Active Control of Machine-Tool Vibration in Cutting Operations using Piezo Ceramic Actuators

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Abstract

In turning operations the tool and tool holder shank are subjected to dynamic excitation due to the deformation of work material during the cutting operation. The stochastic chip formation process usually induces vibrations in the machine-tool system. Energy from the chip formation process excites the mechanical modes of the machine-tool system. Modes of the workpiece may also influence the tool vibration. The relative dynamic motion between cutting tool and workpiece will affect the result of the machining, in particular the surface finish. Severe acoustic noise is also induced, the noise level is sometimes almost unbearable to the machine operator. The tool life is also likely to be correlated with the amount of vibrations. It is well known that vibration problems are closely related to the dynamic stiffness of the structure of the machinery and workpiece material. The vibration problem may be solved in part by proper machine design which stiffens the machine structure. In order to achieve further improvements the dynamic stiffness of the tool holder shank can be increased more selectively. Active control of machine-tool vibration is a solution to these problems. Generally, machine tool systems are classified as narrow band systems and as a consequence tool shank vibrations can usually be described as a superposition of narrow band random processes at each modal frequency. These when added together form a more wide band random process. The tool vibrations in a turning operation mainly comprise vibrations in two directions; the cutting speed direction and the feed direction. Usually, the vibrations in the cutting speed direction and the feed direction are linearly independent, except at some of the eigenfrequencies. Consequently, the control problem involves the introduction of secondary sources driven in such way the anti-vibrations generated by means of these sources will interfere destructively with the tool vibration. However, in external longitudinal turning, most of the vibrations are induced in the cutting speed direction. Thus, the control of the vibrations in the cutting speed direction is an adequate solution to the vibration problem. In order to control the vibrating modes of a tool holder it is essential to select a location for the actuators that enables the introduction of secondary vibration in to these modes. However, the location for the mounting of the actuators must be selected carefully to avoid unnecessary reconstructions and/or performance reductions of the lathe. By embedding piezo ceramic actuators in a standard industry tool holder the active control of tool vibration is enabled to a general lathe. A complication in the turning operation is that the original excitation of the tool vibration cannot be observed directly and can therefore not be used as a feedforward control signal. A solution to the controller problem is to control the adaptive
FIR filter with the leaky version of the well-known filtered-x LMS-algorithm. This paper discusses the single-channel feedback control of tool vibration in the cutting speed direction. The single channel control system is illustrated in Fig. 1a below. The tool holder used in this application has an embedded piezo ceramic actuator, i.e., secondary source, which have been developed at the department of telecommunications and signal processing. The construction of the tool holder is shown in Fig. 1b. The tool shank vibrations considered in this paper originate from the cutting speed direction of the tool holder shank. To illustrate the effect of feedback control of tool vibration in the cutting speed direction, the spectral densities of the tool vibrations with and without feedback control are shown in the same diagram. Figure 2a) shows a typical result obtained with adaptive feedback control of tool vibration. It performs a broad-band attenuation of the tool vibration and manage to reduce the vibration level with up to approximately 40 dB at 3.4 kHz. In the experiments, it was observed that the adaptive feedback control of tool vibration resulted in a significant improvement of the workpiece surface. In Fig. 2b) a photo of the workpiece used in the experiments is shown.