EFFECTS ON THE SURFACE QUALITY IN THE MACHINING PROCESSES OF THE TOOL VIBRATIONS

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Abstract

The problem of surface quality and cutting stability in the machining processes is very important and is strictly connected with the final quality of the product. Therefore, this paper describes a new theoretical model for the dynamic cutting forces of orthogonal cutting in turning. A specific advantage for the presented model is the convenience for vibration prediction. The presented dynamic force model is used to predict variable cutting forces with dynamic cutting between cutting tool and workpiece. This model is considered two degree of freedom complex dynamic model of turning with orthogonal cutting system. The complex dynamic system consists of dynamic cutting system force model which is based on the shear angle (φ) oscillations and the penetration forces which are caused by the tool flank contact with the wavy surface.

Keywords: Chatter, surface, dynamic cutting, turning, cutting tool, roughness.

1. Introduction

To overcome surface roughness problems, the researchers propose models that try to simulate the conditions during machining and establish cause and effect relationships between various factors and desired product characteristics. Furthermore,

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the technological advances in the field, for instance the ever-growing use of computer controlled machine tools, have brought up new issues to deal with, which further emphasize the need for more precise predictive models. Surface roughness is a widely used index of product quality and in most cases a technical requirement for mechanical products. Achieving the desired surface quality is of great importance for the functional behavior of a part. On the other hand, the process dependent nature of the surface roughness formation mechanism along with the numerous uncontrollable factors that influence pertinent phenomena, make almost impossible a straightforward solution. The most common strategy involves the selection of conservative process parameters, which neither guarantees the achievement of the desired surface finish nor attains high metal removal rates [1]. The surface finish profile of a machined work is affected by the tool geometry, the work material, the cutting conditions and other factors such as tool wear, built-up edges and cutting dynamics. Cutting dynamics occurs in machining operations due to the interaction between the tool-workpiece structure and the force process. The most important result of this condition is chatter vibration. Regenerative chatter is so named because of the closed-loop nature of this interaction. Each tooth pass leaves a modulated surface on the work due to the vibrations of the tool and workpiece structures, causing a variation in the expected chip thickness. Under certain cutting conditions (i.e., feed, depth, and speed), large chip thickness variations, and hence force and displacement variations, occur and chatter is present. The results of chatter include a poor surface finish due to chatter marks, excessive tool wear, reduced dimensional accuracy, and tool damage. Machine tool operators often select conservative cutting conditions to avoid chatter, thus, decreasing productivity [2].

Dynamic cutting force produces deformation between tool and workpiece. If this deformation remained constant throughout the machining operation a work accurate form could be obtained. However, it varies, and its variation causes errors of workpiece form. The blank of workpiece entering a machining operation does not have an exact geometric form. The sections of a cylinder will not be exactly round; longitudinally it may be barrel shaped or conical, and due to inaccurate clamping it will be rotating with a "run-out". Similarly, a surface to be face-milled will not initially be perfectly flat. Or it may be that in one turning cut the tool path is so programmed that the initial diameter will be reduced to two different diameters. For all this examples, the cutting force varies during the cut. Consequently, the deformation between tool and workpiece also varies, and initial form errors will be copied onto the machined surface. Hence, cutting force F is a function of the depth of the cut a and of feed per revolution f_r . Also, during a cutting pass the cutting force varies and often also the flexibility between toll and work varies [3]. The roughness of a machined surface depends on many factors that can be grouped as: geometric factors, work material factors and vibration and machine tool factors. Vibration and machine tool factors are related to the machine tool, tooling, and setup in operation. They include chatter or vibration in the machine tool or cutting tool; deflections in the fixturing, often resulting in vibration; and backlash in the feed mechanism, particularly on older machine tools. If these machine tool factors can be minimized or eliminated, the surface roughness in machining will be determined primarily by the geometric factors and work material factors described previously [4].

