

System control for a printwheel typewriter

by R. D. Mayo

This paper presents the design goals and architecture of the IBM®WHEELWRITER typewriters. Some of the development efforts and resulting technical innovations, such as a unique print hammer design which minimizes sensitivities to current variations, are discussed. Included is a discussion of a variable-reluctance stepper motor driver that has selectable damping. A novel scheme for initializing the printwheel and escapement motors is given; this includes sensing the font weight. The electronic architecture of the typewriter and the design of a simplified algorithm to handle the many different keyboards that can be attached to the machine with a minimum amount of data storage are explained.

Introduction

The IBM®SELECTRIC System/2000 typewriters, the first IBM typewriters designed for automated manufacturing, represent a major advance in function and price/performance. This was achieved by emphasizing technical innovations, cost-competitive designs, and efficient manufacturing.

The WHEELWRITER typewriters, a significant part of the SELECTRIC System/2000, provide print/erase quality and have the capability of typing carbon copies and multipart forms. The WHEELWRITER 3 and WHEELWRITER 5 typewriter models have all the standard typewriter functions with some text

©Copyright 1985 by International Business Machines Corporation. Copying in printed form for private use is permitted without payment of royalty provided that (1) each reproduction is done without alteration and (2) the *Journal* reference and IBM copyright notice are included on the first page. The title and abstract, but no other portions, of this paper may be copied or distributed royalty free without further permission by computer-based and other information-service systems. Permission to *republish* any other portion of this paper must be obtained from the Editor.

management capability. This paper describes the general architecture of the WHEELWRITER typewriters, as well as some of the significant technical innovations involved.

Machine design goals/machine architecture

The design goals of the WHEELWRITER typewriters were low cost, reliability, and simplicity. This required careful examination of the various components to determine the best combination of price, performance, and reliability. A major consideration for each system was the assembly process, including the elimination of critical adjustments. As a result, a modular architecture utilizing five open-loop stepper motors and a solenoid was implemented. **Table 1** gives a description of the function of each motor.

The objectives of the electrical design closely followed the mechanical design. Commonality of the hardware and software was maintained. The electronic systems were partitioned into three functional areas: power supply, printer card, and function card. **Figure 1** shows a block diagram for this system. The power supply converts the line voltage to the regulated dc voltages required by the digital and analog electronics. The function card attaches to the keyboard and the operator message panel and performs all of the operator-perceived typewriter functions. It contains a microprocessor that monitors the keyboard and converts the operator's inputs into commands recognized by the printer card. As the operator types on the keyboard, the microprocessor on the function card detects the depressed keys and sends appropriate commands to the printer card. The printer card contains the motor drivers and a microprocessor to sequence all of the printer/mechanism functions. This microprocessor translates the incoming commands and activates the motor drivers to perform the requested function.

Connecting the function and printer cards is an asynchronous, serial bus using a simple but powerful token-

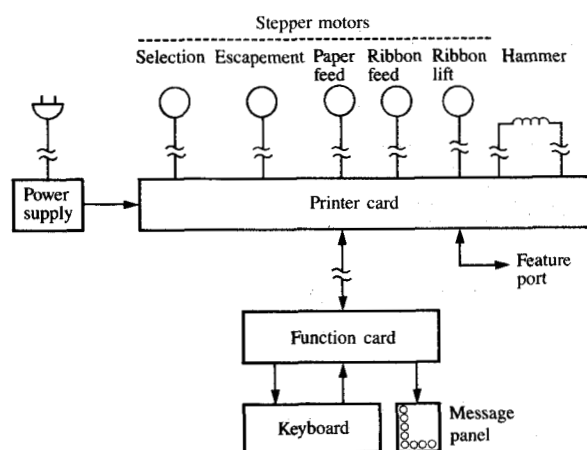


Figure 1

Electronics architecture for WHEELWRITER Typewriters.

passing protocol. This allows the function card to request services of the printer and the printer card to acknowledge receipt of the requests and status of pending requests. Additionally, this serial architecture provides for the attachment of external options via an option connector located at the back of the typewriter.

