

Process Analysis ■ Process Optimization ■ Dynamic Force Measurement

# Effects revealed by Analysis of Force Signals

An examination of the cutting process using piezoelectric force measurements reveals effective data for optimizing the manufacturing process, processing strategies, tools and machine tools.

by Manuel Blattner, Kistler Instrumente AG



**1** Measurement of the force used in the process permits conclusions about the quality of the surface, wear and general characteristics of materials (© Kistler)

Great importance is always placed on process analysis and optimization in the manufacturing industry. For every cutter and tool manufacturer, measurement of the forces and torques generated during machining is a simple option for gaining valuable insights into otherwise invisible processes and the dynamics of cutting.

## Transparency Thanks to High-resolution Force Signals

One of the most useful features of measuring with piezoelectric sensors is the incredibly high-resolution that can be achieved. The piezoelectric effect allows the sensors to reliably record cutting processes at very high frequencies. Using piezoelectric technology to measure the

forces generated during a machining operation allows even the smallest fluctuations in force to be detected. Therefore, even minor adjustments to tool geometry, material, processing strategy or coating become clearly visible. So identifying and quantifying the benefit of any process change becomes simple, allowing evidence based optimisation of both the product and the process.

## Piezoelectric Force Sensor for Precision Measurement Results

Cutting processes are highly dynamic, particularly in the case of interrupted cuts. Both the machine tool and the dynamometer will be stimulated by interruptions. The best way to minimise the negative effects of such events is to use measurement equipment with as high a natural frequency as possible. In contrast with measurement instruments based on other technologies, piezoelectric sensors are distinguished by their rigidity which gives them high natural frequencies, far in excess of that which can be achieved using other technologies. The advantages offered by piezoelectric technology become particularly apparent with cutting processes and make precision measurement possible even for high speed machining with high tooth passing frequencies.

## Discover Wear and Explain Effects

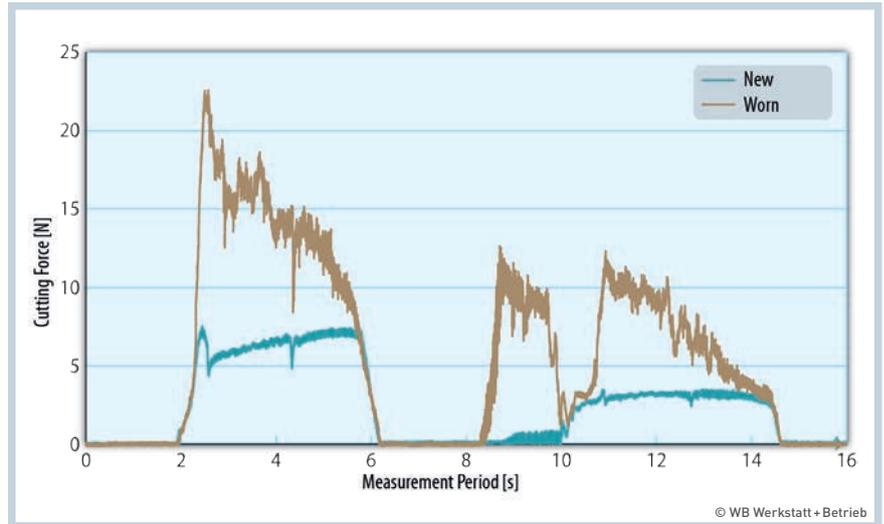
The Kistler Dynamometer makes qualified statements about the variety of data

capture that is possible, including: the machinability of materials, tool geometries and coatings, wear mechanisms, tool life, surface qualities, deviations in shape and vibrations. Because phenomena like wear have a direct effect on the changes in force, they can be tracked using graphs measuring force thus permitting the process to be refined.

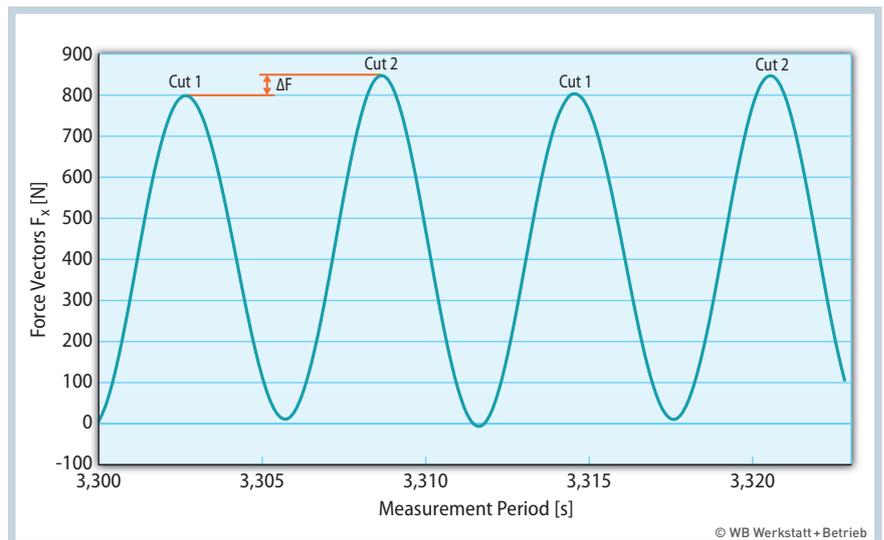
The effect of tool wear can be demonstrated using the example of turning thin-walled work-pieces. Given an appropriate measurement of force, a worn tool shows a significantly higher level of force than that of a new tool (Fig. 2). Such changes in force have definite effects on the tolerances of such thin materials and components. In this test, the processing parameters have been adjusted based on a detailed analysis of force and minimal corrections were made to the processing strategy. Doing this made it possible to significantly reduce tool wear and improve the quality of the work-piece.