2. Dynamic Cutting Model

Chatter or vibration in a machining operation can result in pronounced waviness in the work surface. When chatter occurs, a distinctive noise is made that can be recognized by any machinist. Various criteria are used to evaluate machinability, the most important of which are; tool life, forces and power, surface finish, and ease of chip disposal. Although machinability generally refers to the work material, it should be recognized that machining performance depends on more than just material. The type of machining operation, tooling, and cutting conditions are also important factors, as are material properties. Chatter can be recognized by the noise associated with these vibrations, by the chatter marks on the cut surface, and by the appearance of the chips produced in turning. Machining with chatter is mostly unacceptable because of the chatter marks on the machined surface and because the large peak values of the variable cutting force might cause breakage of the tool or of some other part of the machine Chatter is often a factor limiting metal removal rate below the machine's capacity and hence reduces the productivity of the machine [5]. In this paper, a complex dynamic system is modeled prior to the orthogonal cutting, which forms a mechanical cutting basis for all cutting processes in general. This dynamic system is used for turning. In order to determine the increased values of the damping and surface roughness this system is used. Therefore, for roughness and stability analysis modal analysis and chatter stability tests were performed for different materials, tool length and spindle speed. Chatter process damping model (PDM) is modeled as dynamic orthogonal cutting process with the process damping force. According to constant the shear stress (τ_s) of work material for various cutting speeds and feed ratios and the shear angle (φ) oscillations Static and Dynamic Cutting Force Coefficients (DCFC) are obtained by using the dynamic cutting force model. This model consists of tool penetration effect and oscillation of tool effect as shown in Fig. 1. [6].

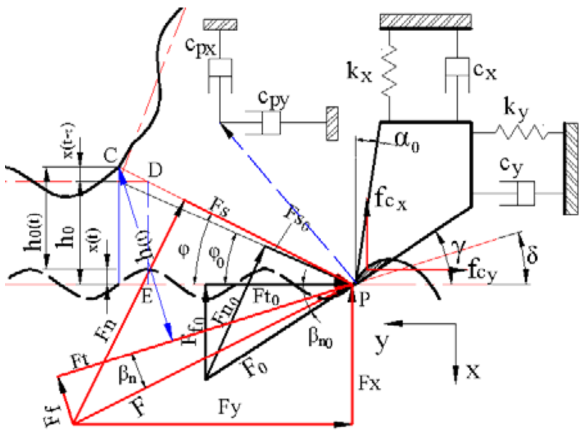

Figure 1. Dynamic cutting model.

According to Fig. 1, with considering the shear angle (φ) oscillations and the penetration, the equations of motion of cutting tool in (x) and (y) directions are:

$$m_x \ddot{x}(t) + c_x \dot{x}(t) + k_x x(t) = F(t) sin(\beta_n + \delta) = F_{xT}(t)$$
$$m_y \ddot{y}(t) + c_y \dot{y}(t) + k_y y(t) = F(t) cos(\beta_n + \delta) = F_{yT}(t) \quad (1)$$

where m_x and m_y are the mass coefficients (kg), cx and cy are the structural damping coefficients (kg/s), k_x and k_y are the stiffness coefficients (N/m). Dynamic force ($F(t)$ [N]) can be represented by:

$$F(t) = a K_f h(t) \quad (2)$$

where K_f is the feed force constant (N/m^2), and instantaneous dynamic chip thickness ($h(t)$) and dynamic chip thickness ($h_0(t)$) are:

$$h(t) = h_0(t) + |PE|\delta \qquad \rightarrow \qquad h_0(t) = h_0 + x(t-\tau) - x(t)$$

$$h(t) = h_0 + x(t-\tau) - x(t) + cot(\varphi)\, h_0\, \delta \qquad \rightarrow \qquad \delta = tan^{-1}\left(\frac{\dot{x}}{V_0 + \dot{y}}\right) \tag{3}$$

