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SIMULATION OF CUTTING LOCUS AND OVERLAP CUTTING BY DIAMOND DRESSING IN CMP PROCESS

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ABSTRACT

Diamond dressing plays a role in regenerating the polishing pad surface during Chemical Mechanical Planarization/Polishing process (CMP). The diamond dresser has many diamond grits distributed on the flat metal surface. During diamond dressing, cutting locus (CL) and overlap cutting points (OP) of diamond grits are created on the pad surface. Expectation of diamond dressing is that CL and OP must be covered all the pad surface and maintain soften, flatten and roughness of the polishing pad. This paper aims to apply a kinematic model and then propose a method for setting speeds for diamond dressing process on the current configuration of CMP tool. Prediction of CL and OP is implemented based on three main factors as rotational speed of pad, rotational speed on dresser and oscillation of dresser. It found that properly choose the speed of pad and speed of dresser can regenerate uniformity of pad surface with well-distributed CL and less OP density. This result can be applied to optimization CMP process.

Key words: Diamond dressing, Cutting locus, Overlap cutting, Kinematic model, CMP

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1. INTRODUCTION

The diamond dressing process plays a key role in regeneration the pad surface topography before and after Chemical Mechanical Planarization/Polishing (CMP) process by recovering surface roughness, removing debris, and residual slurry grits on the polishing pad [1, 2]. The diamond dressing can be considered as a fixed-load surface grinding process of a ductile material. In the diamond process, diamond grits indent into the soft pad surface to break up the glazed areas, generate grooves, and create ridges that to regenerate the surface topography [3, 4]. There are many studies on factors influences dressing rate and pad surface topography that include diamond grit size, dressing force, and cutting locus [5-7]. For cutting locus, many kinematic models between the polishing pad and the diamond dresser were investigated earlier. Li et al. proposed a kinematical model of the diamond dresser to predict pad wear profile. The model is assumed oscillation motion of dresser not continual, it is lifted up and moved to indicated positions pad surface [8]. Chang et al. analyzed CMP conditioning process in a simplified model with kinematic motion used to illustrate the correlation between the cutting path density and the wear profile on pad surface but the effect of oscillation velocity has not to mention [9]. Nguyen et al. have investigated the wear of pad surface under the kinematic model of the sweeping arm. The oscillation of dresser was simplified by linear movement [10]. A pad dressing simulation module of Yeh et al. assumed that the dresser moved back and forth sinusoidal and considered the effect of sweep angle on dressing speed but the pad-dresser speed ratio was set by constant [11]. Chen and Pham [12] has developed the model to investigate the shape and surface roughness of polishing by the distribution of cutting locus. The model shows that the pad cutting rate is proportional to the density of cutting locus. Simulation of CL shows the same trend to the dressing marks as shown in figure 1. Although many aspects of diamond pad dressing have been investigated, most studies cannot completely show the overview of the relation of speeds between the pad and diamond dresser on CL and OP.

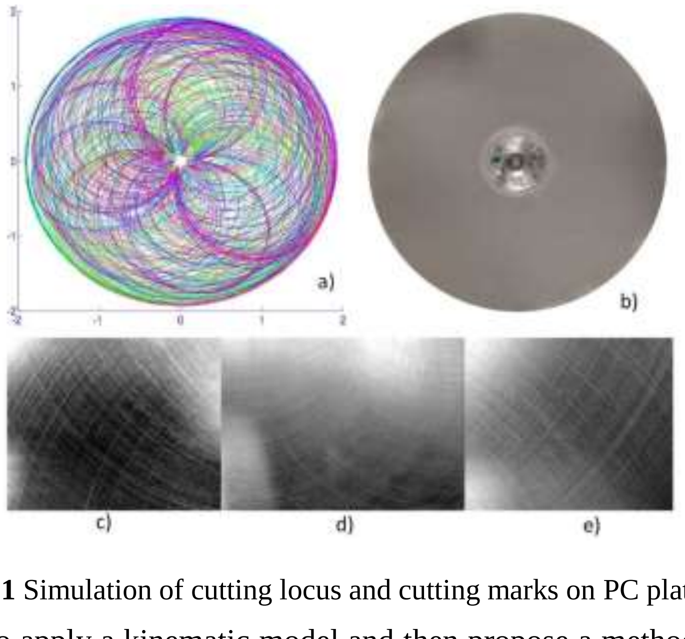

Figure 1 Simulation of cutting locus and cutting marks on PC plate [5]

