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INVESTIGATION OF PROPERTIES OF MACHINE TOOLS

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Abstract: Inspection of machine tools is a foundational element of modern manufacturing quality control. As industries demand tighter tolerances, increased automation and higher productivity, machine tools must operate at peak accuracy. Over time, all machine tools experience degradation caused by mechanical wear, thermal effects, vibration and environmental factors. Regular inspection helps ensure that the accuracy and reliability of machine tools remain within acceptable limits. This paper deals with investigation of machine tools.

Keywords: *inspection, maintenance, machine tool*

1. INTRODUCTION

Machine tools are among the most important means of production in the metalworking industry. The current high standard of living in industrialised nations would be inconceivable had this category of machinery not been developed. The application areas for machine tools are just as diverse as their structural design and degree of automation. According to the technological processes, this extensive field ranges from machine tools for primary forming and forming, through machine tools for cutting to joining machines. These machines have varying degrees of automation and flexibility depending on the workpieces to be machined and the lot sizes. As a result, single-purpose and special machine tools as well as universal machines with an extensive range of potential applications are available on the market. Due to the increasing demands on performance and accuracy, the designer of these machines must ensure an optimum design of the individual machine components (Brecher & Weck, 2024).

2. MONITORING

Monitoring is defined as the activity of gathering information about the functioning state in each system, by means of adequate observation of instruments and measuring apparatus to supervise and intervene for correction purposes. The diagnosis of technical systems could be defined as a process of functional faults and their causes, based on data obtained by control, supervising or monitoring. The rudiments of establishing technical diagnosis have been present for a long time regarding the estimation of the functioning state of a machine or equipment. Thus, it was natural that the functioning anomalies be noticed by the operator of the machine, such as modifications of level or type of emitted noise, too much energy consumed, low output, the vibration level increasing or excessive heating (Marinescu, Ispas, & Boboc, 2002).

3. MEASURING METHODS

Besides the geometric and kinematic behaviour of the load-free machine tool as determined by production-related deviations in its elements and components, the influence of process-induced loads warrants particular attention when assessing the working precision and productivity of a machine tool. In particular, the static, dynamic and thermoelastic deformation properties of the machine play a significant role. The environmental behaviour is also gaining in importance. In addition to their effect on people, environment-related aspects must be considered likewise. The reliability of a machine also has a major impact on the cost-effectiveness of a system which is why it is considered as an important quality characteristic as well. Appropriate measurement and assessment procedures are needed to assess the quality of a machine. The characteristics of the machine under examination must be chosen based on the requirements and appropriate tolerances must be defined. Figure 1 gives an overview of the definitions of performance capacity, productivity, working precision, environmental behaviour, and reliability plus overlapping interrelations between the secondary terms used to describe machines (Brecher & Weck, 2021).
The working precision of a machine tool for the most part, is defined by its geometric and kinematic behaviour. Given the wide range of possible fault causes, geometric and kinematic deviations arising from the manufacture of the machine components and their assembly to be considered first. The elastic load-deformation behaviour of the machine arising from process loads is also very important (Brecher & Weck, 2021). Some of the causes of machine deformations include workpiece weight

forces, dynamic and static process forces, acceleration forces and a wide range of heat sources.

