At present, both the tools and the processes at performed by machine tools are monitored by a wide variety of sensors for the detection of forces, strains expansion, vibrations, acoustic noise emissions and true effective power. In general, the most meaningful information is obtained from the monitoring of forces generated by the metal removal process. To ensure the reliable monitoring of tool wear, in particular, three forces must be measured with the utmost accuracy. Many wear-detecting mechanisms for turning tools demonstrate that the evaluation and appropriate weighting of all three force components is far more reliable than the monitoring of only a single force component. The latter may generally be adequate for the purpose of monitoring collisions and tool breakages, but even here the measurement of the forces in all three directions improves reliability.

Force sensor and electronics in a single housing

Piezoelectric multi-component force sensors made by Kistler Instrumente AG, Winterthur are now being successfully used in lathes to monitor collisions, breakages and wear, due to their exceptional stiffness and compact dimensions. To permit their use under production conditions, in particular, they are now being fitted with integrated charge load amplifiers for signal preprocessing. These deliver voltages at the outputs which are precisely proportional to the forces applied to the sensor. The sensors themselves (Figure 1) are welded to make them hermetically sealed and are provided with an integrated cable output (type of protection IP68) or – for more flexible use – a plug connector (type of protection IP67). By this means, for example, the sensor installation and machine wiring can be carried out separately. Being 10 mm high and 25 mm wide, and featuring an annular-type sensor, the new force sensors with integrated electronics are the same size as, and largely compatible with, existing force sensors for the monitoring of one, two or three force components (title illustration).

Preloaded installation

Multi-component force sensors consist of a package of quartz crystal discs, precision mounted in a steel housing. Through the use
of a variety of crystal shapes and the appropriate positioning of the discs, up to three force components can be measured simultaneously, i.e. in the axial direction (in the direction of the preloading force \(F_z\)) and as a shear thrust force about two orthogonal axes \((F_x, F_y)\). The force components at orthogonal angles to the sensor axis are transmitted as frictionally engaged shear-thrust forces. This means that the sensor must be axially preloaded. A prerequisite for the trouble-free monitoring of several force components (Figure 2) is that the sensor must be precision made. The forces must act on the sensor element under the optimum spatial conditions. To this end, the sensor must be generally preloaded in the machine tool structure. This can be accomplished without difficulty with annular sensors. The requisite preload is achieved with a double wedge (Figure 3). In this way, the sensor can be directly installed and preloaded in a friction-locked fit in a recess in the structure or in the parallel plane of separation between two machine components.

**Universal use through standardised housing**

To permit the use of sensors with housings of standardised dimensions, as described here, many lathes are now being made with recesses of standard dimensions (Figure 4) i.e. 16 mm high, 25 mm deep and 25 mm wide. If provision is made in the design of the machine tool for a recess of this size, the machines will be provided with a mechanical interface permitting the simple integration of sensors. Retrofitting is thus considerably simplified. Similarly, a sensor capable of measuring three force components can easily be installed in place of a single component sensor.

Force sensors can also be installed directly in joints, e.g. between the tool turret and machine slide of lathes (Figure 5) or between the spindle head and machine bed of grinding machines. In this case, the sensor is mounted in a recess in the machine slide or in an

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**Figure 1** Force sensor with integrated electronics for the measurement of three force components generated in lathes

**Figure 2** Precise linearity, extreme sensitivity and the minimum of cross talk between traverse forces are essential for the trouble-free monitoring of up to three force components

**Figure 3** Force sensor, preloaded with a wedge in a standard recess (16 mm high, 25 mm deep, 25 mm wide)
intermediate plate. The requisite preloading of the sensor monitoring element is achieved through the slight projection of the sensor component housing beyond the surface of the joint when the machine parts are bolted together. This form of installation possesses extreme rigidity. The depth of the recess or thickness of the intermediate plates must be at least 10 mm.

**Force measuring systems for reliable process monitoring**

Properly evaluated, multi-component force monitors on lathes offer reliable monitoring for collisions, tool breakages and wear. For the latter, in particular, they are a must, since only by allowing for all the force components is it possible to arrive at reliable conclusions as to tool wear. At the same time, a sensor of very high quality is required, a sensor which stands out by virtue of its uniform sensitivity in all three axes, the minimum of cross talk it generates between the individual force components and the ability of its design to stand up to demanding factory conditions.

Thanks to the integrated electronics (charge amplifier) voltage signals which are proportional to the processing forces are available at the sensor output which can be directly evaluated. Other characteristics are the adaptable cable and plug configuration and the standardised housing dimensions, permitting a force sensor system to be readily adapted to the most wide ranging types of machine.