7.2 INTELLIGENT CNC MACHINE TOOLS AND THEIR DESIGN

The effort to create intelligent machine tools and to equip the machine tools with intelligence is implemented thanks to the development of mechatronics, of control systems and thanks to the mechanical building of the machines themselves. It is absolutely logic that the parallel with human intellect is offered here. However, it is necessary to distinguish between the robust industrial application of intelligence which is able to withstand the full active duty and the laboratory research of intelligence. It can be said that it will take certain time, before the machine tools approach more to the human intellect. This section shall describe the current state in the field of machine-tool intelligence according to the particular manufacturers.

Intelligence is probably the most important term which is known by the current psychology and this term is also very well-known among the laic public. There are many definitions available what intelligence actually is and the opinions have not been unified up to now [www-1]. Let us mention four selected definitions:

Intelligence is the ability to process information, thus all impressions perceived by a person. (J. P. Guilford, long-term President of the American Psychologic Company)

Intelligence is the general ability of an individual to orient intentionally his or her own thinking to the new requirements, it is the general intellectual ability to adapt oneself to the new life tasks and conditions. (Wiliam Stern, German)

Intelligence is the internally broken and at the same time global ability of an individual to act sensibly, to think reasonably and to become equal with his or her ambient efficiently. (David Wechsler, American)

Intelligence is the summary of perceptional, psychomotor and intellective abilities. (author is not known)

Although intelligence is the innate ability, it can be developed by acquisition of experience and by exposition to different situations whose solution requires intelligence. The whole intelligence can be divided into [www-1]:

- practical (particular) intelligence – the ability to handle objects and tools;
- theoretical (abstract) intelligence – the ability to handle terms and features and to think logically (it can be measured by means of IQ tests);
- social intelligence – the ability to get along with people, to be able to establish and keep a social contact (it can be measured by means of EQ tests).

The intelligence degree can be expressed by means of the IQ (intelligence quotient). Its value can be calculated by division of the mental age (measurable by the test) and of the biologic age. This result already considers the biologic age which influences the success rate of the test to a considerable extent. Such a result can be compared subsequently in the whole age spectrum of tested people [www-1].

The other branches than psychology is have the completely different view of intelligence.

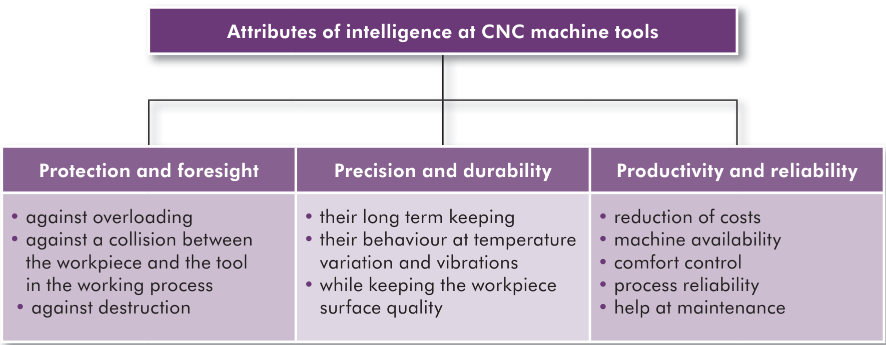

Fig. 7.2.1: Current attributes of industrial intelligence at CNC machine tools

For example, cognitive sciences or information science define the intelligent system generally, without the necessary relation to live organisms. According to them, the intelligent system must be able to react on the changing ambient conditions, i. e. [www-2]:

- to provide the own ability to survive;
- to provide the own ability to be reproduced;
- to be target-oriented and to have the ability to reach this goal;
- to be able to learn.

Intelligence of machine tools

Searching for the parallel between the human intelligence and intelligence of a machine tool is very problematic at the current time. In any case, it is possible to find the common intelligence features of people and machines, due to the fact that the machines have been created by people. Adaptation of a machine tool can take place e. g. in this way:

- comparison of the outputs from the sensors with stored models;
- processing of these signals and deduction of an action;
- adaptation to the changing conditions (i. e. adaptability ability).