Where, h_0 is undeformed chip thickness (mm), $x(t)$ and $x(t-\tau)$ are modulations of the cut and outer work surface (mm), δ is the instantaneous work surface slope generated by the tool oscillation, V_0 is the cutting speed of static cutting (m/s) and $\dot{x}, \dot{y}$ are the vibration velocities (m/s) in each direction. For any given work and tool materials, it is always possible to establish an empirical relation between the shear angle φ_0 and the mean friction coefficient μ_a through experimentation. A general form of the angle relationship [7, 8] for machining steel is given by Wu & Liu [9]:

$$2\varphi_0 + \beta_{s0} - \alpha_0 = C \tag{4}$$

It is assumed that this relation between the shear angle φ and the friction angle β_s is invariant in dynamic cutting. Thus it can be represented by:

$$2\varphi + \beta_s - \alpha = C \tag{5}$$

where C is the material constant which is insensitive to the machining conditions. Also, (0) sub-indexes in Eq. (4) are represented to static conditions. Making use of these formulas, the difference caused by the oscillation of φ [6], which is a theoretical and experimental cutting angle, is calculated. If this difference is substituted into the dynamic cutting model, dynamic resultant cutting force F [N] can be represented by:

$$F = \frac{F_s}{cos(\varphi + \beta_n + \delta)} = \frac{\tau_s\, a\, l_s}{cos(\varphi + \beta_n + \delta)} \qquad \rightarrow \qquad l_s = \frac{h(t)}{sin(\varphi + \delta)} \tag{6}$$

where l_s is instantaneous shear plane length (mm), τ_s is the shear stress of work (N/m^2). Hence, dynamic cutting forces in both directions can be represented by:

$$F_x = \tau_s\, a\, \lambda_{sx}\left(h_0 - x + x(t-\tau) + \lambda_{dx}\, \dot{x} - \lambda_{vx}\, \dot{y}\right)$$

$$F_y = \tau_s\, a\, \lambda_{sy}\left(h_0 - x + x(t-\tau) + \lambda_{dy}\, \dot{x} - \lambda_{vy}\, \dot{y}\right) \tag{7}$$

Where

$$\lambda_{sx} = \frac{sin(C-2\varphi_0)}{sin\,\varphi_0\,cos(C-\varphi_0)}$$

$$\lambda_{sy} = \frac{cos(C-2\varphi_0)}{sin\,\varphi_0\,cos(C-\varphi_0)}$$

$$\lambda_{dx} = \frac{h_0}{V_0}\left[\frac{cos(\varphi_0)cos(C-\varphi_0)-cos(C)}{sin(\varphi_0)cos(C-\varphi_0)} + \frac{cos(C-2\varphi_0)}{sin(C-2\varphi_0)}\right]$$

$$\lambda_{dy} = \frac{h_0}{V_0}\left[\frac{cos(\varphi_0)cos(C-\varphi_0)-cos(C)}{sin(\varphi_0)cos(C-\varphi_0)} + \frac{sin(C-2\varphi_0)}{cos(C-2\varphi_0)}\right]$$

$$\lambda_{vx} = h_0\eta_v\left[\frac{cos(C-2\varphi_0)}{sin(\varphi_0)cos(C-\varphi_0)} + \frac{2\,cos(C-2\varphi_0)}{sin(C-2\varphi_0)}\right]$$

$$\lambda_{vy} = h_0\eta_v\left[\frac{cos(C-2\varphi_0)}{sin(\varphi_0)cos(C-\varphi_0)} + \frac{2\,sin(C-2\varphi_0)}{cos(C-2\varphi_0)}\right] \quad (8)$$

Where η_v is dynamic cutting constant [6]. Thus the dynamic cutting force components have been expressed analytically by the static cutting coefficients λ_{sx} , λ_{sx} and the dynamic cutting coefficients λ_{dx} , λ_{dy} and λ_{vx} , λ_{vx} which can be determined from static cutting tests. If DCFC used to the turning operations, according to Eq.(1) PDM can be expressed as follows;

$$m_x\,\ddot{x}(t) + c_{esx}\,\dot{x}(t) + k_x\,x(t) + c_{vy}\,\dot{y}(t) = F_{esx}\left(x(t)-x(t-\tau)\right)$$

$$m_y\,\ddot{y}(t) + c_{esy}\,\dot{y}(t) + k_y\,y(t) + c_{dy}\,\dot{x}(t) = F_{esy}\left(x(t)-x(t-\tau)\right)$$

