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Experimental Investigation of Chatter Trends in Titanium End Milling

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Abstract

The occurrence of chatter vibrations which mainly originate as result of lack of rigidity in machine parts, cutting tool and instability of the tool-workpiece system during machining is still a recurring concern in the manufacturing industry, especially in the processing of titanium alloys. These vibrations have a detrimental effect on tool performance and product quality. Therefore, this research presents an experimental determination of chatter trends during a Ti-6Al-4V end-milling process, with a focus on the maximum two-dimensional (2D, X and Y plane) displacements of the workpiece. The effect of three factors namely: spindle speed (1000-2000 rpm), feed rate (250-350 mm/min) and depth of cut (0.3-0.9 mm) were investigated using a vertical MV204II/10 CNC end-milling machine. Data was collected using an accelerometer and analyzed in order to examine the statistical significance of each parameter on the developed chatter regression model. The results showed that larger displacement values were obtained at settings of depth of cut of 0.9 mm, feed rate of 350 mm/min and spindle speed of 2000 rpm in the Y-axial direction of the machine tool. Lower surface roughness was achieved at low depth of cut of 0.3 mm, low feed rate of 250 mm/min and spindle speed of 2000 rpm in the direction of the feed. The regression model showed that effective control of the stability of the process and was achieved at lower values of the investigated parameter combinations.

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Keywords: Chatter; Titanium; Maximum displacement; Feed-rate; Depth of cut; ANOVA; Spindle speed

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1. Introduction

The titanium alloy, Ti-6Al-4V has found numerous applications in military aviation [1], sports equipment [2] and the aerospace industry [3, 4] due to its superior thermal and mechanical properties. These properties include high specific strength, low density, low thermal conductivity and high thermal stability. Recently, its low density, chemical inertness at moderate temperatures and biocompatibility has led to adoptions for medical applications as well [5]. Although these material properties offer numerous benefits, the high durability attributes (hardness and toughness) make Ti-6Al-4V difficult to machine during conventional end-milling operations. Other reasons that contribute to its poor machinability are the relatively low thermal conductivity, high oxidation and high strength at even high temperature fields of the tool-chip interface [6]. As a result, machining challenges such as tool wear in modes like chipping and plastic deformation of the cutting edge, flaking of the rake face and delamination in the case of coated tools have been encountered during machining [7]. Such challenges place major constraints to manufactures that face stringent market demands such as high productivity, stable surface integrity, high precision and high surface quality at close tolerances.

One of the solutions that has been a subject of investigation by various researchers is high speed milling as it provides some of the desired process benefits [8, 9]. However, the recurring limitation for productivity and part quality even at high speeds and high precision is the undesired mechanical self-excited vibration called chatter [10]. Chatter is the most challenging vibration to control amongst the three types of mechanical vibrations which include the self-excited, free and forced vibration [11]. Free and forced vibrations have been reported to be controllable or reducible by altering the design of the tool-workpiece system [12]. According to Quintana & Ciurana [13], chatter can be classified into two categories namely, primary and secondary. Primary chatter can be induced by the tool-workpiece friction and thermo-mechanical effects upon chip formation or by mode coupling. Secondary chatter may be initiated by the regeneration of waviness of the workpiece surface. As the overlapping of cuts on the surface of the workpiece creates new wavy profiles, vibration amplification is induced. The initiated regenerative effect extracts energy to start and perpetuates throughout the duration of the interaction between the cutting tool and the workpiece until the chip thickness is exceeded and the cutter jumps out of the cut. The resulting effects are usually evidenced by the variation in the chip thickness due to instabilities in the cutting forces and the phase change difference between the successive residual surfaces [14, 15]. Uncontrolled chatter occurrence may lead to numerous negative effects on the process, namely: poor surface quality, unacceptable inaccuracy, excessive noise, disproportionate noise, machine too damage, reduced material removal rate, increased cost in terms of production rate, waste of materials, waste of energy, environmental impact in terms of materials and energy, cost of recycling, processing or dumping non-valid final parts to recycling points [16].

It is therefore important to devise strategies that can be used to establish machining conditions in which a component can be produced in a stable domain. Stable machining can be performed by either selecting process parameters (spindle speed (spindle), feed rate, depth of cut) using a stability lobe diagram prior to machining or by changing the process parameters through online detection of vibrations. Over the years, a great deal of literature has shown numerous strategies presented by researchers in order to mitigate these operational concerns. Typical research works involved explaining [17, 18], modeling or predicting [19, 20], monitoring, detecting or identifying [21], avoiding [22], reducing [23], controlling or suppressing chatter [24]. These research works showed that chatter is a highly complex phenomenon due to the diversity of elements that constitute the dynamic system and its behavior. These include the cutting tool, the workpiece material, the tool holder, the machine structure and cutting parameters. In addition, due to the mentioned dynamics, an accurate prediction of chatter stability is still very difficult. Hence, there is a continued growth in chatter investigations since the initial studies conducted by Tobias and Fishwick in 1961 [17].

In the case of this work, the focus was on the experimental investigation of chatter trends for the end milling process of Ti-6Al-4V super alloy in order to realize active chatter reduction. The objectives of this work involved: (1) selection of an appropriate sensors (accelerometers) for the online detection of the raw vibration signals in the time domain, (2) the transformation of significant features of the raw vibration signals from the sensors to the

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