Automatic Monitoring of Tool Wear and Breakage when Drilling and Grinding

by U. Heisel, Berlin, W. Germany

1 Introduction

Damages frequently occur during machining because of tool breakage that is due to a short-term overloading of the tool or to long-term symptoms of wear that exceed the permissible limits on tool life. The characteristic signs that such has occured are significant changes in the machining-force ratios. Equivalent measured quantities are detected and evaluated for the monitoring of machining forces during industrial production.

2 Measuring principles

2.1 General remarks

The use of dynamometric bearings in the main spindles of machine tools does not require any design changes, and it makes it possible to measure as many as three separate force components, even for small tools such as a drill that is 3 mm in diameter [1, 2]. The system can therefore be used for the process monitoring of machining operations that go beyond drilling, i.e. for milling, turning or grinding. It is therefore especially distinguished by the extraordinary bandwidth of uses, without it being necessary to take special measures for its installation or put up with changes in rigidity.

2.2 Method by which the dynamometric bearings function

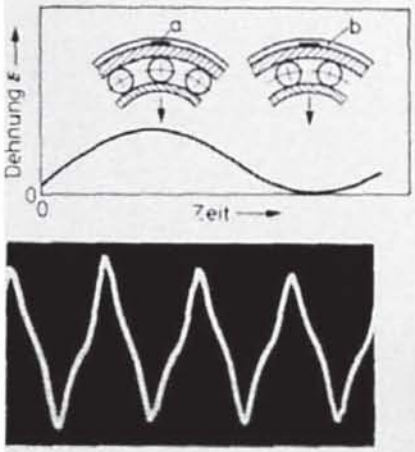
Standard anti-friction bearings that have been prepared for the measurement of force are called dynamometric bearings [3 to 5]. The measurement of forces is made possible by expansion measuring strips that are glued into a groove which has been subsequently cut into the outer ring. The method by which they function is based on the fact that distortion is caused by the rolling of the rolling elements in the bearing assembly. The distortion is transferred to the measuring grids of the expansion-measuring strips embedded in the bottom of the groove and produces a change in the resistance, which is analyzed by a bridge circuit.

When the dynamometric bearings are running, they produce an alternating current at the bridge output (Fig. 1), the amplitude of which is proportional to the force applied. The frequency changes with the speed of the spindle. The measuring signal is a yardstick for the external and internal forces being applied to the bearing. Internal bearing forces such as the preloading forces, centrifugal forces and hydrodynamic forces affect the measuring points in the same direction. Equal proportions are balanced out by subtracting the difference of the signals produced by two measuring points opposite each other. The result is an output voltage that changes in a linear fashion with the external force [6, 7].

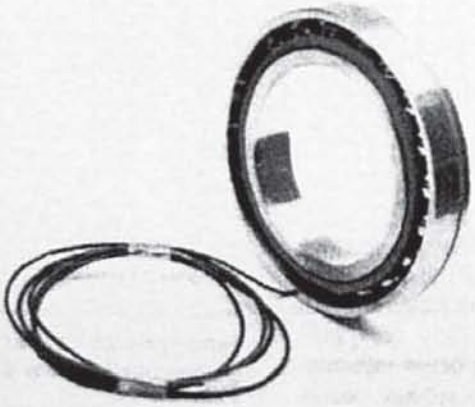
3 Process monitoring when drilling and milling

The use of dynamometric bearings for process monitoring during automatic production runs has been the subject of various investigations for a number of years. Thus, *Sprato* [8] reports on a microprocessor-controlled monitoring system for drilling operations. The analysis circuit described there processes the average value of the rise in axial force due to the wear on the main cutting edge of drilling tools in such a way that it is possible to recognize when the wear limit is reached and take the corresponding control measures entailed. The criterion for defining the limit value is a percentage factor laid down for the initial value with a sharp tool, this factor being 60% in the above-mentioned publication for drilling and with super-high-speed-steel twist drills of 10 mm diameter in St 50 steel when n is equal to 1000 rpm and s is equal to 0.10 mm. This factor has to be determined experimentally and recorded on tables for various machining parameters in order to determine the load limits. There are various systematic investigations for the drilling [9 to 11]. On the other hand, there are no comparable investigations of recent date for milling.