This paper aims to apply a kinematic model and then propose a method for setting speeds to predict CL and OP in diamond pad dressing based on the current configuration of CMP tool. Firstly, the geometric model of diamond pad dressing is developed. Secondly, cutting locus of diamond grit on the pad surface is calculated. Thirdly, the rotational speed polishing pad is chosen as normal use. Next, rotational speed and oscillation of dresser head are adjusted and checked for how to cutting locus of diamond grit can cover all the pad surface by programming with MATLAB software. Then OP in such cases are also compared and discussed. Finally, the value of speed that induces less OP and more CL will be chosen. It is found that properly choose speeds of pad and dresser can induce well-distributed CL and reduce OP density. This result can be applied to optimization CMP process.

2. MODEL DEVELOPMENT

In order to develop a geometric model, dimension of CMP tool named HS-720C of HAMAI Company needs to be investigated and measured. That CMP tool along with a polishing pad radius (R_p) of 360mm and two polishing carriers with radius (R_h) of 170mm. In this study, the polishing carrier has been designed as the dresser head. The polishing pad can rotate in duo directions with speed (n_p) in range of 0~120 RPM. The dresser head not only rotates around their center with rotational speed (n_d) in range of 0~120 RPM but also oscillates a distance (e=±50mm) from the original center with oscillation frequency (τ) in range of 0~10 stroke/min. Figure 2 presents the development process of the geometric model. As shown in figure 2, one dresser carrier has three disk-type diamond dressers with radius (r) of 50mm. The dressers are fixed on the dresser carrier. The diamond dresser with many diamond grits, it assumes that every diamond grit is randomly bonded on a flatten disc surface of the diamond dresser by distance (r) and angle (θ) from the dresser center and on O_dO_{d1}-*axis*. The polishing pad center O_p is set as the original coordinate system. The points O_d, O_{d1}, O_{d2}, O_{d3} donate the dresser carrier center, the centers of the dresser 1, 2, and 3 respectively. D is the original distance between the pad center and the carrier center (D=180mm), R is the distance between the head center and dresser center (R=110mm), and variable e is the distance of oscillation motion, at the beginning e equals zero. It is assumed that the oscillation of the dresser carrier is sinusoidal. Variable e by time can be expressed as Eq. (1)

$$e(t) = E\sin\left(\frac{\pi\tau t}{30}\right) \tag{1}$$

In the geometric model, each diamond grit on the dresser can be seen as a point, distance (l) between diamond grit (P) and the carrier center (O_d) and is impressed as Eq. (2)

$$l = \sqrt{R^2 + r^2 + 2Rr\cos(\theta)} \tag{2}$$

When the pad rotates with angle velocity ω_p, the dresser head rotates with angle velocity ω_d and oscillates with frequency τ, the cutting locus of a diamond grit can be expressed as follows

$$\begin{aligned} x(t) &= l\cos(\alpha + \beta + \omega_d t - \omega_p t) + (D + e(t))\cos(\omega_p t) \\ y(t) &= l\sin(\alpha + \beta + \omega_d t - \omega_p t) - (D + e(t))\sin(\omega_p t) \end{aligned} \tag{3}$$

where α is the initial angle of the dresser on the carrier.