Where, $K_f = \tau_s\,\lambda_{sx}$; $K_t = \tau_s\,\lambda_{sy}$; $c_{esx} = c_x + a\,K_f\,\lambda_{dx}$; $c_{vy} = -a\;K_f\,\lambda_{vx}$; $F_{esx} = -a\,K_f$; $c_{esy} = c_y - a\,K_t\,\lambda_{vy}$; $c_{dy} = a\,K_t\,\lambda_{dy}$; $F_{esy} = -a\,K_t$.

The process damping occurs further due to penetration of the tool into the wavy work surface. A ploughing force model has been proposed to describe the contact relationship between tool flank and machined surface. Based on this ploughing force analysis, a small volume of work material is pressed by the tool during wave cutting. In the meantime, a resistance force is generated by the stress field inside of the displaced work material. It is therefore reasonable to assume that the process damping force is equal to resistance force. The resistance force has been proven to be proportional to the volume of the displaced work material [6].

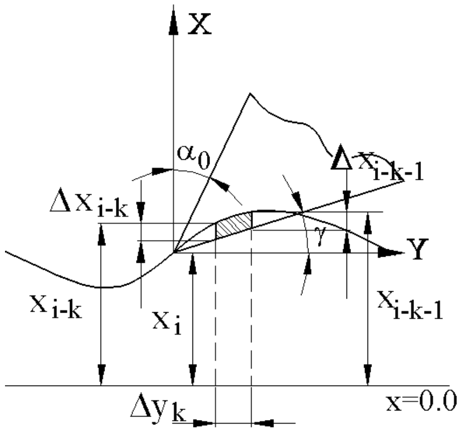

Figure 2. Penetration model of the cutting tool.

According to Fig. 2, total dynamic forces in both directions are written as follows:

$$F_{xTot}(t) = -\left(F_x(t) + f_{cx}(t)\right)$$
$$F_{yTot}(t) = -\left(F_y(t) + f_{cy}(t)\right) \tag{9}$$

where $f_{cx}(t)$ and $f_{cy}(t)$ are resistance force components in the (x) and (y) directions (N) and they can be expressed as:

$$f_{cx}(t) = c_{px}\,\dot{x}(t) \quad ; \quad f_{cy}(t) = c_{py}\,\dot{y}(t) \tag{10}$$

Hence, the equations of motion in the (x) and (y) directions are written as:

$$m_x\,\ddot{x}(t) + c_{tx}\,\dot{x}(t) + k_x\,x(t) + c_{vy}\,\dot{y}(t) = F_{esx}\left(x(t) - x(t-\tau)\right)$$
$$m_y\,\ddot{y}(t) + c_{ty}\,\dot{y}(t) + k_y\,y(t) + c_{dy}\,\dot{x}(t) = F_{esy}\left(x(t) - x(t-\tau)\right) \tag{11}$$

where c_{px} and c_{py} are the penetration damping coefficients (kg/s), $c_{tx} = c_{esx} + c_{px}$ and $c_{ty} = c_{esx} + c_{px}$ are damping coefficients (kg/s). In order to solve Eq.(11), if the equation for τ decomposition form is written independent of time and according to the course taken by the relative movement of tool tip to the workpiece [10],

$$l = V_0\,t + y \tag{12}$$

where, V_0 is the linear speed in the rotation direction of the workpiece (m/s), y is the displacement of tool tip independently from workpiece on the axis y during cutting (m). When the derivative of Eq. (11) is taken as time related,

$$\frac{dl}{dt} = V_0 + \dot{y} \approx V_0 \qquad (13)$$

where $\dot{y}$ was neglected, since, according to linear speed, it has no significant value for linear modeling. Eq. (11) with these simplifications;

