMERI machine has limitation of roller rpm (20-30 rpm) because of machine structure and servo motor capacity installed on it. Considering this limitations, roller rpm for this study were selected as 22, 25 & 28 rpm, which gives corresponding cutting speeds of 14.37, 16.33 & 18.29 m/min. Depth of cut was imparted continuously while chasing operation was on roller to the total depth of cut (2.59 mm). The feed of 1.219,



a)



b)

Fig. 1—CMERI machine: a) Experimental setup; b) Chasing operation (machining grooves)

1.602, and 1.905 mm/min were selected to impart depth of cut according to the existing industry practices.

Traditionally, High Speed Steel (HSS) is used as a tool material for chasing of CTC roller. Tool material for this study was HSS inserts, carbide inserts, and CVD coated inserts. As the U-type chaser tool is primarily used for rough machining and V-type chaser tool for finish cut on CTC roller, it was decided to explore the single teeth and double teeth configuration of U-type tool to reduce the rough machining time (Table 1).

Piezoelectric force dynamometer [Kistler- 9272, quartz 4-component dynamometer (Fx, Fy, Fz, Mz)] was used

Table 1—Process parameters at three levels

| Process parameter | Levels | | |
|---|---|---|---|
| | L1 | L2 | L3 |
| | U | V | U |
| Tool shape (A) | Single teeth | Single teeth | Double teeth |
| Tool material (B) | HSS | Carbide | CVD insert |
| Feed (C), mm/min | 1.219 | 1.602 | 1.905 |
| Cutting sped (D), m/min | 14.37 | 16.33 | 18.29 |

to measure redial force (Py) and tangential force (Pz). Each experiment was repeated three times (corresponding to three replications) and results were recorded for tangential and radial force (Table 2). Vibration analyzer (type IRD-880) along with accelerometer (IRD-970) measured tool vibrations during chasing. Accelerometer used has resonant frequency of 27 Khz and nominal sensitivity of 50 mV/g. Taguchi parameter optimization method was used to evaluate the best possible combination for minimum cutting force and minimum vibrations during grooving (chasing) operation on the CTC roller.

#### Selection of Orthogonal Array

Each parameter was analyzed at three levels in order to explore non-linear relationship of process paramenters[6] (Table 1). Designed experiments were based on the orthogonal array (OA) technique, which is a fractional factorial with pair wise balancing property. L9 ($3^4$) standard OA, which is obtained by assigning selected factors and their levels in respective columns of L9 OA, was used in experimental study (Table 2). Main effect of process parameters was estimated by assuming negligible interactions. However, experiments were carried out randomly to avoid unidentified noise sources, which were not considered during the study. The variation of response is examined using an appropriately chosen S/N ratio, depending on the objective function. In present study, quality characteristic is a force on tool due to variation of process parameters in designed range and tool vibrations to minimize cutting forces and tool vibration. So, S/N ratio for 'Lower the better' type of response was used and is given[7] as

$$\text{S/N ratio( in dB)} = -10\log\left[\frac{1}{\text{n}}\sum_{i=1}^{n} Yi^2\right] \quad \dots (1)$$

where i, no. of trial; $y_i$, measured value of quality characteristic for $i^{th}$ trial condition; n, no. of repetitions. Signal to noise ratios were calculated using Eq.(1) for each of the nine experimental conditions (Table 2). Factor effects can be separated out in terms of S/N ratio and in terms of mean response.

## Results and Discussion

Mean response referring to average values of performance characteristics for each parameter at different level was calculated (Table 3). Radial force Y has been found minimum at $1^{st}$ level of parameter A (tool shape), $2^{nd}$ level of parameter B (tool material) and $3^{rd}$ level of parameter C (feed) and D (cutting speed). S/N ratio (in bold) also suggests that the same level of parameters ($A_1$, $B_2$, $C_3$, and $D_3$) is best level for minimum radial force Y in chasing of CTC tea rollers. Parameters levels ($A_1$, $B_2$, $C_1$ and $D_3$) are the best levels for minimum Tangential force Z in chasing of CTC tea rollers (Table 3). Similarly for tool vibrations during chasing operation (Table 3), parameters levels ($A_2$, $B_2$, $C_3$ and $D_2$) are the best levels for minimum tool vibrations in chasing of CTC tea rollers.