$$\beta = \arcsin\left(\frac{r\sin(\pi - \theta)}{l}\right) \tag{4}$$

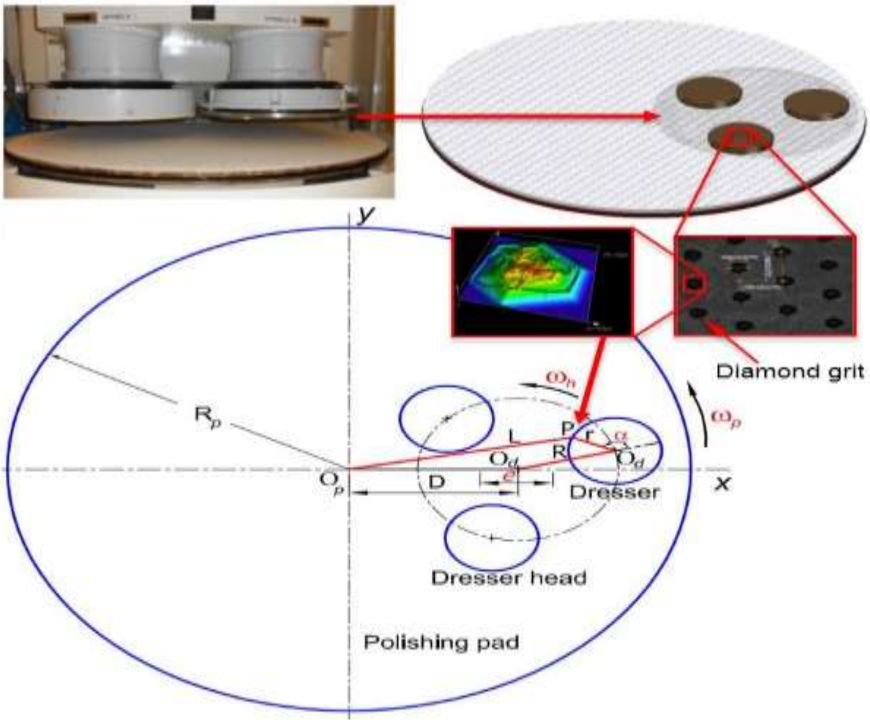

Figure 2 Geometric model of pad dressing process on HAMAI machine

Dimensionless of cutting locus can be expressed as Eq. (5)

$$x(t) = D\left[\frac{l}{D}\cos\left(\alpha+\beta+\omega_d t-\omega_p t\right)+\left(1+\frac{E\sin\left(\frac{\pi\tau t}{30}\right)}{D}\right)\cos(\omega_p t)\right]$$
$$y(t) = D\left[\frac{l}{D}\sin\left(\alpha+\beta+\omega_d t-\omega_p t\right)-\left(1+\frac{E\sin\left(\frac{\pi\tau t}{30}\right)}{D}\right)\sin(\omega_p t)\right] \quad (5)$$

Pham and Chen [12] has proposed the model to predict OP in which the intersection point of cutting locus can be considered as overlap cutting point (OP). To determine OP, a couple of adjacent points on each cutting locus are considered as a line segment and the equation of the line segment is expressed under the point-slope form. Finally, OP of segment lines is solved in sequence. OP of two line segments is solved as Eq. 6:

$$y_{op} = \frac{1}{m_i - m_j}\left(m_i y_j - m_j y_i + m_i m_j\left(x_i - x_j\right)\right)$$
$$x_{op} = \frac{y_{op} - y_i + m_i x_i}{m_i} \quad (6)$$

where m_i, m_j are the slopes of line segments on the cutting locus i^{th} and j^{th}. The line segment is formed by a couple of adjacent points as $y - y_i = m_i(x - x_i)$ and $y - y_j = m_j(x - x_j)$. The condition for (x_{op}, y_{op}) is the OP of two line segments, if the point (x_{op}, y_{op}) locates inside the intersection zone of two rectangles containing two line segments [13, 14]. Eq. (6) is then used for simulation of OP. Variations of ω_p, ω_d, and τ will be adjusted and selected for comparison of CL and OP.

3. SIMULATION

3.1. Check model

In order to do simulation, Eq. (3) is first checked to be determined that the equation is right or not. Four special cases of parameters have been chosen, including case a) only the dresser head rotates (n_p=0, τ=0); case b) only the polishing pad rotates (n_d=0, τ=0); case c) speed of pad and dresser head equal ($n_p = n_d$, τ=0); case d) speed of pad and speed dresser head is different ($n_p \neq n_d \neq 0$, τ=0). It is assumed each diamond dresser having a diamond grit. Therefore, the simulation has been taken by MATLAB for 3 points and then the normalized cutting locus on the pad surface by the distance between dresser center and dresser center (D). Simulation parameters are shown in Table 1 and simulation results of CL are shown in figure 3.

Table 1 Simulation parameters

Description	Symbol	Value
Dresser diameter (mm)	R_d	100
Pad diameter (mm)	R_p	720
Pad-dresser center distance (mm)	D	178
Oscillation distance (mm)	E	30
Rotation speed of pad (RPM)	n_p	0~120
Rotation speed of dresser head (RPM)	n_d	0~120
Oscillation speed of dresser (stroke/min)	τ	0~10
Dressing time (second)	t	60

