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Optimizing the Process Parameters for controlling the Vibration in Turning of TWIP Steel Rod

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Abstract: **Turning process embodies the separation of the metal atop exterior surface of a pirouette work piece in cylindrical shape. It is one among the most commonly used technique of cutting largely when finishing of the product. The pennant of turning variables for instance, speed of cutting, rate of feed and cut of depth, in the turning process need to be designated cautiously to ameliorate the turning potency by amplifying the productivity and minimizing the total cost of manufacturing for each integrant. A high vibration ushers to penurious surface finish and reduces the productivity followed by shortening of tool life, in order to avoid that the vibration of the cutting tool must be controlled. In this experimental work, an investigation is made to understand the reverberations of these turning parameters in the voyage of a work piece, made up of twinning induced plasticity (TWIP) steel, by using response surface methodology. Statistical tools are used for designing of the experiments. Then the process parameters were optimized by maneuver of analysis of variance, regression analysis and techniques of optimization to accomplish the context of minimum tool vibration and low chip frequency, consequently ameliorating the surface roughness in the wake of turning process.**

Index Terms: Optimizing, Process parameters, Vibration, Turning, TWIP steel.

I. INTRODUCTION

Machining operations, such as milling, turning, and drilling are paramount in production industries. Turning by definition is the process of removal of metal or material from a cylindrical surface of the work piece that leads to a reduction of the diameter to a specified dimension. Usually the reduction of the turning process is done with the rotating work piece and relatively stationary cutting tool. However feed is provided to the cutting tool to advance it for the removal of the metal from the work piece. The turning process usually requires a maximum surface finish with minimum amount of residual stresses. In the manufacturing cramming, to obtain a maximums surface finish with minimum residual stresses the cutting tool vibration must be maintained less. At the outset the vibration of the cutting is targeted to be less instead of zero because of the fact in turning vibration of the cutting tool is unavoidable. This unavoidable phenomenon which strive the quality of the work piece, accuracy of machining, cutting tool life and increase in the operation cost. The grail of manufacturing industry has always emphasized the low-cost manufacturing and products of high-quality in a dwarf time. Modern manufacturing industries endeavor to escalate these attributes. To attain the high cutting staging, manufacturing industry necessitates wielding of optimal turning variables [1]. Correspondingly, cutting variables such as speed of cutting, rate of feed and cut of depth in the course of the turning process are to be chosen agreeably to maximize the productivity, for reduction of total manufacturing cost of each work piece, or to accomplish a preconceived congruous criterion.

Since the cost of digitally controlled machine tools is high, as juxtaposed with the prosaic counterparts [2], their working desideratum to be energetically discharged to churn out the desired product [2]. During the turning process, vibrations arise due to the friction in between the tool and the work piece. Therefore, the staging of the machine hang on deliberately on vibration due to the turning subpoena, in this a vibration less schema sooner required. The rate of retrogression rate and inexactitude which increase with the utilization of the cutting tool that can be set on by monitoring of vibration [2]. Theories of vibration are theories of coupling situation that have embellished prominent [3]. The research has also super scribe the amalgamate sitch, emanate out of vibration apropos the position of the momentum [3], which engenders vibration in direction of cutting force and conversely, paramount to a multi-directional esplanade [4]. It also urges that escalate in the clearance of flank, rake angle is spurt the solidity of dynamic procedure of turning due to the dissimilitude effects. Furthermore, a mathematical model and a linear differential correspondence is opted for cutting speeds, high and low dynamic action of cutting also the tool rake is lodged. Furthermore, the process variables are influenced the vigor of initial friction.

The turning activity of TWIP steel rod explored in respect of work piece wear and the surface quality deportment of cutting tools. Investigation flaunted the inter-relationship in between the input &output variables such as tool insert nose radii, feed rate and the coating insert methods. The study has given little results towards the right selection of tools in turning of TWIP steel rods. In the investigation of the turning experiments are exhibited on 3 different composed TWIP steels rods at 3 different turning feeding rates, depths and non-coolant associated cutting speeds. In addition the investigation targeted mainly for reducing both ruggedness of the surface and also consumption of power by evaluating the optimized turning parameters. The repercussions of the

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turning parameters and hardness of work piece over the surface roughness, power consumption and sound level and are assessed. The detection manifested that feed rate has the most significant impact in turning process, particularly over the power consumption and surface roughness. The cutting speed and depth of cut also have shown meticulous effects followed by feed rate.