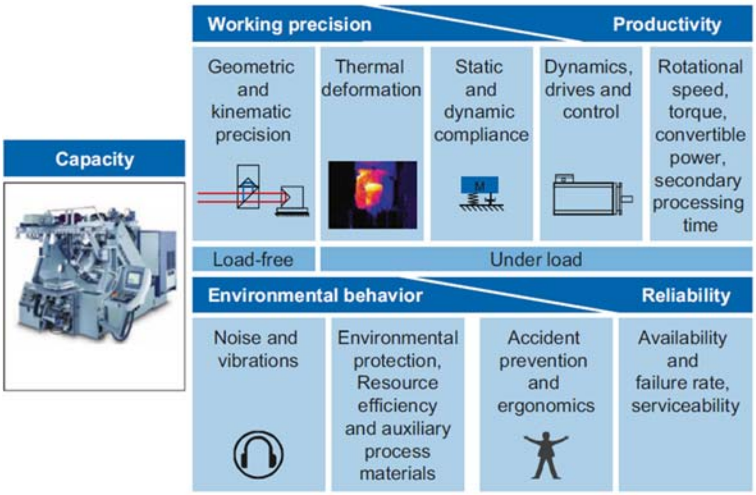

Figure 1. *The characteristics of machine tools (Brecher & Weck, 2021)*

4. VIBRATION SOURCES

The designation of the natural frequencies of diverse equipment and machines is important in various aspects, because this will allow the error to be detected in time and can assist in the repair or redesign of the equipment under investigation. Based on machine vibration, you can get a comprehensive picture of the machine state and consequently the current state of each machine part. In the field of vibration diagnostics, three test methods are typically used: resonance test, bearing vibration test and motion-animation test. The modal analysis analytically derived by the finite element method and executed by the software can be used in practice to describe the vibrations of flexible bodies and related properties. A flexible body can also be considered mechanically known if it is possible to predetermine the motion of the flexible body, even if it is excited at any point by a force function (Kiss & Szilágyi, 2020).

In the factory several vibration sources are present, independent from the device, of which the oscillation –propagating partly in the ground, partly through the air– can get into the workspace of the equipment. Such sources, but not limited to them, might come from the bridge crane passing over the equipment from time to time, the forklift carrying heavy weight rolled plate products, the high voltage electric induction of heating furnaces, the raw aluminium ingots hitting the ground following transport, the vibrations of other machines auxiliary equipment located in the factory. These sources summary are called the environmental sources, and their synergies are considered (Szilágyi, Takács, Kiss, & Tóth, 2016).

5. Thermoelastic behaviour

The thermoelastic machine behaviour is influenced by many factors. The correlation between the different causes and the result, for example an error at the Tool Centre Point (TCP), is shown in Figure 2. The thermoelastic machine behaviour –for example the temperature distribution and the resulting deformations of the machine– is determined by many design and thermal factors. In addition to the influences internal to the machine (process as well as fluid, drive and motion systems), there are also thermal environmental influences acting on the machine at the same time which cause heat to be introduced into the machine structure. These thermal environmental influences lead to an uneven and unsteady temperature distribution, which is dependent on the thermal material properties, the mass distribution and the location of the heat sources. Together with the effective elongation lengths and their coefficients of expansion, the component structure (ribbing scheme, wall thicknesses), the location of the components relative to each other and the type and fitting of the position measuring systems, displacements and inclinations of the machine structure and, with that, errors at the TCP result from this temperature field. The direction of the occurring displacement is also of importance for the final dimensional deviation on the workpiece (Brecher & Weck, 2024).

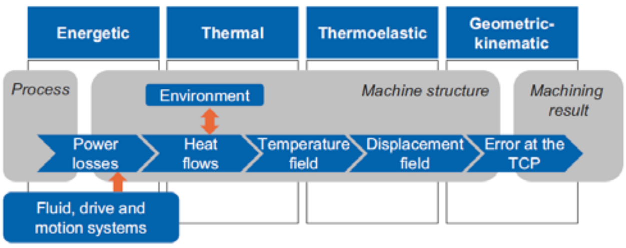

Figure 2. *Thermal functional chain of thermoelastic structural deformations (Brecher & Weck, 2024)*

Internal machine influences or internal heat sources refer to the thermal influence factors that occur when operating the machine either in the loaded or unloaded state (see Figure 3). These are the lossy components like bearings, motors or transmissions and the machining process itself. Some of the heat produced increases the temperature of the tool and workpiece. The heat is conducted from these parts into the machine structure or emitted into the environment. A significant amount of the heat is stored in the chips. This heat can contribute to the table heating up considerably, in particular with machines which have a horizontal clamping surface.