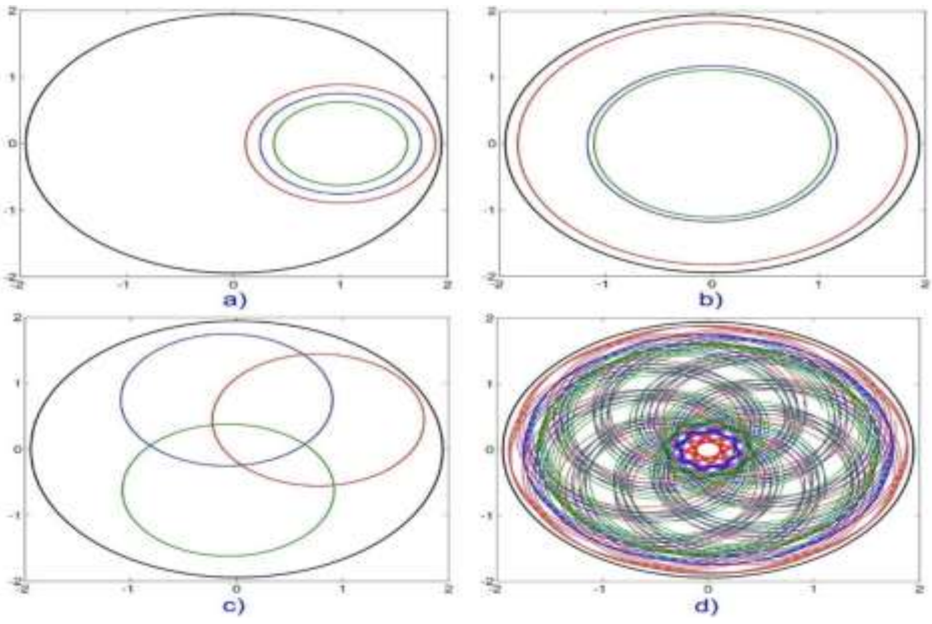

Figure 3 Simulation of pad cutting locus in diamond dressing process with time of 30 seconds and oscillation of dresser head equals to zero; a) only the dresser head rotates (n_p = 0); b) only the polishing pad rotates (n_d = 0); c) speed of pad and dresser head equal 40 RPM ($n_p = n_d$); d) speed of pad equals 40 RPM and speed dresser head equals 51 RPM ($n_p \neq n_d$)

As shown in figure 3, black colored cycles present the boundary of the pad. Red, blue, and green curves are three cutting loci of three diamond grits. Simulations of cutting locus can be considered in four cases follow:

Case 1: figure 3a) rotational speed of pad ($n_p=0$) equal zero and the dresser head rotates with rotational speed ($n_d \neq 0$), cutting locus of three diamond grits are three concentric cycles, the center point is the center of dresser head. A dressing area is the dresser head area.

Case 2: figure 3b) rotational speed of pad ($n_d=0$) equal zero and the dresser head rotates with rotational speed ($n_p \neq 0$), cutting locus of three diamond grits are three concentric cycles, the center point is the center of dresser head. A dressing area is the dresser head area.

Case 3: figure 3c) rotational speed of pad equals rotational speed of the dresser head ($n_p=n_p$), cutting locus of three diamond grits are three cycles. A dressing area is the dresser head area.

Case 4: figure 3d) simulates pad-cutting locus in case of the rotational speed of the pad n_p=40RPM and rotational speed of the dresser head n_d =51RPM. The results show that three curves distributed nearly all over the pad area, and if dressing time increases, recover of dressing area will be filled.

Although in diamond dressing process, all four cases are not used actually, it can be recognized that Eq. (3) is correct and can be applied for further process. By the results of simulations, it can be affirmed that the model is correct as in the real one. In which, cases of 1, 2, and 3 show pad cutting locus totally overlapping and distribution of cutting locus cannot fully recover the pad surface and amount of dressing time does not influence on dressing area. Therefore, these special input parameters such as $n_p=0$, $n_d=0$, *or* $n_p=n_d$ that first needs to be eliminated in setting the speed for the diamond dressing process.