Using these procedures, it is possible to reach the effects, when the machine operators are excluded from the machining process and the machine behaves according to the intelligence algorithm which the machine-tool manufacturer inserted into it. Moreover, it is known that despite this „influencing“ of the machining process the operator can achieve improvement of this inserted intelligence, thanks to his unrepeatable experience and knowledge of the CNC machine tool. Fig. 7.2.1 shows attributes of intelligence at CNC machine tools. It is also necessary to provide communication between the machine operator and the CNC machine tool, which is the prerequisite to assess the machining process state and for the possible subsequent reaction.

Heidenhain

Heidenhain company has presented two groups of software functions which aim at the optimization of the machining process regarding to the performance and quality of the resulting workpieces. These are optional functions of the control systems, TNC series which are determined for milling machines or multifunctional machining centres with the possibility to perform turning and milling operations. Some partial functions are well-known and proven already from the previous versions of TNC and iTNC systems, the new aspect is represented especially by the comprehensive concept and advantages of utilization of the functions complementing each other in groups.

Dynamic Efficiency

Dynamic Efficiency helps to increase cutting performance and to reduce the machining time and it includes three software functions:

- trochoidal milling – function for roughing of grooves and pockets;
- AFC – it regulates the feed adaptively in dependence on the machining situation;
- ACC – it decreases tendency to oscillation and therefore it enables bigger feeds and bigger material removal.

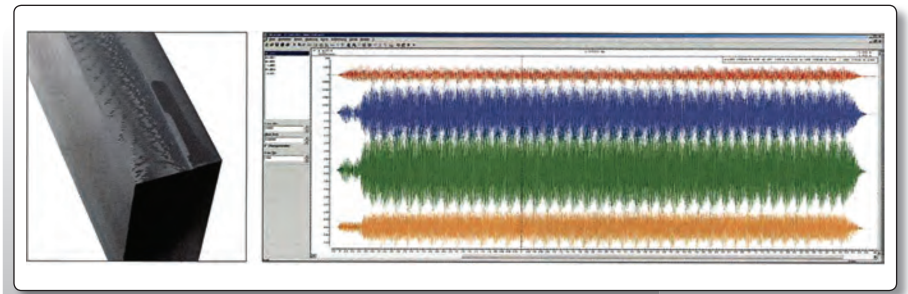

Fig. 7.2.3: Oscillation consequences on the workpiece surface [Heidenhain]

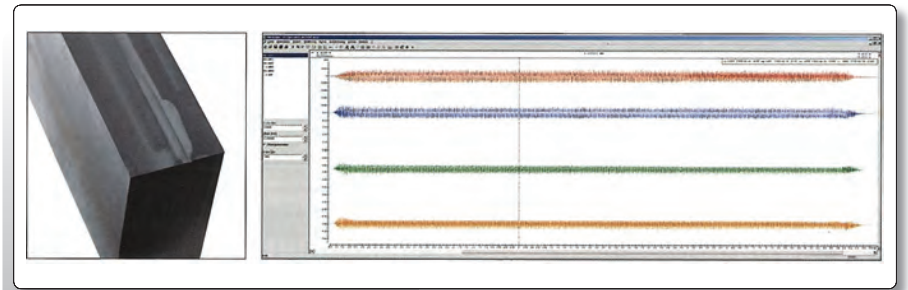

Fig. 7.2.4: Active Chatter Control [Heidenhain]

The Dynamic Efficiency function enables a bigger volume of chips per time unit as well as the productivity increase, without the necessity to use special tools. The tool overloading and the premature cutting edge wear are prevented, which contributes considerably together with the additional profit of the process reliability to the economy improvement.

The adaptive feed control (AFC – Adaptive Feed Control) regulates the feed size from TNC in dependence on the current spindle output and on the other process data (Fig. 7.2.2). In fact, the AFC function enables to eliminate prolongation of machining time. The optimization of machining time is also manifested at the castings with variation of dimensions or materials (cavities). By means of the appropriate feed regulation, AFC tries to observe the previously learned maximum spindle output during the whole machining time. When the machining feed is increased in the zones with smaller material removal, the total machining time is reduced.