Therefore, further experience must be gained in particularly this area for a universally applicable tool monitoring system. *Lechler* [12] reports on the first such efforts using the example



1



2

Fig. 1. Schematic representation (top) and oscillogram (bottom) of the bridge output signal of a dynamometric bearing

a expansion measuring strip, *b* groove (drawing by courtesy of Promess GmbH, Berlin, W. Germany)

Fig. 2. Angular-contact deep-groove ball bearing prepared as a dynamometric bearing

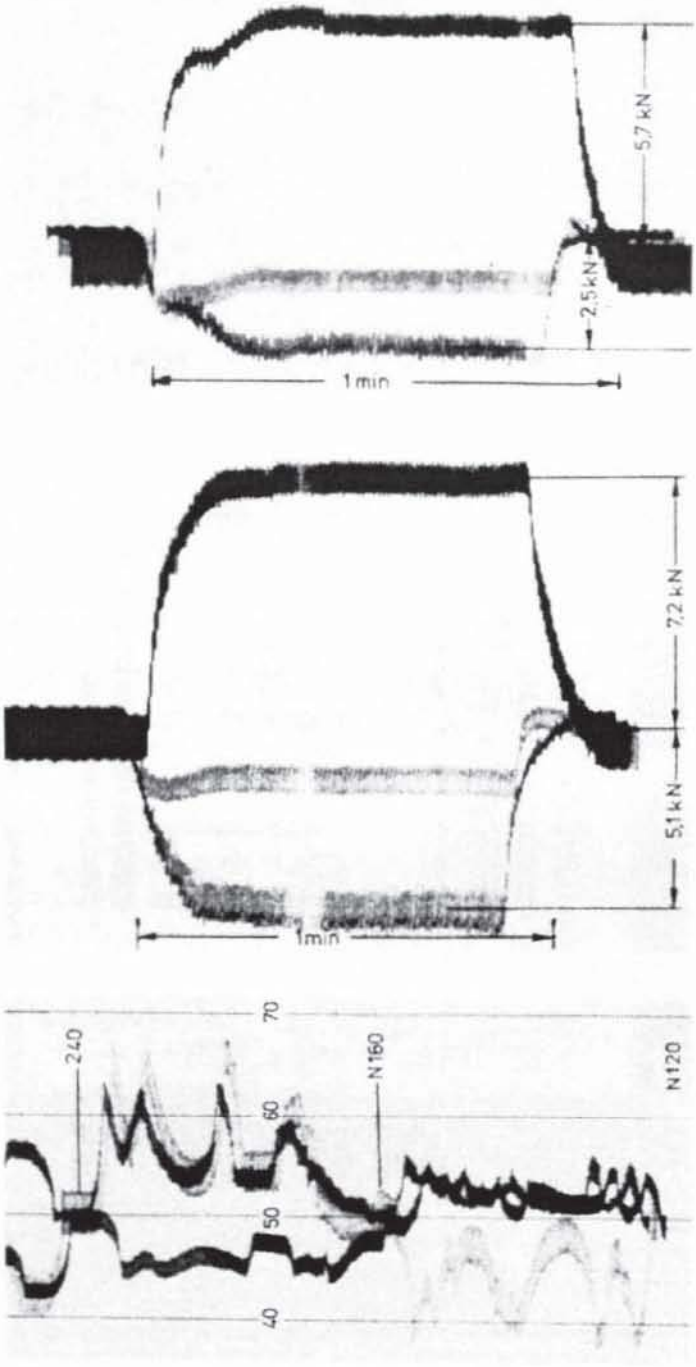


Fig. 3. Force components during milling (top: of a sharp milling cutter, middle: of a dull milling cutter, bottom: during face milling of a gearbox)