3.2. Effects of speed on OP and CL

Eq. (5) and (6) are applied for this simulation. To implement simulation the rotational speed of the pad (n_p) is set in constant, rotational and oscillation speeds of the dresser (n_p, τ) are set in a range of value. The first simulation, n_p is set at 30RPM, n_d is from 40~50RPM, and τ from 1~10 stroke/min. Dressing time is 60 seconds. Simulation results are shown in figure 4. In the figure, a centered graph (surface graph) compares the change of OP, in which x-axis shows the range of rotational speed (n_d), y-axis indicates oscillation speed (τ), and z-axis depicts value of OP. Outer graphs illustrate the distribution of CL and OP (blue) in some special cases. As shown in figure 4, at n_d=40RPM; τ=10, the value of OP is highest and CL does not cover all the pad surface. However, at n_d=44RPM; τ=10. CL covers almost pad surface and OP is very low and well-distributed. The lowest OP can get at n_d=40RPM; τ=1 and n_d=40RPM; τ=7. It can be seen that oscillation speed effects to CL and OP more than rotational speed does. The oscillation speed at 3, 6, 9, and 10 can cause OP more than the rest. Therefore, for n_p=30RPM, τ should not be 3, 6, 9, and 10. Besides, increasing the rotational speed of the dresser can increase cutting locus, but at rotational speeds of 40, 46 and 49RPM, CL is not well-distribution that results in increases of OP.

In the second simulation, the speed of pad is set at 40RPM, the rotational speed of dresser is put in a range 50~60RPM, and oscillation speed of dresser is from 1~10 stroke/min. Dressing time is set 60 seconds. Simulation results are shown in figure 5. Due to the increase of n_p and n_d, the value of OP in the z-axis of the figure is higher than OP in Figure 4 (1.3×10^5 in figure 4 and 2.2×10^5 in figure 5). From the figure 5, high density of OP is easily detected at (n_d=50; τ=10), (n_d=56; τ=8), (n_d=60; τ=8), (n_d=60; τ=10),… Otherwise, conditions of (n_d=59; τ=10) or (n_d=57; τ=7) resulted in a well-distribution CL and less OP. This results also shows that high value of n_d can increase CL but τ is more effective on the distribution of OP. In diamond dressing process, OP can obtain pad surface roughness, but a high density of OP that can effect on the delivery of slurry and also cause to damage the pad surface [12].

Regarding simulation results, the relation between the rotational speed of the pad, rotational speed of dresser and oscillation of dresser needs to be considered. It can be concluded that from this model, the value of n_p, n_d and τ of diamond dressing can be well-selected and then the physical surface of the pad can be predicted