#### Analysis of Variance (ANOVA) and Significance of Parameters

ANOVA study indicated that parameters A, B and C had significant effects on radial force Y (Table 4), which significantly increases as cutting points (teeth) increases; as material removal was double as compared to that with the single point (U & V shaped with one teeth) tool apart from other parameter effects. ANOVA for tangential force Z (Table 5) shows that parameters A and C have most significant effects and cutting speed has marginal effect.

Parameters A and C have significant effects on tool vibrations during chasing operation (Table 6), which increased considerably (Table 2) while machining with two teeth geometry (tool shape Level 3; U double teeth) of tool as compared to single point cutting during this study. ANOVA model suggests that A (tool shape) and C (feed) are the most significant factors for all quality characteristics (radial force Y, tangential force Z and tool vibrations) during chasing operation, although B (tool material) and D (cutting speed) have marginal significance to affect radial force Y and tangential force Z respectively. Error variance was also evident with PCR values of 33.38%, 38.62% and 47.47% for Radial force Y, Tangential force Z and tool vibrations respectively during chasing operation.

**Estimation of Optimum Performance Characteristics**

Optimum radial force Y ($\mu_{Fy}$) was predicted at selected levels of significant parameters ($A_{1n,}$ $B_2$, $C_3$, $D_3$). Estimated optimum radial force Y ($\mu_{Fy}$) can be calculated as[8]

$$\mu_{Fy} = \overline{A_1} + \overline{B_2} + \overline{C_3} + \overline{D_3} - 3\overline{T_{FY}} \quad \ldots(2)$$

where $\mu_{Fy}$ is optimum radial force Y, and $\overline{T_{FY}}$ is overall mean of radial force Y with parameters at optimal level. From Table 2, mean $A_1$ = 283, mean $B_2$ = 365, mean $C_3$ = 608, mean $D_3$ = 406 and mean $T_{FY}$ = 511 N. Hence $\mu_{Fy}$ = (283+365+608+406) – (3*511) = 129 N.

A confidence interval for predicted mean radial force Y on a confirmation run can be calculated[8] as

$$CI = \sqrt{F_a(1, f_e).V_e.\left[\frac{1}{n_{eff}} + \frac{1}{R}\right]} \quad \ldots(3)$$

$$n_{eff} = \frac{N}{1+[\text{total DOF associated in the estimate of mean}]} \quad \ldots(4)$$

where *Fa (1, fe);* F ratio required for *a,* risk; *fe,* error DOF; *Ve,* error variance; R, no. of replications for confirmation experiments; n, total no. of experiments; and $n_{eff}$, effective no. of replications.

Using values for radial force (Y) as *Ve* = 60408.25 and Fe = 18 from Table 5, total DOF associated with the estimate of mean $\mu_{Fy}$ = 4 * (3 - 1) = 8; No. of trials = 9; N = 3 x 9 = 27; $n_{eff}$ = {27 / (1+8)} = 3; $f_{0.05}(1,18)$ = 4.4 (tabulated), CI is calculated as

$$CI = \sqrt{4.41 * 60408.254 * \left[\frac{1}{3} + \frac{1}{3}\right]}$$

CI = 421 N.

Optimum tangential force Z ($\mu_{Fz}$) was predicted at selected levels of significant parameters ($A_{1,,}$ $B_2$, $C_1$, $D_3$).

Table 2 -- L9-OA and experimental data results (raw data) with corresponding signal-to-noise ratio[S/N (dB)]

| Experiment No. | Total shape | Total Material | Feed | Cutting speed | Cutting force Y Radial force N | | | Cutting force Z, Tangential force N | | | Average vibration, µ 60 to 60K CPM Band | | | Y force S/N ratio | Z force S/N ratio | Vibration S/N ratio |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | Trial 1 | Trial 2 | Trial 3 | Trial 1 | Trial 2 | Trial 3 | Trial 1 | Trial 2 | Trial 3 | dB | dB | dB |
| 1 | 1 | 1 | 1 | 1 | 303 | 332 | 365 | 231 | 233 | 249 | 37 | 35 | 32 | -50.48 | -47.52 | -30.81 |
| 2 | 1 | 2 | 2 | 2 | 235 | 241 | 236 | 234 | 222 | 219 | 24 | 21 | 22 | -47.51 | -47.05 | -26.99 |
| 3 | 1 | 3 | 3 | 3 | 278 | 266 | 287 | 192 | 182 | 194 | 26 | 21 | 23 | -48.86 | -45.54 | -27.39 |
| 4 | 2 | 2 | 3 | 1 | 286 | 273 | 251 | 287 | 278 | 281 | 27 | 25 | 22 | -48.64 | -49.00 | -27.87 |
| 5 | 2 | 1 | 2 | 3 | 348 | 376 | 394 | 171 | 182 | 190 | 46 | 54 | 68 | -51.43 | -45.16 | -35.08 |
| 6 | 2 | 3 | 1 | 2 | 474 | 447 | 432 | 274 | 269 | 239 | 24 | 20 | 23 | -53.09 | -48.33 | -27.00 |
| 7 | 3 | 1 | 3 | 2 | 929 | 944 | 1122 | 573 | 564 | 590 | 80 | 73 | 82 | -60.02 | -55.20 | -37.89 |
| 8 | 3 | 2 | 1 | 3 | 600 | 472 | 633 | 396 | 278 | 416 | 65 | 68 | 78 | -55.16 | -51.33 | -36.97 |
| 9 | 3 | 3 | 2 | 1 | 1186 | 1097 | 1002 | 567 | 581 | 567 | 85 | 96 | 82 | -60.81 | -55.15 | -38.88 |