This can be accessed from literature survey that some papers are delineated on optimization of parameters influencing the vibration attributes of the turning of TWIP steel rod by applying the response surface methodology in view of the mathematical & analytical study. Accordingly, this analysis is accorded to the inspection of ramification of the turning feed rate, turning speed and tool depth of cut over the frequency of chip and tool vibration concomitantly for the turning of TWIP steel work pieces with the response surface methodology, the experiment establish the optimized process parameters with the help of 2 heuristic algorithms [5].

II. Methodology

The methodology accustomed to explore the process parameter optimization of turning process of the TWIP steel rod with the RSM as shown in the figure 1. In addition, to it the sequence of operating procedure is elucidating as follows:

Step 1: Review of literature on turning process, machining vibration, RSM and the required terms. Step 2: scheming of experiment. During this step, design of RSM is made to estimate the repercussions of the process parameters over the surface roughness succeeding the process of turning. Step 3: Investigational procedure involve in designating the significant material, that is the TWIP steel rod and then performing the process of turning maneuver theCNC-M392 machine. Step 4: Analysis of the data with the RSM towards optimizing process variables of turning. In the next step the outcomes & colloquy are used for substantiating the enactment of the experiments.

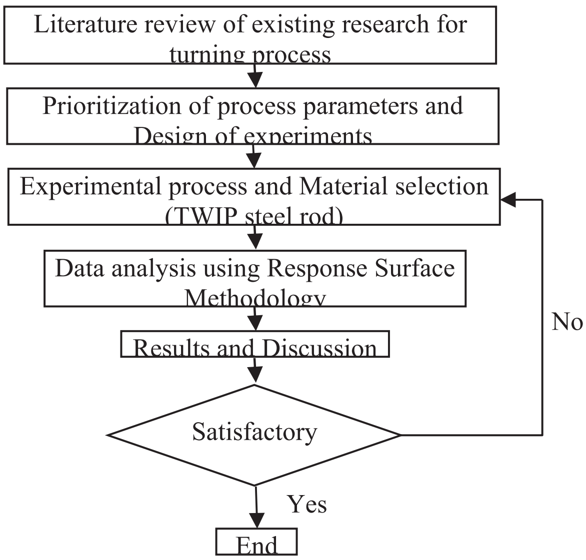

Figure 1. Flow chart showing the methodology of Turning

III. Experimental work

Material used: In this experiment, twining induced plasticity steel rods are used.

Arrangement of TWIP steel rod in CNC Machine for turning. The implementation of the experiment is carried on a CNC lathe machine as given in the Figure 2 that has 5.8 kW power and also 2200 rpm of spindle speed (maximum). The work piece is a medium carbon TWIP steel, as detailed in the above literature. The diameter and length of work piece are100 and 500 mm. Work piece is mounted over the tailstock that requires good support. After finishing the establishment of CNC machine, the surface of work piece exhibited to remove the external surface layer of work piece that is robust, as given in the figure 3.

A. Cutting Tool Holder and the Insert

As shown in figure 2 the considered insert that is the TWIP steel turning grade. Titanium carbide and Tungsten carbide of insert the caper bound because of the cobalt (Co). The tool insert is prepared with the face centered cubic (fcc) structures to enable the precision and cutting speed of process, hence developing the smoothness to the TWIP steel rod work piece. By dint of the distinctive properties, such as high resistance and low friction against the crack, wear and diffusion and coated tools also be utilized at reducing the time, high cutting speeds and cost used for the turning processes. Then after tool insert can be fasten to tool holder, the tool clamp is further tightened with the help of clamp screw, as given in the figure 5. Two marshalling of the tool overhang (65 and 130 mm) are utilized. Then after, tool holder can be reinforced over the tool turret and cutting tool can be explicitly centered, in view of center of CNC tailstock tool.

B. Design of Experiments with Response Surface Methodology (RSM)

The RSM is utilized for evaluation of emphasis of appurtenances towards the turning process variables by complying roughness of rod surface. Feed rate, Speed &depth of cut are unfettered parameters that are selected for the analysis using RSM and in competence with previous literature study [6,7]. The Figure 3validates the subservience alliance among the dependent parameters and the independent variables (chip frequency and vibration variables) that are crucial to peruse the roughness of the surface.