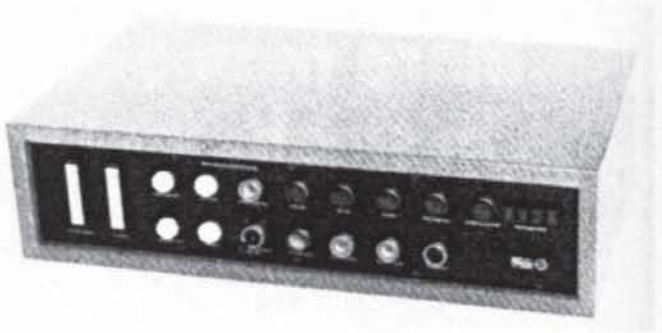


Fig. 4. Electronic analysis unit of a tool monitoring system for drilling and milling

of a microprocessor-controlled tool monitoring system developed for machining centres. Various investigations into the relationship between wear and changes in the machining force components have been made with the dynamometric bearing in Fig. 2, which is installed in a *Werner* TC 1 machining centre. Fig. 3 shows above and in the middle, as representative of many investigations, the cutting forces when machining a tool with a sharp and a dull milling cutter. At the bottom this illustration shows the behaviour of the force components during the machining of a gearbox with a facemilling cutter.

The dynamometric signals are processed with a microprocessor-controlled analyzer (Fig. 4) for the process monitoring. The procedure is such that the initial values with sharp tools during setting-up work are stored and, as required values, compared with the respective actual values during the entire machining with consideration being given to preselectable limit values. This makes it possible, as schematically depicted in Fig. 5, to distinguish between tool wear and breakage as well as chipping of the cutting edge. Furthermore, in addition to an integrated monitoring of the bearings it is also possible to control the starting cut so that the wrong tools or changes in the cutting conditions can be detected immediately after the tool makes contact with the workpiece.

With the exception of the tool wear that occurs over a long period of time, the machine is immediately shut down when the above-mentioned faults arise. The fault is acoustically signalled and displayed on the monitoring unit. In the case of wear the machine is not shut down until the end of the cut in order to avoid undesirable withdrawal marks. This is achieved by the fact that the force signals are not directly compared. Instead, the integral of the forces is observed throughout the cutting time. Thus, the fact that the tool-life limit has been exceeded is not recognized until the end of the cutting.

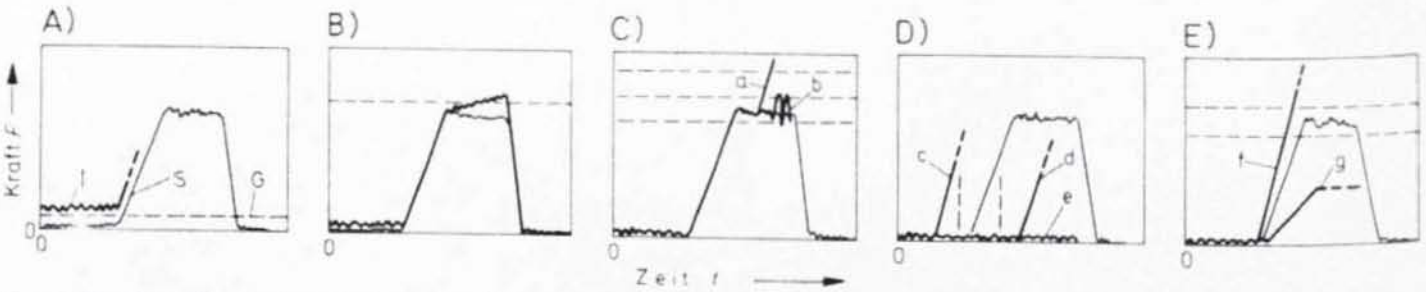


Fig. 5. Functions of the tool-monitoring system depicted in Fig. 4

A) monitoring of the spindle-bearing forces and speed, *B)* tool wear monitoring, *C)* detection of tool breakage, *D)* and *E)* monitoring of starting cut
a tool breakage, *b* chipping of cutting edge, *c* tool too long or diameter too large or feed speed too great, *d* tool too short or diameter too small or feed speed too low, *e* no tool or no feed, *f* rise in force too great, *g* rise in force too small, *G* limit value, *I* actual value, *S* required value

Worn or broken tools can be replaced automatically after the machine is shut down. In both cases replacement tools are searched for and inserted in the work spindle. In order to avoid a repeated change of the tools that have become unfit for immediate re-use, the modified characteristic tool values are filed in the control system after the old ones have been erased.

