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On milling of thin-wall conical and tubular workpieces

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ABSTRACT

Thin-wall tubular-geometry workpieces have been widely applied in aircraft and medical industries. However, due to the special geometry of this kind of workpieces and induced poor machinability, the desired accuracy of machining tends to be greatly degraded, no matter what type of metal-cutting task such as milling, drilling or turning is undertaken. Though numerous research reports are available that the tool path can be planned on the basis of preset surface profile before actual milling operation is performed, it is still difficult to predict the real-time surface profile errors for peripheral milling of thin-wall tubular workpieces. Instead of relying on tool path planning, this research is focused on how to real-time formulate the appropriate applied cutting torque via feedback of spindle motor current. On the other hand, a few suitable cutting conditions which are able to prevent potential break/crack of thin-wall workpieces and enhance productivity but almost retain the same cutting quality is proposed in this research. To achieve this goal, estimated surface profile error on machined parts due to deflections caused by both tool and workpiece is studied at first. Traditionally, by adjusting cutting parameters such as feed rate or cut depth, the deflection of tool or workpiece can be expected not to exceed the specified limit. Instead, an effective feedback control loop is proposed by this work for applying real-time appropriate applied cutting torque to prevent potential break/crack of the thin-wall conical workpieces. The torque estimation approach by spindle motor current feedback and the corresponding fuzzy logic controller are employed. Compared with constant cutting torque during milling operation in tradition manner, it is observed that the time consumption of milling cycle by aid of the aforesaid fuzzy logic controller is greatly shortened while the resulted cutting accuracy upon finish of workpiece can be almost retained.

1. Introduction

Milling upon complex thin-wall workpieces gradually becomes significant for electronic, aircraft and medical industries [1,6,7]. Many thin-wall components employed in these aforesaid industries are conical or tubular in geometry. The major problem is that significantly serious deflections of tool and workpiece are always induced by applied cutting force so that unacceptable manifest in form of surface profile error on finished products occurs [1]. Another important issue is chatter phenomenon which results in poor surface quality of finished workpiece [2]. In general, the chatter phenomenon can be categorized into 4 types: frictional chatter, thermo-mechanical chatter, mode coupling chatter and regenerative chatter. Numerous researches can be referred. For instance, in 2013 Aggogeri et al. proposed a piezo-based Active Vibration Control

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(AVC) system to supress chattering vibrations [3]. Wang et al. tried to optimize the spindle design so that the the dynamic behavior of the machine tool can be improved [4]. Tsai et al. presented on-line chatter prevention by acoustic signal feedback and spindle speed control strategy [5].

Highly non-linear and dynamic feature by surface profile error and lack of effective compensation policy during milling operation deteriorates the dimensional accuracy [6]. Though numerous research reports are available that the tool path can be planned beforehand on the basis of preset surface profile before actual milling operation is performed, it is still difficult to predict the real-time surface profile errors for peripheral milling on thin-wall tubular workpieces [7–10]. Instead of relying on off-line tool path planning, how to formulate and tune the appropriate applied cutting force/torque by feedback of spindle motor current during milling process is focused by this research. First of all, milling dynamics for thin-wall cone-geometry workpieces, including milling vibration and static deflection, is studied. Secondly, based on the dynamic model constructed earlier, a cutting torque feedback control strategy to compromise between productivity and suppression of severe vibration of spindle and cutter is proposed. Finally, the proposed fuzzy logic control strategy is examined by intensive milling experiments to verify its effectiveness.

2. Milling dynamics

The milling dynamics for thin-wall tubular-geometry components, including vibration of spindle and static deflection of workpiece, is studied at first. Unstable vibration such as chatter occurring during inappropriate milling operation conditions upon thin-wall workpieces certainly downgrades the quality of the finished products and shortens the tool life. Therefore, it is necessary to prevent these problems from any inappropriate choices of metal-cutting conditions. At first, the free body diagram between the workpiece and flat-end mill is shown in Fig. 1. The cutting force for the ith element, $dF_{t,i,j}(\theta_j)$, can be described as follows [7]:

$$dF_{t,i,j}(\theta_j) = [K_{tc} \cdot f_c \cdot \sin\theta_j + K_{te}]g(\theta_j)dz \tag{1}$$

where K_{tc} is the tangential cutting force coefficient, K_{te} the tangential edge force coefficient, f_c the feed rate per tooth and θ_j the rotational angle of jth tooth. $g(\theta_j)$ is the window function used to judge whether the workpiece is actually cut by the flat-end mill. $g(\theta_j)$ can be expressed as follows:

$$g(\theta_j) = \begin{cases} 1, & \theta_{en} \le \theta_j \le \theta_{ex} \\ 0, & otherwise \end{cases} \tag{2}$$

where θ_{en} and θ_{ex} are the entry angle and exit angle repesctively. The cutting torque for ith element, $dT_{c,i,j}$, can be described as follows:

$$dT_{c,i,j} = r \cdot dF_t \tag{3}$$

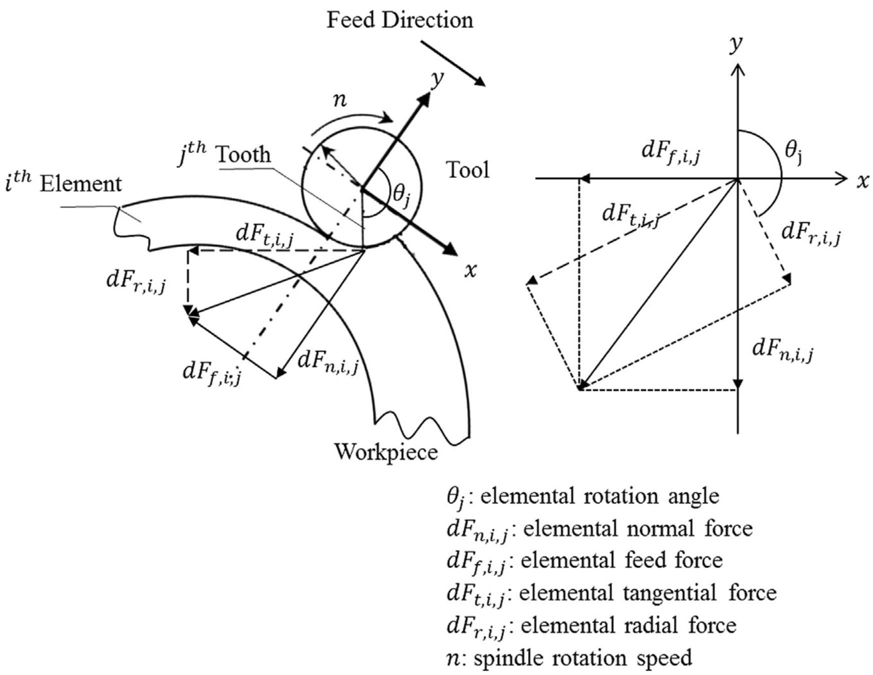

Fig. 1. Free body diagram between workpiece and flat-end mill.