The prowess of user can be divided as the slacken variable that has the strong unforeseen effect over the alliance of variables. By disparity, the fidelity can be utilized as the liaise vacillating that supremacy of the outcomes. In the present research, the central composite design (CCD) is the manner plump for design of experiment. The approach can be integrated with the RSM to set up a quadratic type model for a variable response [8]. CCD has the most prominent amid the categorization of the RSM depiction because of some the patronage reasons:

(i) CCD is cleaving into 2genusscrutinize that act for poles apart the effects that can be shrewdly performed. The former one resembles the impact of linear &the later one resembles the convexity ramification. In accordance, when speculative analysis has the informative points towards the

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maiden subset for having non-significant type of curvature effect.

(ii) CCD is one of the effective technique in optimization, which facilitates the intelligence over the assessment variables such that the overall investigational error with the slightest indispensable reciprocity.

(iii) CCD is to be cast-off in the copious investigational areas. CCD accommodates a new fractional factorial or design factorial of central points, which are associated with the set of optimum points, empower a faultless guesstimate of curvature.

In CCD, 2set of hypothetical designs that can be plump for (small or full). For the following experiment, a small type of CCD is selected, as depicted in the Table 2.

C. Vibration cum Detector framework

The intuitive Dasy Lab software is used to quickly and easily scrutinize the vibration statistics by waged with unveils straight over the screen. In addition to it the accelerometer is accustomed to recognize and attain the vibration statistics.

An accelerometer can be laid down over the wedge to be examined [9]. Accelerometers can be established with the noteworthy wax as they are having a good ascend tool for the lightweight detector in ad interim investiture.

III. Results And Discussions

This fragment contributes the RSM outcomes deploy on the quantifications of chip frequency and vibration. Further, their associations with turning process parameters are computed with the interaction plots, main effect plots and surface plots. Furthermore, optimization and mathematical models are furnished. Table 2 bestows the disposition of experiments along with the chip frequency and vibration outcomes.

A. Development of the Vibration Model

Variance Analysis: Estimated coefficients of regression for the vibration that are shown in the Table 2show that the numerals are statistically different. Main effects are obtained from p - value, such that the value is lower than 0.05, then it could be made that the outcome is significant. Although the feed rate, cutting speed and depth of cut were remarkable to the model of response is at 0.05.

Residual Plots-Vibration: The below figure 8 depicts the plots of residual at odds with the proportion and the fitted values and frequency in dataset& the index of observation. These outcomes are disseminated desultory hinged over the contoured values and the index of observation.

Furthermore, the outcomes depict that p value of residuals (0.213), more than that of 0.05 towards the vibration. Then a linear relationship cans be discerned then the residuals were made in opposition with the percent of values [10]. The data depicts the proportions of each of the turning parameter also their amalgamation, which has been assessed from the equation no (1).

The amalgam of the depth of cut and cutting speed has the biggest endowment for the vibration, which is accompanied with the depth of cut, cutting speed and feed rate.

$$\text{Contribution} = \frac{\text{adjusted sum of squares for each other}}{\text{total adjusted sum of squares}}$$

B. Plot of Interaction for the Vibration

As the figure 4 depicts the ascendency of feed rate and depth of cut on the vibration. Accordingly, increase of the feed rate (C) & the depth of cut (B) bestows the escalate in vibration.

C. Plot of Contour for Interaction Factor

The figure 5 shows the contours of vibration at all of the different proportions of turning speed variables. Accordingly, the rise in the depth of cut promotes to the hike in the vibration rise.

The below Table 1 shows the experimental design-values of the process parameters.

