

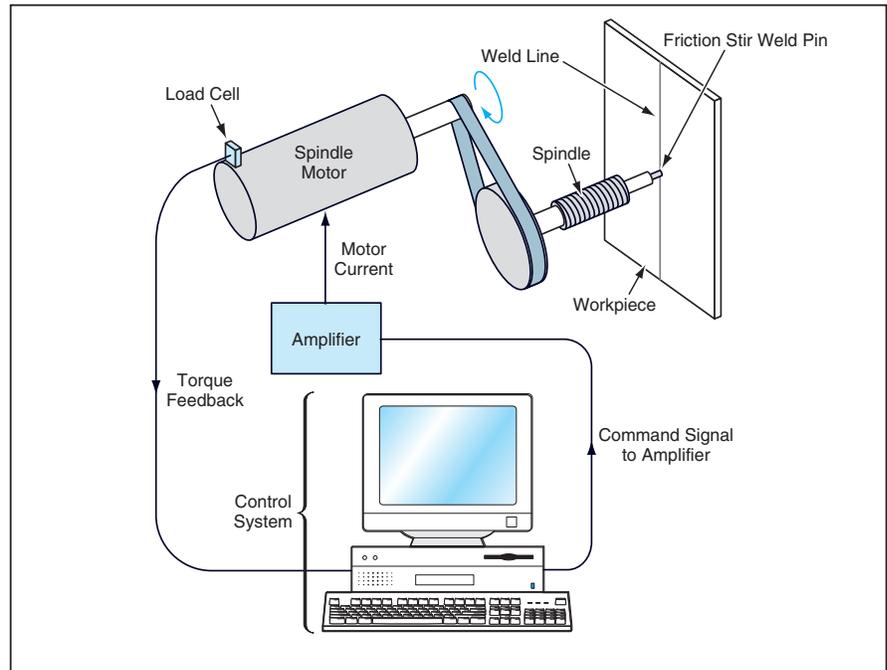
## Heat Control via Torque Control in Friction Stir Welding

Torque would be controlled and rotation measured to measure and control heat input.

Marshall Space Flight Center, Alabama

In a proposed advance in friction stir welding, the torque exerted on the workpiece by the friction stir pin would be measured and controlled in an effort to measure and control the total heat input to the workpiece. The total heat input to the workpiece is an important parameter of any welding process (fusion or friction stir welding). In fusion welding, measurement and control of heat input is a difficult problem. However, in friction stir welding, the basic principle of operation affords the potential of a straightforward solution: Neglecting thermal losses through the pin and the spindle that supports it, the rate of heat input to the workpiece is the product of the torque and the speed of rotation of the friction stir weld pin and, hence, of the spindle. Therefore, if one acquires and suitably processes data on torque and rotation and controls the torque, the rotation, or both, one should be able to control the heat input into the workpiece.

In conventional practice in friction stir welding, one uses feedback control of the spindle motor to maintain a constant speed of rotation. According to the proposal, one would not maintain a constant speed of rotation: Instead, one would use feedback control to maintain a constant torque and would measure the speed of rotation while allowing it to vary. The torque exerted on the



The Motor Current Would Be Regulated to maintain constant torque, as part of a scheme to measure and/or control the total heat imparted to the motion of the friction stir weld pin.

workpiece would be estimated as the product of (1) the torque-multiplication ratio of the spindle belt and/or gear drive, (2) the force measured by a load cell mechanically coupled to the spindle motor, and (3) the moment of the load cell would be used as a feed-

back signal for controlling the torque (see figure).

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## Manufacturing High-Quality Carbon Nanotubes at Lower Cost

The cost is about 1/20 of that of other processes.

Goddard Space Flight Center, Greenbelt, Maryland

A modified electric-arc welding process has been developed for manufacturing high-quality batches of carbon nanotubes at relatively low cost. Unlike in some other processes for making carbon nanotubes, metal catalysts are not used and, consequently, it is not necessary to perform extensive cleaning and purification. Also, unlike some other processes, this process is carried out at

atmospheric pressure under a hood instead of in a closed, pressurized chamber; as a result, the present process can be implemented more easily.

Although the present welding-based process includes an electric arc, it differs from a prior electric-arc nanotube-production process. The welding equipment used in this process includes an AC/DC welding power

source with an integral helium-gas delivery system and circulating water for cooling an assembly that holds one of the welding electrodes (in this case, the anode).

The cathode is a hollow carbon (optionally, graphite) rod having an outside diameter of 2 in. ( $\approx 5.1$  cm) and an inside diameter of 5/8 in. ( $\approx 1.6$  cm). The cathode is partly immersed in a water