Internal influences

Machine elements
- bearings, guide systems
- ball screw drives
- motors
- transmissions
- hydraulics

Process
- cutting heat
- chips
- cooling lubricants

Cooling
- motor cooling
- spindle cooling
- frame temperature control

External influences

Shop floor climate
- temperature distribution (vertical/ horizontal)
- temperature fluctuations
- airflows

Heat sources:
- sun
- radiators
- adjacent machines

Heat sinks
- foundations
- open shop doors

Figure 3. *Causes for thermoelastic deformation (Brecher & Weck, 2024)*

The thermal state of the cooling lubricant, which wets most of the workspace, is also included among the internal heat sources. It can be an unpredictable influencing factor, but it can also be purposely used to achieve a uniform temperature distribution. The thermal impact can also be influenced by cooling individual components (spindles, motors) which have an indirect effect on the surrounding machine structure. Among other factors the thermal environmental influences depend on the installation side of the machine. Here, the shop floor climate, characterised by both air temperature fluctuations and horizontal and vertical air temperature gradients, is important (Brecher & Weck, 2024). Like the load and speed variations, the temperature fluctuations in the shop floor also prevent the machine from reaching thermal equilibrium.

6. MACHINE PROPERTIES

The direct measurement of machine properties uses instruments to measure individual machine parameters. This method makes it possible to separate different fault influences. Uniquely mapping machine faults to their causes usually makes it easier to decide on whether to opt for design-based or production-based improvement measures. For general acceptance testing of production machines, the

costs of the measurement are simply too high in terms of time and money. Often special instruments adapted to the size of the machine are used to measure individual parameters such as deviations in curvature, straightness, angle, and position (Takács, Zsiga, Makó, & Barak, 2009).
For most of the parameters to be measured when the machine is in a load-free state, the acceptance guidelines of DIN 8601 and ISO 230 provide exact descriptions of the procedures for measurement and limit values for different machine types and sizes. Rules have been set out for inspecting the behaviour of milling machines under static and thermal loads in DIN V 8602. Tests under load are usually carried out on prototypes or reference machines. This is because series-production machines usually have comparable behaviours. Only the state of the art of noise emissions from machine tools has been documented in VDI standard 3742. This standard covers the average characteristic noise emission values for various machine tools (lathes, milling machines, grinding machines, cold circular saws, and drilling machines) as a function of the drive input and maximum spindle speeds, including sample machining applications. These parameters can be used to measure noise emissions from a specific machine based on an average from comparable machines. When a machine needs to be measured relatively quickly at specific time intervals for potential changes in its precision, machine self-testing is the logical path to take. A three-coordinate measuring probe is inserted into the tool holder, for example of a milling machine. A standardised test object is set up in the workpiece clamping area and aligned with predefined measuring points and geometric dimensions. The machine moves along predefined paths based on the geometry of the test object and takes samples of the test object at predefined points using the measuring probe clamped onto it, just like a coordinate measuring machine. The evaluation of the deviations measured between the measuring point coordinates and their target positions provides general information about the geometric deviations of the machine. The aggregate effects of multiple fault influences are contained in the measuring result. Provided that the deviations lie within the given tolerances, the geometry of the machine will be accepted. If not, the machine is then examined more thoroughly using the direct method of measurement. In the indirect measurement of machine properties, the machine being tested produces sample workpieces using predefined geometric shapes. It is possible to assess machine precision by measuring the geometrical deviations of the workpiece (Liu, Li, Wang, & Tan, 2011).

7. SUMMARY

Machine tool inspection is essential for maintaining machining accuracy, productivity, and reliability. As manufacturing demands grow, systematic and well-documented inspection programs ensure that machine tools remain capable of producing high-quality parts. By combining precise geometric verification, modern laser measurement technologies, dynamic performance testing, and adherence to international standards, manufacturers can extend machine lifespan and optimise overall production efficiency.

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