TABLE I.
EXPERIMENTAL DESIGN

Standard order	Order of Run	Cutting speed in mm/s	Depth of cut in mm	Feed rate in mm/s	Vibration Volt	Chip frequency Hz
1	1	50	1.9	0.21	0.092	2079.8
12	2	45	1.4	0.15	0.0701	1004.8
3	3	190	1.4	0.16	0.149	6789.5
8	4	120	1.5	0.9	0.10589	7199.4
6	5	122	0.78	0.15	0.1213	9101.8
11	6	125	2.22	0.16	0.10248	1135.87
13	7	125	1.4	0.16	0.10311	5459.2
7	8	124	1.6	0.15	0.10278	5134.8
10	9	126	1.5	0.16	0.10239	5432.8
15	10	125	1.5	0.15	0.1209	6215.9
14	11	201	1.0	1.1	0.1509	6188.2
4	12	200	2.1	1.9	0.1608	2124.9
5	13	49	1.2	1.1	0.05	2011.8
9	14	124	1.4	1.6	0.11577	1578.9
2	15	126	1.52	1.6	0.10340	4819.7

Figure 2. Experimental setup

TABLE II.
VARIABLES OF ANOVA

Source	DF	SS	Adj SS	F value	p value
Model	9	0.012541	0.001415	10671.88	≤0.0011
Linear	3	0.000210	0.000891	291.4	≤0.001
A: Cutting speed	1	0.000071	0.0009	619.8	≤0.001
B: Depth of Cut	1	0.00021	0.000125	128.7	≤0.001
C: Feed rate	1	0.00009	0.00021	35.11	0.0019

D. Surface Plot showing Vibration

The figure 5 shows the plots of surface for vibration lie upon the depth of cut and feed rate. The quarry vibration is then accomplished. Consequently, there is a less quantity of the depth of cut and more quantity of feed rate.

The vibration (V) set up procured from stratagem in the antecedent fragment act for the equation (2).

Vibration:

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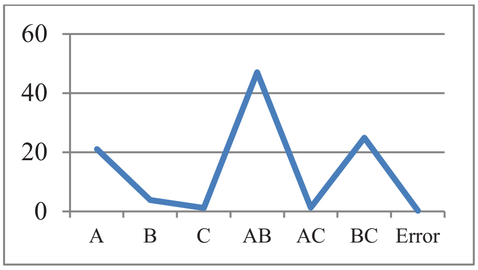

Figure 3. Percentage contribution of variables

$V = 0.08627 - 0.000497A - 0.02857B - 0.1079C + 0.0000021A^2 - 0.008091B^2 - 0.34638C^2 + 0.000271AB + 0.000418AC + 0.2698BC.$

Build out of the Chip Frequency Setup

Analysis of the Variance: The ANOVA given in the data details each of the terms of model (A, B, A B, A C, B C, A2 &C2) are needful for detailing frequency of the chip formation because of the less p value. Moreover, the outcomes of the setup show the more accurate as that of R-square value that is more (98.73%).

As the forecasted coefficients of regression analysis towards the frequency of chip are compared. The outcomes of coefficients are notably different. And the p values are less than 0.05 towards the linear term, which is the set of variables, can show the deportment of frequency of chip. Cutting speed & depth of cut were noteworthy to the model of response at p = 0.05.

Figure 4. Graph showing depth of cut vs Vibration

Plots of Residual for the Frequency of Chip: The Figure 6showsplots of residual for the frequency of chip in opposition to the ration and the fitted values and frequency of numerals are in dataset along with the index of observation.

The outcomes are apportioned contingently established on the values of fitted hypothesis and index of observation. Hence, the outcomes depict that value of p of the residuals (0.078) is greater than 0.05 towards the frequency of the chip. A linear alliance is then perceived along with the plotted residuals against percentage values.

Figure 7shows the benefaction of everyone noteworthy variable and their amalgam. Cutting speed has giant benefaction for the frequency of the chip, accompanied with combination of process parameters.

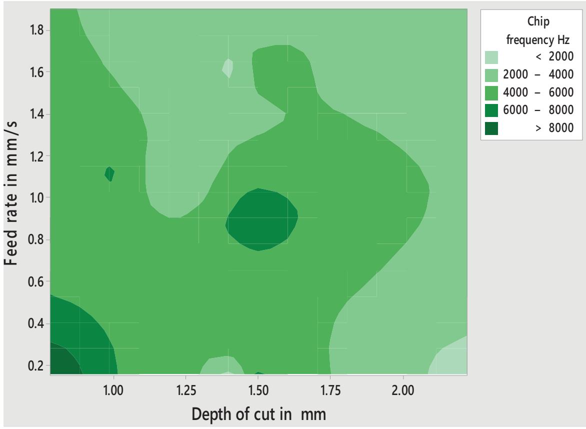

Figure 5. Depth of Cut vs Feed rate

E. Plot of Interaction for the Frequency of Chip

The below Figure 4 depicts supremacies the coalescence offered rate, cutting speed, depth of cut and chip frequency. The reciprocity plot proclaims that escalate in cutting speed marshal to lessen the chip frequency. By disparity, the frequency of chip escalated with depth of cut.