Table 3—Result for individual quality characteristics, S/N ratio (dB) for average output quality parameter

| Parameter | S/N ratio for radial force Y | | | S/N ratio for Tangential force Z | | | S/N ratio for tool vibration | | |
|---|---|---|---|---|---|---|---|---|---|
| | L1 | L 2 | L 3 | L 1 | L 2 | L 3 | L 1 | L 2 | L 3 |
| Tool shape A | **-48.951** | -51.055 | -58.662 | **-46.705** | -47.496 | -53.893 | -28.399 | **-29.984** | -37.912 |
| Tool material B | -53.978 | **-50.438** | -54.252 | -49.292 | **-49.127** | -49.674 | -34.593 | **-30.611** | -31.091 |
| Feed C | -52.910 | -53.251 | **-52.507** | **-49.059** | -49.119 | -49.916 | -31.595 | -33.648 | **-31.051** |
| Cutting speed D | -53.312 | -53.540 | **-51.817** | -50.554 | -50.197 | **-47.343** | -32.520 | **-30.628** | -33.146 |

Table 4—ANOVA for radial force Y

| Source | Sum of squares (SS) | Degrees of freedom (f) | Variance (V) | F- ratio | Pure sum of squares (SS')= Sa-(Ve*Fa) | Contribution on (P), % |
|---|---|---|---|---|---|---|
| A | 1936362.033 | 2 | 968181.02 | 16.0272966 | 1815545.523 | 38.59* |
| B | 322168.0389 | 2 | 161084.02 | 2.66658952 | 201351.529 | 4.28* |
| C | 1208626.82 | 2 | 604313.41 | 10.0038217 | 1087810.310 | 23.12* |
| D | 150132.6083 | 2 | 75066.3041 | 1.242649772 | 29316.099 | 0.62 |
| E (error) | 1087349 | 18 | 60408.2549 | | 1570614.627 | 33.38 |
| T (Total) | 4704638.088 | 26 | | | 4704638.088 | 100.00 |

Tabulated F-ratio at 95% confidence level: F(0.05, 2, 18) = 3.55 (tabulated),*Significant at 95 % confidence level

Table 5—ANOVA for tangential force Z

| Source | Sum of squares (SS) | Degrees of freedom (f) | Variance (V) | F- ratio | Pure sum of squares (SS')= Sa-(Ve*Fa) | Contribution on (P), % |
|---|---|---|---|---|---|---|
| A | 454578.7281 | 2 | 227289.36 | 12.3452575 | 417756.594 | 33.70* |
| B | 12973.71894 | 2 | 6486.8595 | 0.35233479 | -23848.415 | -1.92 |
| C | 361941.135 | 2 | 180970.57 | 9.82944482 | 325119.001 | 26.23* |
| D | 78741.40156 | 2 | 39370.701 | 2.1384258 | 41919.268 | 3.38 |
| E (error) | 331399 | 18 | 18411.0670 | | 478687.743 | 38.62 |
| T (Total) | 1239634.19 | 26 | | | 1239634.190 | 100.00 |

Tabulated F-ratio at 95% confidence level: F(0.05, 2, 18) = 3.55 (tabulated),*Significant at 95% confidence level

