Adaptive Control in Grinding

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Editor’s Note

One other driving force behind the need for adaptive control in grinding that must be added to Dr. Hahn’s position is the industrial move toward higher levels of automation through the use of increasingly sophisticated computer techniques. Grinding, milling, turning, inspection, and logistic systems are being integrated with a drive toward greater throughput. World competition is demanding faster and faster process schedules. High-speed machining techniques are, therefore, being seen more frequently as a requirement in machine specifications. As the speed of process increases, the manual capability to control decreases and the need for adaptive control increases. At some point, the ability to adaptively control becomes one of the limitations to the ability of the manufacturing industry to automate.

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The Need for Adaptive Control

The input variables to grinding machines, as described in chapters 1 and 2, are typically the rough and finish feedrates, amount of finish stock, sparkout time, dressing interval, and dressing parameters. As shown earlier, they affect the 2 important inputs to the grinding process; namely, the normal force at the wheelwork contact, $F_n$, and the topography of the wheel face or wheel sharpness, which is indicated by the
WRP (see Chapter 1). Those 2 process variables govern all of the output variables; i.e., stock-removal rate, \( Z_w \), surface finish, \( R_a \), surface integrity, and, ultimately, cost per piece.

In addition to the 2 grinding process input variables, \( F_n \) and WRP, random stock variations, random stock runout variations, variations in microstructure and workpiece hardness are also imposed on the grinding operation with the expectation that a high-quality output consisting of uniform size, taper, roundness, surface finish, and surface integrity will be achieved in a short cycle time.

Many grinding systems are able to absorb those random inputs and produce satisfactory output quality. However, as size, taper, roundness, surface finish, and surface integrity tolerances become more stringent and skilled operators become less available, adaptive controls are necessary to produce high-quality output at low cost.

In conventional grinding systems, the 2 important grinding process variables, \( F_n \) and WRP, are usually not well controlled. Generally, the sharpness of the grinding wheel, as measured by WRP, changes during the grinding process. As the wheel dulls, the real area of contact increases (see Chapters 1 and 2), causing the WRP to fall. That, in turn, causes the induced force, \( F_n \), to rise (see Eq. (1.15)). The increasing real area of contact, coupled with the increased normal force, soon exceeds the threshold of thermal damage, and poor surface integrity may result. To ensure good surface integrity, adaptive controls are needed to monitor "on line," the wheel sharpness, to achieve self-sharpening conditions, to limit the increase of interface normal force, and/or to initiate a dressing operation.

In conventional grinding systems that are not highly rigid and are required to produce close size and taper tolerances in a short cycle time, variable deflections of the system at the termination point of the cycle cause size and taper variations. Where in-process gaging can be used, the size error at the gage location can be eliminated, but taper errors or size errors at other locations are not eliminated. On fast-grinding cycles with random input stock variation, the induced normal force may not reach the steady-state value before sparkout begins. In that case size and taper errors can be caused by random initial stock variations unless a long sparkout time is provided. Therefore, adaptive controls are needed to absorb stock variations on low or moderately rigid machines operating on fast cycles.

In grinding operations where it is desired to hold close size tolerances on compliant systems without in-process gaging, variations in the threshold force (see Chapter 1) at the termination point of the grind cycle also cause size errors. Those threshold forces (force below which stock removal ceases) are often significant in operations where the difference