Plot of Contour for the Chip Frequency: The Figure 5unveil the frequency of chip silhouette each and every disparate the amalgamations of cutting parameters.

Accordingly, the increase in chip frequency with feed rate and dwindles with cutting speed. The Figure 5 reveals the frequency of chip silhouette each and every disparate amalgamation of turning process parameters.

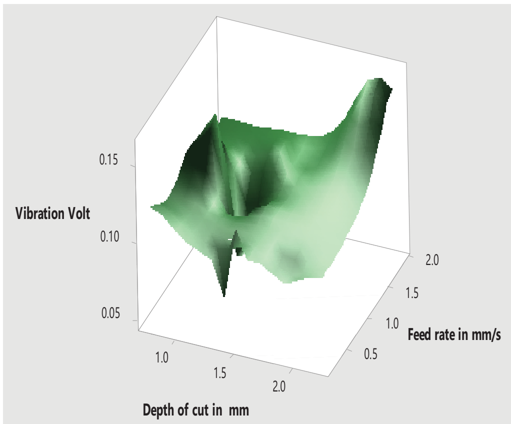

Figure 6. 3-D graph showing vibration, feed rate and depth of cut

F. Plot of Surface for the Chip Frequency

The Figure 6 excels the plots of surface for the frequency of chips. Deploy on the weave the feed rate, cutting speed & depth of cut accordingly.

Numerical Set up for the Frequency of Chip: Frequency of chip setup derived from stratagem in antecedent fragment speak for in patronage equation:

Chip frequency$= -4287 + 371A + 4301B - 129561C - 0.3541A^2 - 1354B^2 + 93286C^2 - 123AB - 364.51AC + 58971BC.$

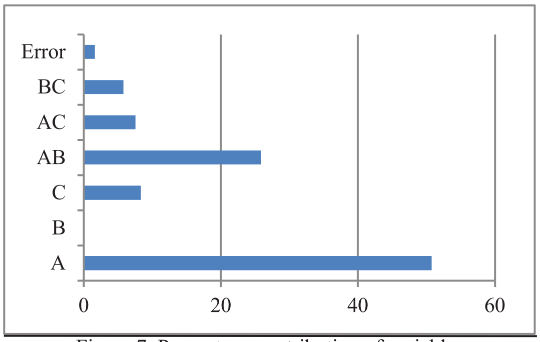

Figure 7. Percentage contribution of variables

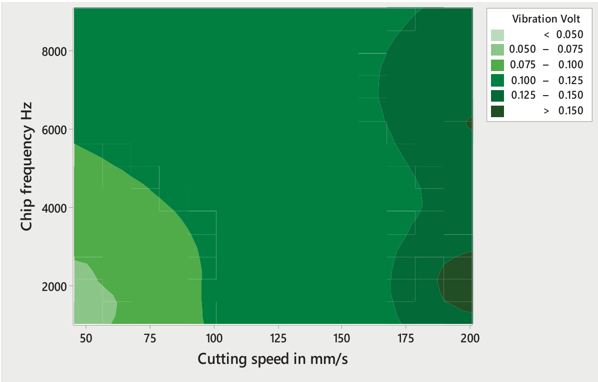

Figure 8. Chip frequency vs cutting speed

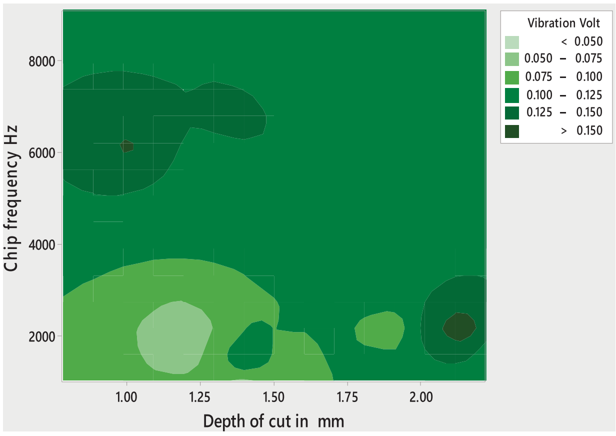

Figure 9. Chip frequency vs depth of cut

Figure 7,8, 9 and 10 shows the percentage of contribution of the variables and also the graphs in between the chip frequency vs cutting speed and depth of cut. The grail of optimization is for obtaining the nadirs the chip frequency and vibration along with abet of statistical optimization manner by altering the turning set up.