Table 6 —ANOVA for average vibrations

| Source | Sum of squares (SS) | Degrees of freedom (f) | Variance (V) | F- ratio | Pure sum of squares (SS')= Sa-(Ve*Fa) | Contribution on (P), % |
|---|---|---|---|---|---|---|
| A | 14209.18519 | 2 | 7104.5926 | 7.58857505 | 12336.741 | 24.04* |
| B | 1399.185185 | 2 | 699.59259 | 0.74725057 | -473.259 | -0.92 |
| C | 18420.51852 | 2 | 9210.2593 | 9.83768494 | 16548.074 | 32.25* |
| D | 431.4074074 | 2 | 215.7037 | 0.23039797 | -1441.037 | -2.81 |
| E (error) | 16852 | 18 | 936.22222 | | 24341.778 | 47.44 |
| T (Total) | 51312.2963 | 26 | | | 51312.296 | 100.00 |

Tabulated F-ratio at 95% confidence level: F(0.05, 2, 18) = 3.55 (tabulated),*Significant at 95% confidence level

Estimated optimum $\mu_{Fz}$ can be calculated as

$$\mu_{Fz} = \overline{A}_1 + \overline{B}_2 + \overline{C}_1 + \overline{D}_3 - 3\overline{T}_{Fz} \qquad \ldots(5)$$

where $\overline{T_{Fz}}$ is overall mean of radial force Z with parameters at their optimal level.

From Table 2, mean $A_1$ = 217, mean $B_2$ = 290, mean $C_1$= 287, mean $D_3$ = 245 and mean $T_{Fz}$ = 321 N. Hence $\mu_{Fz}$ = (217+290+287+ 245) – (3*321) = 77.05 N. A confidence interval for the predicted mean tangential force Z on a confirmation run is calculated using Eq. (3) and (5) as C I = 232 N.

Table 7—Comparison of predicted and confirmation experimental results

| Optimum machining parameter | Investigated level optimal parameter | Predicted average value | Confirmation Experimental average values |
|---|---|---|---|
| Radial force Y | $A_1, B_2, C_3, D_3$ | 129 N | 172 N |
| Tangential force Z | $A_1, B_2, C_1, D_3$ | 77.5 N | 130 N |
| Tool vibrations | $A_2, B_2, C_3, D_2$ | 17 ¼ | 23 ¼ |

Optimum tool vibration during chasing operation ($\mu_{Tv}$) was predicted at selected levels of significant parameters ($A_2, B_2, C_3, D_2$). Estimated optimum $\mu_{Tv}$ can be calculated as

$$\mu_{Tv} = \overline{A_2} + \overline{B_2} + \overline{C_3} + \overline{D_2} - 3\overline{T_{Tv}} \quad \ldots(6)$$

where $\overline{T_{Tv}}$ is overall mean of tool vibrations during chasing operation with parameters at optimal level.

From Table 2, mean $A_2 = 34$, mean $B_2 = 39$, mean $C_3 = 42$, mean $D_2 = 41$, and mean $T_{Tv} = 47$ ¼. Hence $\mu_{Tv}$ = (34+39+42+ 41) – (3*47) = 17 ¼. A confidence interval for predicted mean tool vibration on a confirmation run is calculated using Eqs (3) and (6) as C I = 52 μ.

#### Confirmation Experiments

Nine experiments (3 repetitions for each of 3 experiments) at optimal setting were conducted during chasing operation recommended by investigation for radial force Y, Tangential force Z and tool vibrations. At investigated parameters optimal levels, following was found: average radial force Y, 172 N; average Tangential force Z, 130 N; and tool vibrations, 23 μ. Comparison between predicted and confirmation experiment values (Table 7) indicated that predicted values are within the range of confidence interval.

## Conclusions

Optimum parameter levels for minimum radial forces Y are 1st level of parameter A (tool shape), 2nd level of parameter B (tool material), 3rd level of parameter C (feed) and 3rd level of parameter D (cutting speed). This implies that the level of parameters at designated levels as $A_1, B_2, C_3, D_3$ are the best combination to get minimum radial force Y in chasing of CTC tea rollers. Optimum parameter levels for minimum tangential force Z are $A_1$, $B_2$, $C_1$, $D_3$ and that for minimum tool vibrations during chasing operation are $A_2$, $B_2$, $C_3$, $D_2$. ANOVA model suggests that tool shape and feed are the most significant factors for all the three quality characteristics (radial force Y, tangential force Z and tool vibrations) during chasing of CTC rollers. ANOVA also suggests that tool material has marginal significance to affect radial force Y and cutting speed has marginal significance on tangential force Z. Radial force Y significantly increases as the cutting points increases; as the material removal was double as compared to that with the single point (U & V shaped with one tooth) tool.

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