#### Validation of Simulation Results

In addition to recording tool wear, piezoelectric dynamometers provide highly detailed insights into the process. Analysis of the forces generated has particular importance for tool manufacturers. The effects of even the smallest fluctuations in the tool geometry can be made visible by viewing the measurement of force, thus making accurate optimization of the tools possible. Many manufacturers use simulation software to understand the effects of various parameters better. Verification of the results of simulation using force and torque signals is exceptionally important. Reliable databases can



**2** The new tool shows clear and easily traceable changes in the cutting force at the deepest level. The forces used by a worn tool increase significantly. (Source: Kistler)



**3** The various levels of force used for the two cuts for milling faces indicates a high level of irregularity (Source: Kistler)

only be built using verified data, which in turn increases the quality of the simulations. Furthermore, piezoelectric dynamometers provide the necessary data for reliable proof of the improvement of the tool life. This information provides irrefutable evidence for every tool manufacturers' sales department.

Manufacturing irregularities (such as a lack of balance, concentricity issues or minor imprecision in the manufacture of the tools) effect processes negatively and pass those effects on to the final product. Analysis of force signals can identify such irregularities very clearly and so help indicate them. Uneven contact by the individual cutting teeth can be identified and the different forces generated by each tooth seen (Fig. 3). Based on these in-

sights, trouble-shooting becomes easier and evidence based and so irregularities and weaknesses can be eliminated.

#### Heat Build-up barely affects Measurement Results

Every cutting process converts a large part of the mechanical energy used into thermal energy. This thermal energy affects the machine, the tool and the material, as well as the piezoelectric dynamometer and it results in perceptible drift in the signal. Over the last few years, Kistler has developed a new line of products, which can largely correct this phenomenon thanks to clever mechanical construction. This line of products reduces thermal drift in comparison with the previous generations of dynamometers. The

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4 Measurement of force while milling with a stationary Type 9255C dynamometer © Kistler

Kistler line of products described here covers a large range of forces, starting with the smallest level of force in the newton and sub-newton range extending up to 30 kN and all these products have been developed specifically for use in the machining industry.

#### Dynamometers for Every Use

Stationary dynamometers are versatile and exceptionally robust. They can be easily mounted on machine tools without modifications to the tool clamps. The material will then be mounted directly on the dynamometer, such as for measuring the reaction force during milling or drilling. Stationary dynamometers can also be used for lathe operations. When used in this manner, they record the orthogonal

forces ( $F_x$ ,  $F_y$ ,  $F_z$ ) using an adapter mounted directly on the tool turret.

Rotating cutting dynamometers (RCDs) measure the forces generated by the cutting tool and make immediate, precise recording of these cutting forces possible. RCDs are directly mounted into the spindle interface and rotate with it. The tool itself is mounted on the RCD with the help of a tool clamp. RCD's are designed to monitor milling and drilling operations. In addition to the three orthogonal forces, they also measure the torque  $M_z$  directly and provide evidence about the tool wear on a rotating tool.

Kistler Instrumente AG offers a turnkey solution for cutting force applications, with the whole measuring chain, consisting of the sensors, charge amplifiers, data acquisition and user-friendly software specific to cutting force measurement. The software al-

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## BACKGROUND

### The Piezoelectric Effect

If mechanical energy is applied to a piezoelectric material (such as a crystal), an electrical charge is produced proportional to the force applied to the crystal.

Kistler dynamometers use the high sensitivity, robustness and thermal stability of piezoelectric technology to measure highly dynamic cutting processes precisely.

### Uses for Measurements of Cutting Force

Kistler dynamometers allow the qualification of processing strategies, investigations of chip generation and the verification of process simulations and models possible, as well as optimization of tool life.

Measurement of the force also permits statements to be made about:

- Machinability of materials
- Tool geometries and coatings
- Mechanisms of wear
- Surface qualities
- Deviations in shapes and
- Vibrations

allows the electronic systems to be controlled easily and provides features for the analysis, processing and exporting of data. ■

*Translated by Kistler Instrumente AG*