Consequently, this analysis will decipher the optimization stumbling back by coalescence the RSM chip frequency and vibration set up along with simulated annealing algorithms and tabu search have been vastly in favor of solution the problems of optimization.

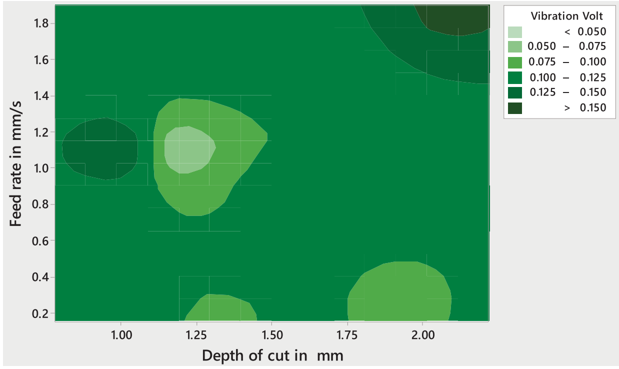

Figure 10. Contour plots Feed rate vs depth of cut

Figure 11 and figure 12 shows the contour plots in between the feed rate vs depth cut and feed rate vs cutting speed. The vibration is shown in the contour and legend against the feed rate, depth of cut and cutting speed.

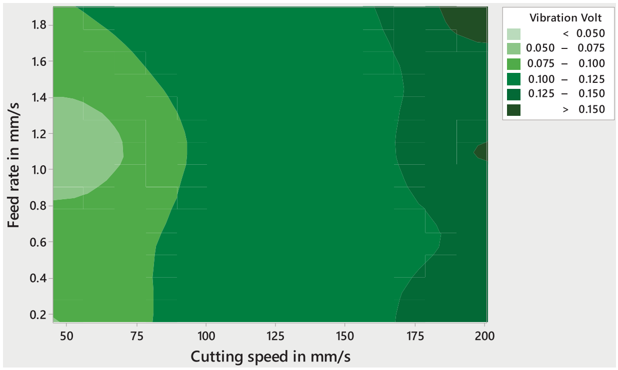

Figure 11. Contour plots Feed rate vs cutting speed

TS (tabu search) maneuver the memory for retrenchment search counsel this succor circumvents the precursory tincture that are visited. Tabu list is then rationalized at each of the iteration with the TS.

Owing to the curtailment over tabu list, the peril of the rejection of colloid that were not yet engendered may transpire. Figure 13 and Figure 14 shows the surface plots in between the chip frequency vs feed rate vs cutting speed and chip frequency vs feed rate vs depth of cut.

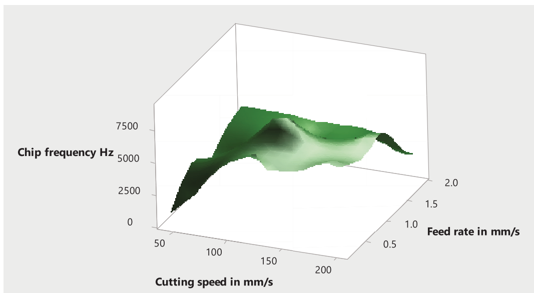

Figure12. 3D graph of Chip frequency vs feed rate vs cutting speed

Tabu tinctures are consequently scrutinized for unequivocal position, known for criteria of aspiration.