Moreover, the AFC function spares the machine mechanical system by the feed decrease, if the maximum output is exceeded at the spindle. The spindle is protected efficiently against its overloading in such a way.

Big milling forces occur at roughing. In such a case, oscillation can appear in dependence on the tool speed, machine resonance properties and volume of chips. This oscillation means big load for the machine and it causes visible traces on the workpiece surface (Fig. 7.2.3). The tool is also worn very intensively and irregularly, the tool rupture can also occur in the extreme case. In order to decrease tendency of a certain machine to oscillation, the company now offers the efficient regulation function ACC (Active Chatter Control) – Fig. 7.2.4. The utilization of this regulation function is manifested especially positively in the heavy-duty milling field. By means of ACC it is possible to reach the considerably better cutting performance. In dependence on the machine type, the machining volume can be increased by more than 25 % during the same time. The machine load is decreased and the tool service life is increased at the same time.

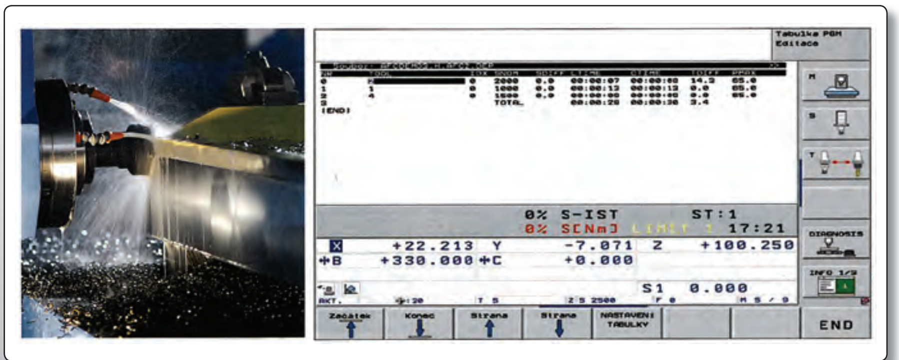

Fig. 7.2.2: Adaptive Feed Control [Heidenhain]

Dynamic Precision

The Dynamic Precision term summarizes the optional functions for the control system which suppress efficiently dynamic errors of machine tools. They improve the dynamic machine behaviour, they reach higher rigidity and therefore they enable milling operations at the limit of technological possibilities, independently of the machine age, its load and of the machining position, while everything is possible without any

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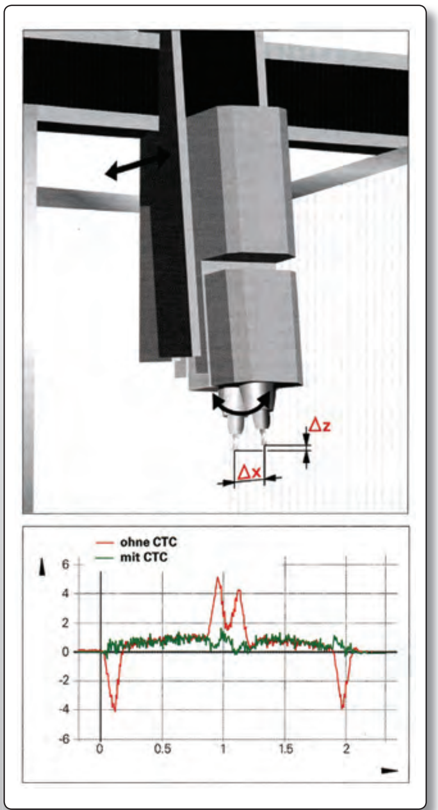

Fig. 7.2.5: Keeping the tool position setting error in the tolerance thanks to the CTC function [Heidenhain]

intervention to the machine mechanical system. Slow machining is not necessary for precise workpieces with the high surface quality any more. Machine tools work with Dynamic Precision software quickly and precisely at the same time. The particular Dynamic Precision functions are available as the options for control systems Heidenhain:

- CTC – compensation of position deviations dependent on acceleration in the tool centre (TCP) and higher precision in acceleration stages due to this (Fig. 7.2.5);
- AVD – active vibration suppression for the better surface;
- PAC – position-dependent adaptation of regulation parameters;
- LAC – adaptation of regulation parameters in dependence on load and higher precision independently of ageing and load due to this;
- MAC – motion-independent adaptation of regulation parameters.

