Detecting transition to chatter mode in peakless tool turning by monitoring vibration and acoustic emission signals

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Abstract Stability of a peakless tool turning on slender shafts was studied under conditions of low- and high-magnitude vibrations by registering and short-time Fourier transformation (STFT) processing of acoustic emission (AE) and vibration acceleration (VA) signals. Both VA and AE signals have been registered in three positions of the cutting tool on the workpiece and for different shaft diameters. Both amplitude- and frequency-dependent AE and VA characteristics were obtained and analyzed for overall process signal length as well as for single frames. It was shown that power spectrum characteristic could be used for monitoring the fast-occurring changes in the cutting process stability. A criterion of the cutting process stability based on the power spectrum has been offered.

Keywords Peakless tool turning · Precision · Chatter · Acoustic emission · Vibration

1 Introduction

Application of peakless cutting tools in machining allows achieving higher precision and quality of processed surfaces \cite{1, 2, 3}. In some cases, it becomes even possible to achieve a roughness level comparable to that of fine grinding. At the same time, peakless tool machining is prone to chatter cutting mode, which is an undesirable factor for providing both surface quality and machining precision. In addition, the vibrations may cause enhanced wear of cutting tools. In order to avoid the vibrations during peakless tool machining, it is reasonable to detect a moment of time when transition from steady to chatter cutting has started. Such an approach implies acquisition and analysis of the real-time signals obtained from a sensor so that either cutting process parameters or the worn tool could be timely changed before the full-scale chatter cutting is established. The cutting process monitoring is feasible with the use of many transducers such as accelerometers, acoustic emission (AE) sensors, strain gauges, microphones, and eddy current coils. The most widely used ones are accelerometers and AE sensors because of their low cost and easy handling.

Main AE sources in metal cutting are as follows: plastic deformation in chip separation, tool/workpiece friction, chip impacting against the tool, tool’s edge failure, and elemental chip breaking. Basically, the AE signals are distinguished between continuous and burst ones \cite{4, 5, 6}. Earlier studies helped establish a relationship between the AE signals and cutting parameters such as cutting speed or strain rate within the chip formation zone as well as the tool’s wear and failure \cite{8, 9, 10, 11, 12, 13, 14, 15, 16, 17}.

It was shown \cite{6, 21, 22} that both cutting tool wear and vibrations generated during the cutting determine the dynamic behavior of the mechanical system. The vibrations have effect on contacting at the tool/workpiece interface so that both real contact area size and the cut layer thickness dynamically vary during cutting and thus change the deformation conditions and AE signal generation in the chip formation zone \cite{6, 21, 22}.

The use of both AE and vibration acceleration (VA) sensors seems a promising approach for monitoring various mechanical processes. The vibration acceleration signal is intuitively simple and requires minimal treatment before analyzing it. On the other hand, the AE signal is sensitive to the microscopic-
level events and therefore could be effective for detecting the incipient defects. For example, the AE signal was shown to be more effective for condition monitoring on gearboxes and ball bearings and for detecting the defects as compared to the vibration analysis \[23–26\]. Also, the efficiency of AE monitoring on ball bearings was reported for different working conditions \[27–36\].

It was noted also \[37\] that extending the frequency range of monitoring due to combined acquisition of both AE and vibration signals allowed for higher sensitivity of detecting defects in gear wheels.

Both AE and vibration acceleration signals are generated and then changed dynamically during the metal cutting. The AE high-frequency signal is responsible for microscopic-scale friction, deformation, and fracture events while the low-frequency vibration acceleration signal denotes the macroscopic events relating to the entire mechanical system. Analyzing both of them allows better understanding of dynamic processes, which develop in the process of metal cutting.

Metal cutting could be considered as a combination of two processes such as (1) cutting edge penetration into a workpiece and (2) sliding on the workpiece/tool interfaces. According to the insights reported \[38–43\], three shear strain localization zones could be formed in the cutting process. The primary shear deformation zone I is a volume of metal with either homogeneously or inhomogeneously distributed shear strain \[44, 45\] and where the heat is released due to severe plastic deformation (Fig. 1). The secondary deformation zone II is adjoining both the tool’s rake face and primary shear zone; in other words, it is a zone where the chip is contacting the rake face. The chip/rake contact length is characterized by the presence of both sliding and sticking zones (Fig. 1).

The tertiary shear zone III is adjoining both flank face and primary shear zone. Also, there is a transition zone between the tertiary and primary zones. The chip/flank face contact length may contain both sticking and sliding zones too.

The sticking and sliding zones’ lengths may vary depending upon the cutting conditions such as tool and workpiece materials, cutting mode, and cooling \[46–48\]. The heat is generated in the secondary and tertiary zones both due to shear deformation and friction.

When the chip sticks to the rake face, it may form an intermediate stagnation (tribological) layer (Fig. 1) which may cover the rake face so that sliding is really at the interface between the chip and this layer. The chip experiences resistance to sliding as determined by the shear stress needed to overcome its cohesion to this layer. According to \[49\], the sticking provides high contact stress and almost zero sliding speed, which results in forming adhesion bonds at both workpiece/flank and chip/rake faces.

The sliding zone is characterized by a discontinuous contacting mode when the chip and/or workpiece contacts the tool faces only by asperities so that heat is released only within the real contact areas in the form of near-melting temperature flashes \[50\].

The above-described processes serve as the AE signal sources and could be sensitive to the vibrations imposed. The objective of this paper is to study the relationship between the AE and the vibration acceleration signal in peakless tool turning on the different stiffness shafts and develop a AE criterion for early detection of the chatter mode.