If there is not enough storage capacity available for replacement tools in the tool magazine, it is necessary to set priorities. Certain machining cycles can also be left unmonitored. It will be advisable to decide in favour thereof when, for example, roughing work is to be done on cast workpieces with varying allowances, and frequent responses of the time alarm are to be avoided as a result of starting cuts that differ greatly in terms of time and their characteristic rate of climb.

Furthermore, a more sophisticated version of the system presented can be used for the adaptive control of the machining process, for example, to prevent chattering by selectively changing the values of the feed and cutting speeds. This means that a unit is available for automatic tool monitoring that is a field-proven development in terms of its possible uses and, in particular, the requirements of automated production.

Literature

1 *Müller-Gerbes, H., Scharf, A.:* Hydraulische Überwachung für Kurzbohrer mit Hartmetall-Wendelschneidplatten beim Bohren bis ins Volle. Werkst. u. Betr. 113 (1980), 10, p. 679–681.

2 *Lechler, G.:* Kraftmeßspindel und Kraftmeßlager – ein neues Meßsystem zur Prozeßsteuerung, Ind.-Anz. 102 (1980), 34, p. 18–19.

3 *Lechler, G.:* Automatisierung mit überwachten Werkzeugen. Der Konstrukteur (1981) 1, 2, p. 30–32.

4 *Frase, D.:* Das Kraftmeßlager, ein Hilfsmittel zum Erkennen betriebs- und verfahrensbedingter Kräfte in Maschinen. Wälzlagertechnische Sonderschriften (WTS) Nr. 740720 der SKF Kugellagerfabriken GmbH, Schweinfurt.

5 *Kaiser, G.:* Messen von Laufgenauigkeit und Lagervorspannung an wälzgelagerten Werkzeugmaschinenspindeln. wt-Z. ind. Fertigung 61 (1971) 12, p. 747–750.

6 *Münnich, H.:* Wälzlagerforschung im Dienste der Walztechnik. Wälzlagertechnische Mitteilungen Nr. 82 der SKF Kugellagerfabriken GmbH, Schweinfurt.

7 *Lechler, G.:* Untersuchungen der thermischen Eigenschaften von Hauptspindellagerungen und Geradführungen an Werkzeugmaschinen. Produktionstechnik Berlin, Bd. 2. Carl Hanser Verlag, München u. Wien 1978.

8 Kraftmeßeinrichtung. Deutsche Patentanmeldungen: P 2746937.0 und P 2911479.2-52: Anmelder: G. Lechler.

9 *Sprato, E.:* Automatisierte Werkzeugüberwachung bei der Bohrbearbeitung. Ind.-Anz. 103 (1981) 5, p. 30–31.

10 *Ernst, P.:* Indirekte Verschleißmessung beim Bohren mit Wendelbohrern. Ind.-Anz. 98 (1976) 28, p. 465–466.

11 *Sack, W.:* Prozeßüberwachung des Bohrvorgangs durch Vorschubkraftmessung. Dissertation TH Darmstadt, 1978.

12 *Masuha, J. R.:* Torsionssteifigkeit und Bohrverhalten von Spiralbohrern mit Sonderprofilen. Produktionstechnik Berlin, Bd. 16. Carl Hanser Verlag, München u. Wien 1980.

13 *Lechler, G.:* Werkzeugüberwachung mit dem Kraftmeßlager. Schweizer Masch.Mkt. (1980) 5, p. 40–41.

Illustrations 2, 3, 4 by courtesy of Fritz Werner Werkzeugmaschinen GmbH, DIAG, Berlin, W. Germany. The author is employed by this company. This article was first published in German in "Werkstatt und Betrieb" 114 (1981) 8, p. 523–525.