УДК 621.9

V.P. Larshin,
Doctor of Sciences,
Professor,
Odessa National Polytechnic University
vplarshin@rambler.ru

N.V. Lischenko,
Ph. D.,
docent,
Odessa National Polytechnic University
odmnv@rabler.ru

A CUTTING TOOL VIBRATION MECANISM ON METALWORKING MACHINES

***В.П. Ларшин, Н.В. Ліщенко*. Механізм вібрацій ріжучого інструмента на металорізальних верстатах**. Представлено механізм виникнення вібрацій ріжучого інструменту на верстатах з ЧПК на основі існуючих фізичних уявлень про примусові, вільні і самозбудні коливання в технологічної системі різання, яка складається з взаємодіючих підсистем інструменту і заготовки.

***V.P. Larshin, N.V. Lishchenko*. Cutting tool vibration mecanism on metalworking machines.** A cutting tool vibration mechanism on CNC machines characteristic based on existing physical representations of the forced, free and self-excited oscillations occurrence in the technological cutting system consisting of interacting tool and workpiece subsystems is given.

Introduction. To ensure reliable operation of advanced high-speed CNC machine a control system should provide not only precision programmable tool displacement relative to a workpiece, but also diagnosis of the cutting technological system. The weakest link in the system is the cutting tool (CT) life which should be sufficient for reliable operation of the CNC machine for the desired cutting time.

The industrial cutting systems vibration problem is generally known, starting with the F. Taylor's works. Domestic researchers in this field, for example, A.I. Kashyrin, V.I. Dikushin, V.A. Kudinov and many others are also known. They paid much attention in their works to the physical principles of vibration when cutting hard and easily workable materials, because an insight in the mechanism of vibration allows identifying appropriate ways to deal with this phenomenon.

Modern construction materials (stainless and heat resistant steels as well as alloys, titanium and its alloys, etc.) have high performance, but also they have a low machinability, which leads (because of the unpredictable influence on the process of cutting force and temperature factors) to low CT life. On the other hand for easily workable workpiece materials such as aluminum and its alloys a high cutting speed is currently using in high speed machining with increased feed and depth of cut. In both cases (i.e. hard and easily workable materials) a cutting vibration problem refers to the number of actual one in mechanical engineering, since the appearance of vibration is usually associated with a CT life as well as a premature failure of the machine spindle unit. There are some exceptions connected with the controlled vibrations which improve the CT work, such as these in vibrodrilling.

It is well known a necessity to increase the metal removal rate as well as machining production on the CNC machines. In order, however, to do this the so-called "chatter" arises and does this phenomenon a far more significant concern. That is why a manufacturer faces not only features of a machine and tool, but also the dynamic characteristic of the spindle and work subsystems.

To avoid as the chatter as the other significant dynamic oscillations the most promising for use on modern CNC machines is small vibration sensors, such as AP2019 type. These sensors can be embedded in the various directions of the machine coordinate system. However, so far no reliable methods the CT state technological vibrodiagnostics, which can be implemented on the basis of these sensors and available CNC system computational resources.

The purpose of this research is to develop a CT state vibrodiagnostics automated system based on a USB type modular system NI CompactDAQ followed by programming the diagnostic algorithm (without any additional hardware) in modern CNC system having available computing resources.

The main material. There are known technological methods of diagnosis by different estimating criteria for the CT state needed to solve a technological management task. They vary depending on the nature of selected physical parameters i.e. sources of information about the CT state: power, torque, cutting temperature, cutting vibrations (displacement, velocity, and acceleration), acoustic emission (sonic and ultrasonic), the parameters of quality of processing parts etc. [1].

In the physical dynamics there are two kinds of vibration: forced vibration and self-excited one. Forced vibrations are generated by the action of a periodic force, for example, due to an imbalance of the rotating spindle or CT edges interrupted operation (e.g. drill or mill edges). In this case, the vibration source (a spindle or CT edges) vibrates interacting with the technological system elements. As a result, the vibration frequency spectrum consist of the spindle and associated with it structural elements speed components as well as the rate of introduction into the machining material of the cutting edges.

In order to understand the vibration self-excitation mechanism it is necessary to consider the nature of free vibrations in cutting [2] which arise, for example, when the cutting forces suddenly released, i.e. when the next CT edge is exited from the contact area. In this case sudden elimination of the impact of cutting forces on the machine takes place. These vibrations are characterized by their own or natural frequency, which is known to be determined by the elastic system stiffness and its reduced (i.e. inherent) mass [2].