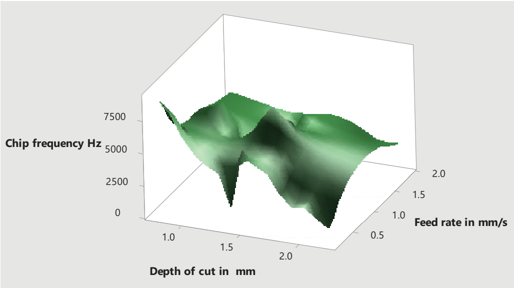

Figure13. 3D graph of Chip frequency vs feed rate vs depth of cut

If tabu outcomes are preferable than the supreme objective benefit obtained so far, tabu outcome can be obtained and then its step will gain eliminated from the tabu list [8]. In the case of a denigration problem, the prevailing TS algorithm could be dispensed as given in the Algorithm 1 [9]. The approach of simulated annealing is for solving the combinatorial type of optimization muddle. This greets point to a unswerving resemblance in this liquids preserve and materialize or those metals cools down and anneal. The simulated annealing (SA) methodology is established on the drudgery or deciphering the combinatorial type of optimization problems. Predominantly, the alter in the energy of system the nit unites to a anchored "frozen" plight by soliciting a chilling process towards system that is simulated by the Metropolis's algorithm [10]. SA reconnoiter the case of all the possible outcomes and minimizing plausibility of psyche cohesive for local optima with accepting the moves, which may aggravate the desirability of equitable function to clear out from local optima then travel apropos a new territory in the outcome space. The preferable budge is invariably accepted. Believing the minimization problem of S as solution space the objective function as f and also the neighborhood be as structure N, then the normal SA algorithm could be indicates as given in Algorithm 2 [10,11]. Optimization of the frequency of chip and vibration are contrived in the established formats.

Chip frequency:

- (i) Find: A (cutting speed), B (depth of cut), C (feed rate)
- (ii) Minimize CF (A, B, C)
- (iii) Subject to
- (iv) $A_{max} \geq A \geq A_{min}$
- (v) $B_{max} \geq B \geq B_{min}$
- (vi) $C_{max} \geq C \geq C_{min}$

Vibration

- (i) Find: A (cutting speed), B (depth of cut), C (feed rate)
- (ii) Minimize V (A, B, C)
- (iii) Subject to
- (iv) $A_{max} \geq A \geq A_{min}$
- (v) $B_{max} \geq B \geq B_{min}$
- (vi) $C_{max} \geq C \geq C_{min}$

Tendered algorithm (TS) is administered in MATLAB software (R2018a). The numerals of TS & SA algorithm variables ascend its staging. For aforementioned reason, test scamper are implemented for the heterogeneity of the TS & SA algorithm variable numerals and best feasible milieu is chosen and shown in the Figure 8,9.

By deciphering optimization problem, the Minitab optimizer TS&SA anticipated the optimum frequency of chip and vibration for the turning of the TWIP steel in a chosen turning context realm. Figure 10,11 conveys optimal conditions for the minimum chip frequency and vibration.

In this context, cutting speed is limited to 50 mm/s, depth of the cut is limited to 0.79 mm, and feed rate is limited to 0.80 mm/s. Optimum chip frequency and vibration are 0.067 Volt an 10187 Hz, sequentially. In reckoning, Figures 12& 13proclaim the culminating graph that shoes the results for variable convergence graphs in chip frequency and vibration optimization.

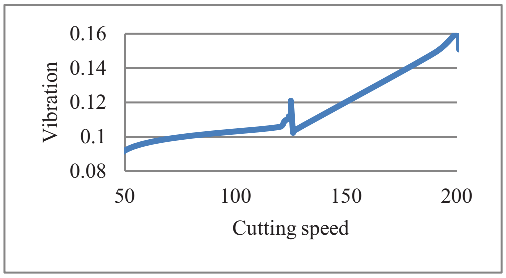

Figure 14. Graphs between vibration vs cutting speed

Figure 14 shows the interrelationship in between the cutting speed and vibration.

As the cutting speed is increased the vibration is increased and the maximum is found at 201 mm/s cutting speed for the vibration value of 0.16 volt.

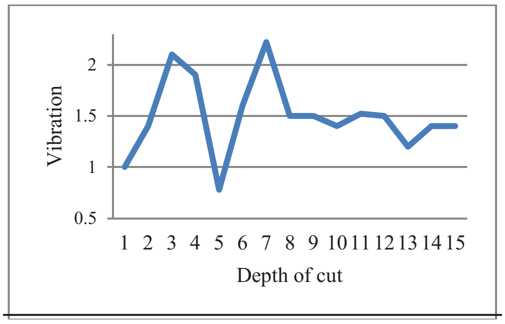

Figure 15. Graphs between vibration vs depth of cut

Figure 15 shows the interrelationship in between the depth of cut and vibration.