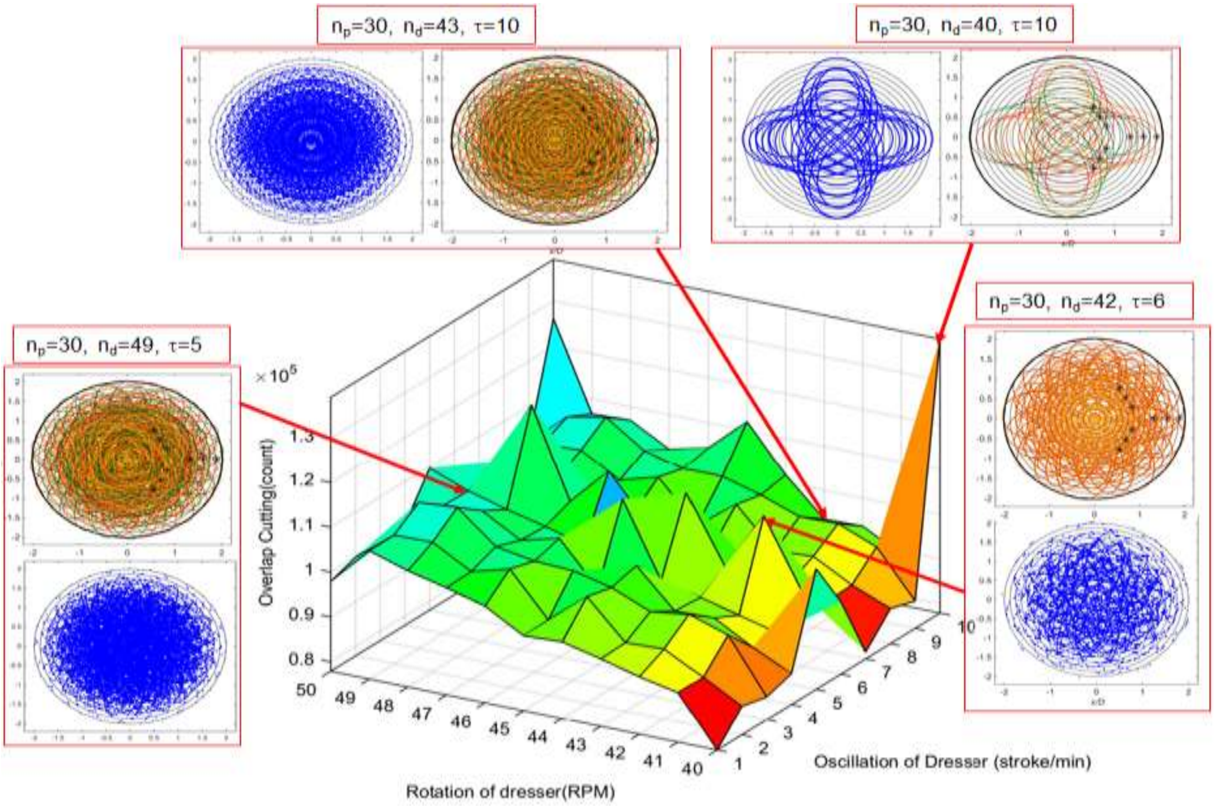

Figure 4 Overlap cutting points on the pad surface with different conditions of n_p=30, n_d=40-50, τ=1-10

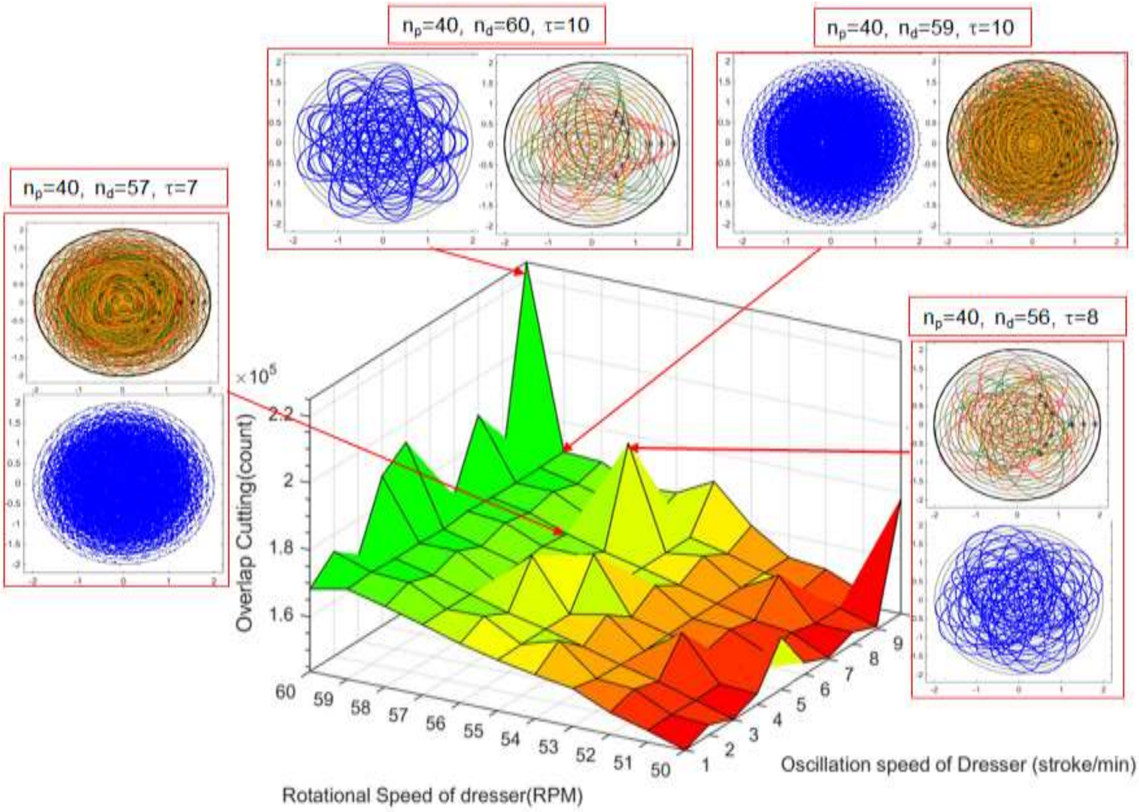

Figure 5 Overlap cutting points on the pad surface with different conditions of n_p=40, n_d=50-60, τ=1-10

4. CONCLUSIONS

This paper has developed the model to predict cutting locus and overlap cutting. Geometric model of diamond dressing has been built. Simulations of OP and CL have done with differences of conditions for comparison. Effects of rotational speed and oscillation speed of dresser on OP and CL have been discussed. Simulation results that help the diamond dressing process well-prepared via predicting CL and OP. Results of this study can be further applied for optimization of diamond dressing design and improvement of the dressing process.

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