$$\dot{x}(t) = \frac{dx}{dt} = \frac{dx}{dl}\frac{dl}{dt} = (V_0 + \dot{y})\frac{dx}{dl} \approx V_0 \frac{dx}{dl} \longrightarrow x' = \frac{dx}{dl}$$

$$\ddot{x}(t) = \frac{d^2x}{dt^2} = \frac{d}{dt}(V_0 + \dot{y})\frac{dx}{dl} = \ddot{y}\frac{dx}{dl} + (V_0 + \dot{y})\frac{d^2x}{dl^2}\frac{dl}{dt} \approx V_0^2 \frac{d^2x}{dl^2} \longrightarrow x'' = \frac{d^2x}{dl^2}$$

$$\dot{y}(t) = \frac{dy}{dt} = \frac{dy}{dl}\frac{dl}{dt} = (V_0 + \dot{y})\frac{dy}{dl} \approx V_0 \frac{dy}{dl} \longrightarrow y' = \frac{dy}{dl}$$

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the following equations is obtained,

$$m_x V_0^2 x'' + c_{tx} V_0 x' + k_x x + c_{vy}.V_0.y' = F_{esx}\left(x(l) - x(l - \pi d)\right)$$

$$m_y V_0^2 y'' + c_{ty} V_0 y' + k_y y + c_{dy} V_0 x' = F_{esy}\left(x(l) - x(l - \pi d)\right) \qquad (12)$$

thus, according to constant (l) equation of motion is obtained instead of time dependent one, τ . If both sides of Eq. (12) are reduced for simplification,

$$\tilde{c}_{tx} = \frac{c_{tx}}{m_x V_0} \qquad \tilde{k}_x = \frac{k_x}{m_x V_0^2} \qquad \tilde{c}_{vy} = \frac{c_{vy}}{m_x V_0} \qquad \tilde{F}_{esx} = \frac{F_{esx}}{m_x V_0^2}$$

$$\tilde{c}_{ty} = \frac{c_{ty}}{m_y V_0} \qquad \tilde{k}_y = \frac{k_y}{m_y V_0^2} \qquad \tilde{c}_{dy} = \frac{c_{dy}}{m_y V_0} \qquad \tilde{F}_{esy} = \frac{F_{esy}}{m_y V_0^2}$$

and if these values are placed and the equation is equaled to zero, and if Laplace transformation is applied, the characteristic equation of the system is obtained,

$$\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}\begin{Bmatrix} x'' \\ y'' \end{Bmatrix} + \begin{bmatrix} \tilde{c}_{tx} & \tilde{c}_{vy} \\ \tilde{c}_{dy} & \tilde{c}_{ty} \end{bmatrix}\begin{Bmatrix} x' \\ y' \end{Bmatrix} + \begin{bmatrix} \tilde{k}_x - \tilde{F}_{esx} & 0 \\ -\tilde{F}_{esy} & \tilde{k}_y \end{bmatrix}\begin{Bmatrix} x \\ y \end{Bmatrix}$$
$$+ \begin{bmatrix} \tilde{F}_{esx} & 0 \\ \tilde{F}_{esy} & 0 \end{bmatrix}\begin{Bmatrix} x(l - \pi d) \\ x(l - \pi d) \end{Bmatrix} = \begin{Bmatrix} 0 \\ 0 \end{Bmatrix}$$
(13)

$$\begin{bmatrix} s^2+\tilde{c}_{tx}\,s+(\tilde{k}_x-\tilde{F}_{esx})+\tilde{F}_{esx}\,e^{-\pi ds} & \tilde{c}_{vy}\,s \\ \tilde{c}_{dy}\,s-\tilde{F}_{esy}+\tilde{F}_{esy}\,e^{-\pi ds} & s^2+\tilde{c}_{ty}\,s+\tilde{k}_y \end{bmatrix}\begin{bmatrix} X(s) \\ Y(s) \end{bmatrix}=\begin{bmatrix} 0 \\ 0 \end{bmatrix} \quad (14)$$