Kovosvit MAS

Of course, it is necessary to pay attention to the minimization of machine thermal deformations already at the machine designing itself. Most of all, the design with thermal symmetry should be projected during the designing stage so that only the linear components of thermal errors can arise on the tool point, because it is more complicated subsequently to eliminate (to compensate) the angular components of thermal errors.

Moreover, it is necessary to utilize the design assembly groups and elements with higher efficiency (reduction of produced heat), to locate heat sources suitably or to insulate them properly, and if it is possible, it is also necessary to use unconventional materials with low thermal conductivity and dilatability (e. g. natural granite). The inseparable part of the suitably performed design should be represented by the sufficient removal of arising heat (cooling of the particular heat sources, rinsing or blowing of the whole frames, it is necessary to guarantee the continuous chip removal from the working area, etc.) [Mindl 2013].

In addition to the suitably performed design of the machine tool, the machine user should provide the favourable conditions in the manufacturing hall (machine ambient). The ideal solution is if the manufacture takes place in the air-conditioned hall. However, it is rather expensive to run such a hall. If this is not possible, at least the essential principles should be observed for machine operation in the manufacturing hall, i. e. it is necessary to decrease temperature variations in the machine ambient in the hall to the minimum, to screen away radiation (sunshine and other heat sources in the ambient) and to minimize the air flow. However, all above-mentioned solutions how to minimize thermal deformations of the machines are often insufficient or their price is very expensive. In comparison with them, the software temperature compensations of machine tools represent a very cheap way how to minimize thermal deformations of the machines [Mindl 2013].

At the current time the most usually used type of the software temperature compensation is obtained from the linear (multiple) regression analysis (so-called MLR form English Multiple Linear Regression). This is the simple mathematic description (usually having the form of a polynomial function) and the common machine control systems (e. g. Siemens, Heidenhain) offer thus function as a standard. The big advantage is that the compensation algorithm is obtained rather quickly, because these MLR models are often compiled based on the empirical data only from one calibration measuring for the selected working mode. Moreover, this sole working mode is usually performed at the constant spindle speed, without the motion of the other motions axes and without machining ("idle run"). While the creation time of the MLR models is short,

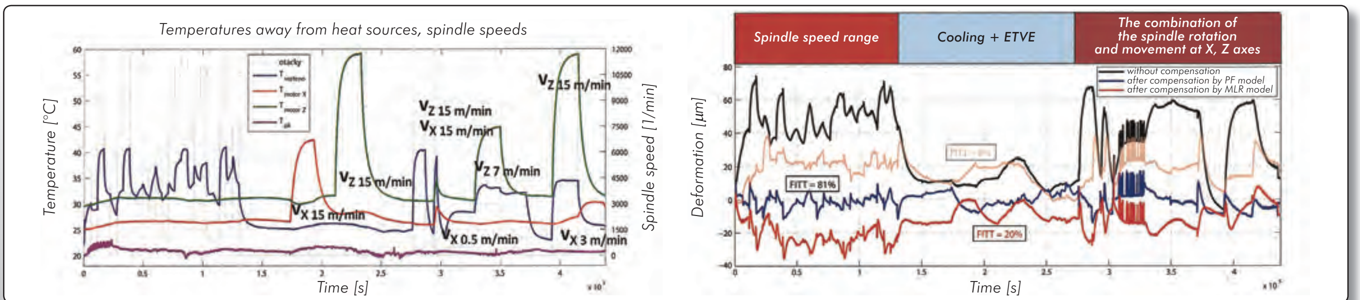

Fig. 7.2.6: Course of speed and feed velocities, including the result comparison of the transmission function and MLR temperature compensation [Kovosvit MAS and Engineering Faculty of Czech Technical University in Prague]