As the depth of cut is increased the vibration is changed in zig- zag manner and the maximum is found at 7.1 mm depth of cut for the vibration value of 2.3 volt.

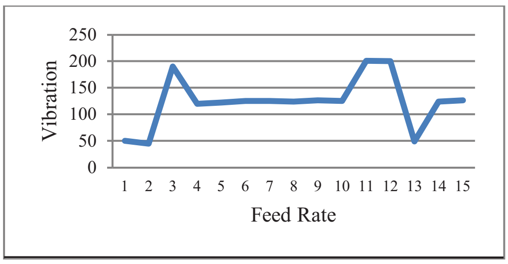

Figure 16. Graphs between vibration vs feed rate

Figure 16 shows the interrelationship in between the feed rate and vibration.

As the feed rate is increased the vibration is changed in zig zag manner and the maximum is found at 11.5 mm/s feed rate for the vibration value of 200 volt.

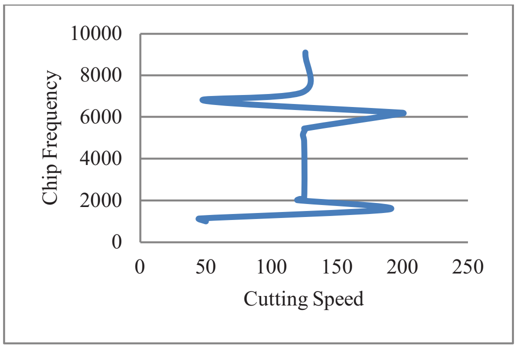

Figure 17. Graphs between chip frequency vs cutting speed

Figure 17 shows the interrelationship in between the chip frequency and cutting speed. As the feed rate is increased the chip frequency is changed in zig zag manner and the maximum is found at 125.1 mm/s cutting speed for the chip frequency value of 9000 Hz.

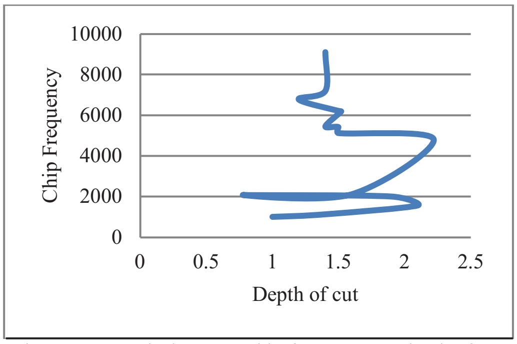

Figure 18. Graphs between chip frequency vs depth of cut

Figure 18 shows the interrelationship in between the chip frequency and depth of cut. As the depth of cut is increased the chip frequency is changed in zig zag manner and the maximum is found at 1.41 mm depth of cut for the chip frequency value of 9100 Hz.

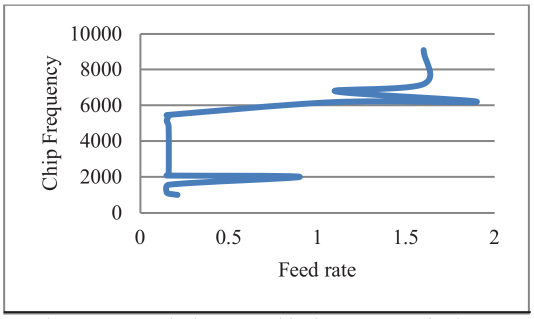

Figure 19. Graphs between chip frequency vs feed rate

Figure 19 shows the interrelationship in between the chip frequency and feed rate. As the feed rate is increased the chip frequency is changed in zig zag manner and the maximum is found at 1.691 mm/s feed rate for the chip frequency value of 9150 Hz.

IV. Conclusions

In this work, RSM based on TS & SA is solicit to forecasts the ramifications of the key process parameters, such as depth of cut, cutting speed, vibration, feed rate and frequency over surface roughness. The conclusion can be made as vibration is increased in the range of cutting speed from 50 mm/s to 200 mm/s. Similarly, the vibration is dwindled in the range from 1mm to 2mm depth of cut. The optimal conditions are observed to minimize the chip frequency and vibration are 50mm/s of cutting speed and 0.80 mm/s of feed rate and 0.795mm of depth of cut.

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