$$\begin{aligned} D(s) = {} & s^4+\left(\tilde{c}_{ty}+\tilde{c}_{tx}\right)s^3+\left(\tilde{k}_y+\tilde{c}_{tx}\,\tilde{c}_{ty}+\tilde{c}_{dy}\,\tilde{c}_{vy}+(\tilde{k}_x-\tilde{F}_{esx})\right)s^2 \\ & +\left(\tilde{c}_{tx}\,\tilde{k}_y-\tilde{F}_{esy}\,\tilde{c}_{vy}+(\tilde{k}_x-\tilde{F}_{esx})\tilde{c}_{ty}\right)s+(\tilde{k}_x-\tilde{F}_{esx})\tilde{k}_y \\ & +\tilde{F}_{esx}.e^{-\pi ds}\left[s^2+\left(\frac{\tilde{F}_{esy}\,\tilde{c}_{vy}}{\tilde{F}_{esx}}+\tilde{c}_{ty}\right)s+\tilde{k}_y\right]=0 \end{aligned} \quad (15)$$

with further simplification, $\tilde{c}_{ty1}=\dfrac{\tilde{F}_{esy}\,\tilde{c}_{vy}}{\tilde{F}_{esx}}+\tilde{c}_{ty}$

$$a_4=\frac{1}{\tilde{F}_{esx}} \qquad a_3=\frac{\left(\tilde{c}_{ty}+\tilde{c}_{tx}\right)}{\tilde{F}_{esx}} \qquad a_2=\frac{\left(\tilde{k}_y+\tilde{c}_{tx}\,\tilde{c}_{ty}+\tilde{c}_{dy}.\tilde{c}_{vy}+(\tilde{k}_x-\tilde{F}_{esx})\right)}{\tilde{F}_{esx}}$$

$$a_1=\frac{\left(\tilde{c}_{tx}\,\tilde{k}_y-\tilde{F}_{esy}\,\tilde{c}_{vy}+(\tilde{k}_x-\tilde{F}_{esx})\tilde{c}_{ty}\right)}{\tilde{F}_{esx}} \qquad a_0=\frac{(\tilde{k}_x-\tilde{F}_{esx})\tilde{k}_y}{\tilde{F}_{esx}}$$

$$D(s)/\tilde{F}_{esx}=a_4\,s^4+a_3\,s^3+a_2\,s^2+a_1\,s+a_0+e^{-\pi ds}\left[s^2+\tilde{c}_{ty1}\,s+\tilde{k}_y\right]=0 \quad (16)$$

are obtained.

$$e^{\pi ds}=\frac{-\left[s^2+\tilde{c}_{ty1}\,s+\tilde{k}_y\right]}{a_4\,s^4+a_3\,s^3+a_2\,s^2+a_1\,s+a_0} \quad (17)$$

$$U_1(s)=e^{\pi ds} \qquad U_2(s)=\frac{-\left[s^2+\tilde{c}_{ty1}\,s+\tilde{k}_y\right]}{a_4\,s^4+a_3\,s^3+a_2\,s^2+a_1\,s+a_0}$$

According to the Nyquist criteria, the right side of this equation expresses Nyquist plane curve $U_2(s)$ and the left side expresses critical orbit $U_1(s)$. If $s=j\omega$ is taken in the equation, the roots of the characteristic Eq. (17) is found by equalizing the magnitude of the right side of the equation to 1,

$$\frac{\left|\left(\tilde{k}_y-\omega^2\right)+j\,\tilde{c}_{ty1}\omega\right|}{\left|\left(a_4\omega^4-a_2\omega^2+a_0\right)+j\left(a_1\omega-a_3\omega^3\right)\right|}=1$$

$$\left(a_4\omega^4-a_2\omega^2+a_0\right)^2+\left(a_1\omega-a_3\omega^3\right)^2=\left(\tilde{k}_y-\omega^2\right)^2+\tilde{c}_{ty1}{}^2\omega^2$$

$$a_4^2\omega^8+\left(a_3^2-2a_4a_2\right)\omega^6+\left(a_2^2+2a_4a_0-2a_3a_1-1\right)\omega^4+\left(a_1^2-\tilde{c}_{ty1}{}^2-2a_2a_0+2\tilde{k}_y\right)\omega^2 + a_0^2-\tilde{k}_y{}^2=0 \qquad (18)$$

Thus, the positive real root of this equation gives the chatter frequency of the system.