When a CT tooth enters into the machining material, the CT subsystem "spindle - tool holder - tool" will be deformed by the cutting forces. When these forces are released by the tooth exiting the material, the CT subsystem will vibrate with its own natural frequency. It is assumed that the workpiece subsystem "table - device - storage" stiffness is more than CT subsystem one and can be ignored. The vibration mentioned results a small waviness on the workpiece surface. If the following that is after the first tool tooth impact does not match the natural frequency of the CT subsystem, the chip thickness increases as well as the cutting force. This in turn causes a notable deformation of the system, which leads to a larger oscillation amplitude. The most disadvantageous condition is when the current vibration phase angle will be equal to 180° with respect to the surface waviness previously obtained. Thus, the self-excited vibration in the cutting zone (in domestic literature – auto oscillations) is the result of the unpredictable interaction of several factors. For example, it is so when the vibration phase from the CT edges is late 180° (π radians) from the previous track phase and a cutting power is sufficient to overcome the damping of oscillations. Such vibrations are called self-excited or chatter. Under these conditions the CT subsystem vibrates at its natural frequency (without an externally applied driving force), the cutting force is increased significantly, negatively affects the machining accuracy, CT life, and machine spindle unit longevity. This implies parametric and kinematic nature of self-excited oscillations in a system with positive feedback, which has a reserve of potential energy (spindle motor) and the way to deal with vibrations: either the gain coefficient to reduce or the oscillation phase to output of the positive feedback (180°) condition, or both mentioned simultaneously.

It is possible to avoid auto-oscillations in cutting as well as the chatter if the CT tooth exposure frequency is consistent with the natural frequency of the CT subsystem "spindle - tool holder - tool ". In other words, it is so when the surface waviness and the cutting vibrations are in phase (0°). By the way, the waviness may not be clearly visible, but appears to change the physical and mechanical properties of the surface layer. At this spindle speed, the chip thickness remains constant, cutting goes smoothly (quietly) and the cutter may go to a great depth without causing defects. This phenomenon is called "sweet spot» [2] .

There are two basic approaches to determine spindle speed at which there is no vibration such as chatter or the like [2]. According to the first one the CT subsystem own frequency is found with the aid of using a vibrosensor (accelerometer) and an impact hammer. Then the system transfer function is determined for analytical forecasting oscillations by calculating the sweet spots. It is necessary for this to have a mathematical model of the cutting dynamic system. The second approach for determining the sweet spots is to perform cutting tests. This approach allows obtaining more accurate information but requires a large number of experiments that are carried out with different combinations of spindle speed and depth of cut.

Experimentally determined cutting modes with the sweet spots is then programmed to provide a stable high-performance machine work for a certain combination of machine tool as well as the CT and workpiece subsystems. The best is to use both of these techniques to obtain more accurate information about the vibrations in the machine elastic system.

Described mechanism of self-excited vibrations during cutting may have features depending on the cutting process kind in mechanical engineering technology. For example, a processing on the lathe by a single turning cutter differs from a multiple edge milling by monolithic CT or assembled one. Vibration during drilling (core-drilling, reaming, counter-sinking etc.) depends on the torsional corresponding axial tools oscillations, especially for small diameter drills which change their length under the machining.

Technical systems modeling methods in the cutting dynamics as well as in the cutting thermophysics are divided into two broad classes depending on the adopted methodological concept: distributed or lumped system. In the first case (distributed system) processes are described by partial differential equations, in the second (lumped systems) – by ordinary differential equations. The cutting dynamics usually uses the lumped system concept in which various assumptions are made and simplifying techniques are used (e.g. reduced and general parameters) to substitute a real distributed system by corresponding lumped one.

Conclusion

1. Over a long historical period (more than a hundred years) in the theoretical study of vibrations in the cutting systems the lumped systems concept is used, while the real technological cutting system is distributed one.

2. The emergence of chatter is a manifestation of mechanical resonance in the elastic damping system, but differs by its mechanism of the influence of the previous machining trails, for example, the influence of pre-formed waveness.

3. For the occurrence of oscillations in a machine elastic system it is necessary to create two conditions: antiphase with the previous trails and the required processing gain which is sufficient for the occurrence of positive feedback.

References

1. Григорьев С.Н. Диагностика автоматизированного производства / С.Н. Григорьев, В.Д. Гурин, М.П. Козочкин и др.; под. ред. С.Н. Григорьева. – М.: Машиностроение, 2011. – 600 с.

2 . Badrawy Sinan. Cutting Dynamics of High Speed Machining / / Technology Update. - Volume 8. - Issue 1, 2001 . - P. 24-26.

Надійшла до редакції 09.04.2014