3. Stability Analysis

Two methods are used for the determination of stable areas for chatter-free spindle speed or the system of spindle/tool holder/cutting tool. The first method is the determination of the natural frequency of the system and mode shapes by measuring transfer functions by using an impact hammer and accelerometer. Analytical predictions of performance can be done by using this information. The second method is performed of cutting tests. The method gives the cutting ability of spindle/cutting tool in a better completeness, but requires a number of tests to be performed. The first analysis technique is based on the investigation of stability and plotting the Stability Lobe Diagram (SLD) from the solution of the characteristic equation of the system depending on the critical parameters such as axial cutting depth of the system and spindle speed. Analytic prediction is realized by iterative analytical solution of time changing force coefficient of mathematical model formed by applying it to the distribution of Fourier series. This analysis is made with the acceptance that the force process is linear according to feed and depth which doesn't depend clearly on cutting speed. Additionally, studies have been made recently to mount a sensor/actuator on the tool/tool holder system on the machine tool designed to suppress chatter vibration [10-12]. In the cutting process dealt with in this section, SLD, which give stable and unstable cutting regions for chatter-free cutting, will be drawn according to two different forms explained in the previous section depending on cutting depth and spindle speed. According to τ -decomposition form, the characteristic equation of the system is Eq. (16). The roots of this equation are obtained from the solution of Eq. (18).

Each positive real root $\left(\omega_i(j\omega)\right)$ is substituted back into the right side of Eq. (17) to find $U_2(j\omega_i)$. The phase angle of the resulting number is computed as follows;

$$\psi_i = \tan^{-1}\frac{\mathrm{Im}\left(U_2(j\omega_i)\right)}{\mathrm{Re}\left(U_2(j\omega_i)\right)} \tag{19}$$

and the value of time delay is found

$$\tau_i = \frac{\psi_i + 2\pi k}{\omega_i} \qquad \text{k=0,1,2,3,.....} \tag{20}$$

Depending on this, maximum spindle speed (n) to be gained in stable cutting is found,

$$\tau_i = \frac{\varepsilon + 2\pi k}{2\pi f_i} \qquad \rightarrow \qquad n = \frac{60}{\tau_i} \tag{21}$$

Where, (f_i) is frequency of the cutting tool (Hz); (ω_i) is the spindle speed (rd/s); $(\varepsilon/2\pi)$ the fractional number of waves formed on the surface. It can be seen here that there is a phase shift between the inner and outer waves $\varepsilon = 3\pi + 2\psi_i$. The critical axial depth of cut can be found by writing the reel part of the characteristic equation $\mathrm{Re}(\omega_i)$ to zero. Hence,

$$a_{\lim} = \frac{-1}{2K_f\,\mathrm{Re}(\omega_i)} \tag{22}$$

is calculated.

4. Roughness Formation On Surface

Surfaces of metals are actually rough, and asperities representing the roughness of the surface exist in surfaces of metals. Workpieces, dies and tools are characterized by surface roughness. Until all asperities are flattened, surface roughness has an influence on the friction properties of those surfaces, especially at the beginning of metal forming processes. During the forming process asperities plough into each other, and thus a small sliding always exists. At the beginning of the process, since the tool is in contact just with the peaks of the asperities, the friction properties depend on the distribution of asperities, on their height and their deformation during the process, e.g.

on the roughness of the contact surface. With the flattening of asperities the contact with the tool gets larger and this leads to varying friction properties [13].

Figure 3. a) Chatter surface b) Smooth surface.

However, chatter vibrations are present in almost all cutting operations and they are major obstacles in achieving desired productivity. Regenerative chatter is the most detrimental to any process as it creates excessive vibration between the tool and the workpiece, resulting in a poor surface finish, high-pitch noise and accelerated tool wear which in turn reduces machine tool life, reliability and safety of the machining operation [14,15]. When uncontrolled, chatter causes the rough surface end and dimensional inaccuracy of the workpiece, along with unacceptably loud noise levels and accelerated tool wear. In general, chatter is one of the most critical limiting factors, which is considered in designing a manufacturing process. The cutting force becomes periodically variable, reaching considerable amplitudes and the machined surface becomes undulated [16]. Grinding operation to reduce surface roughness often required. In this case, manufacturing cost is increased. Also, grinding operation can exceed dimensional tolerances of workpiece. Therefore, stable cutting is very important during chip removal.

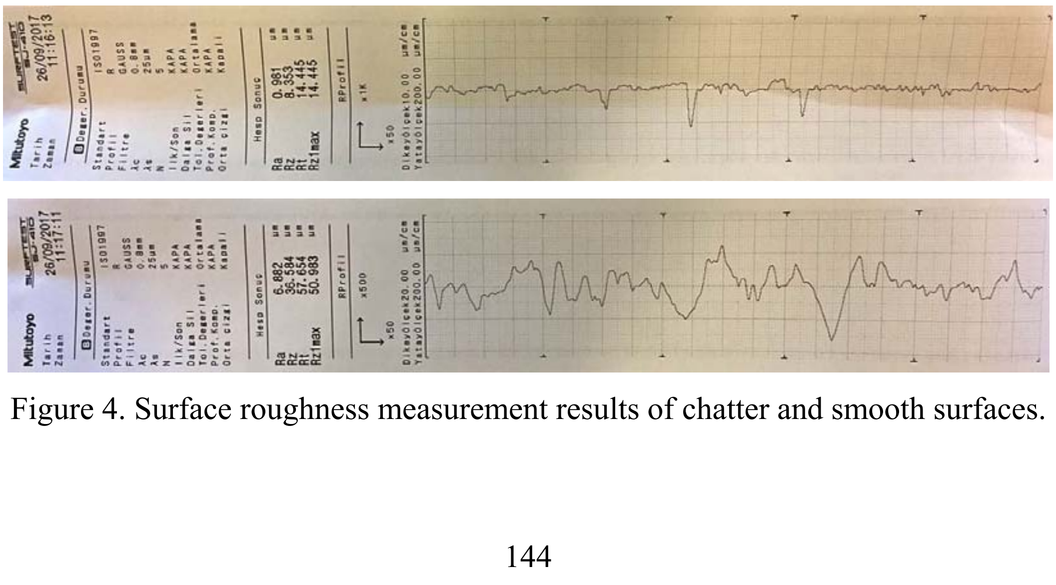

Figure 4. Surface roughness measurement results of chatter and smooth surfaces.

5. Conclusion

Chatter vibrations are major difficulties in all machining processes. These vibrations results rough surfaces, accelerated tool wear and increased dynamic cutting loads. All of these difficulties cause reduced machine tool life, reliability and safety of the machining operation. It is possible to eliminate such negative effects by preventing chatter vibration. Chatter detection and chatter control techniques helps for the stable manufacturing. To control the chatter vibrations, it is necessary to analyze the cutting tool, tool holder and workpiece according to their material properties. It is also important in terms of surface quality of machined parts, installation with other machine elements, friction, tightness, fatigue strength of machine parts over time. These important aspects are even more important in the space and air industry. In space and aerospace industry engine materials are made of Titanium alloyed Inconel materials and they are processed at low cutting speeds because chatter vibration is more occurred when they are machined in vertical axis machining centers. However, with chatter vibration analysis, these materials used in space and aeronautics can achieve stable cutting without vibrations and smoother surfaces and as much serial processing as possible.

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