During the design of the WHEELWRITER typewriters, a number of significant developments were made. The development efforts discussed in this paper are:

1. Stepper motor damping driver;
2. Print hammer;
3. Printer initialization;
4. Printer control;
5. Serial communication;
6. Worldwide keyboard support; and
7. Shared stepper motor driver.

• *Stepper motor damping driver*

The purpose of a power driver is to control the current to an electromechanical device, namely a stepper motor or solenoid. Since the output torque of a stepper motor or the force of a solenoid is controlled by the amount of current in the windings rather than by the applied voltage, the power drivers are designed to keep the current at specified levels whenever a particular device is energized. This is accomplished by using pulse width modulation, wherein the voltage across the coil of the device is turned on and off in short pulses. The duration of the pulses is controlled to give an average voltage across the coil for the desired average current.

The damping driver is a unique current-controlling stepper motor driver developed for use in applications such

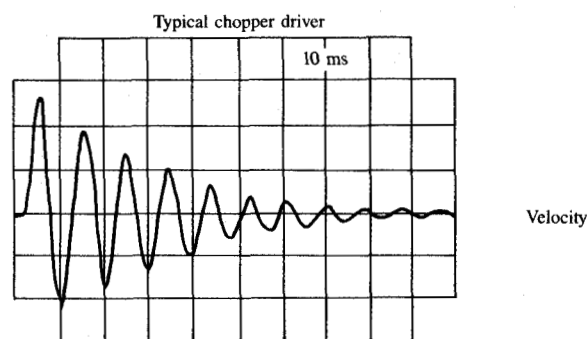


Figure 2

Single-step response with a constant current driver.

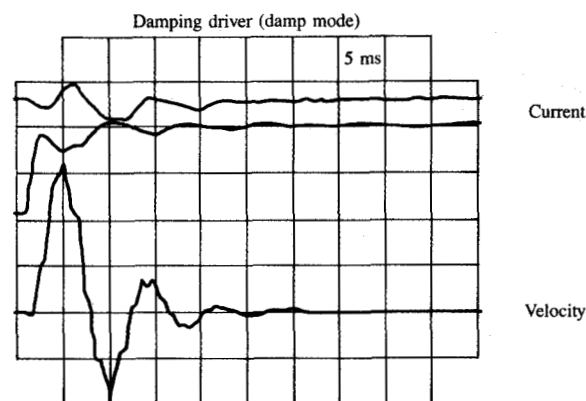


Figure 3

Single-step response with the damping driver.

Table 1 Motors and their function.

<i>Motor name</i>	<i>Function</i>
Selection	Turns the printwheel to position the desired character in front of the print hammer
Escapement	Moves the entire carrier in either direction in response to operator commands to position the printed character in the desired spot
Ribbon feed	Feeds the print ribbon to provide an unused portion of ribbon in front of the printwheel prior to printing
Ribbon lift	1. Raises ribbon to print position when printing and lowers for printline visibility when not printing 2. Raises correction tape in front of printwheel for correction and advances correction tape
Paper feed	Moves paper up and down to desired position in fine (0.53-mm) increments

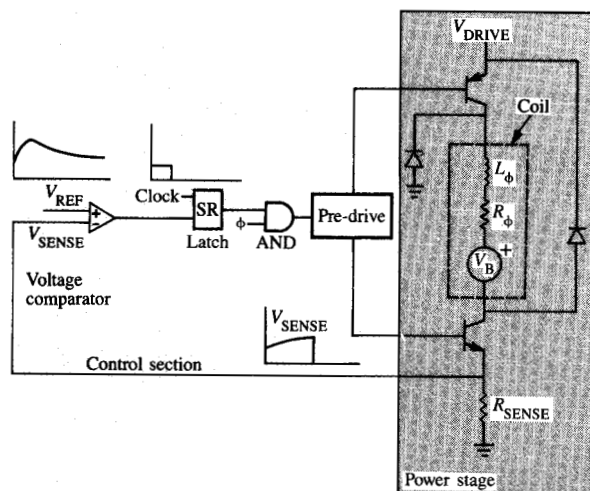


Figure 4

Damping driver for one phase of a stepper motor.

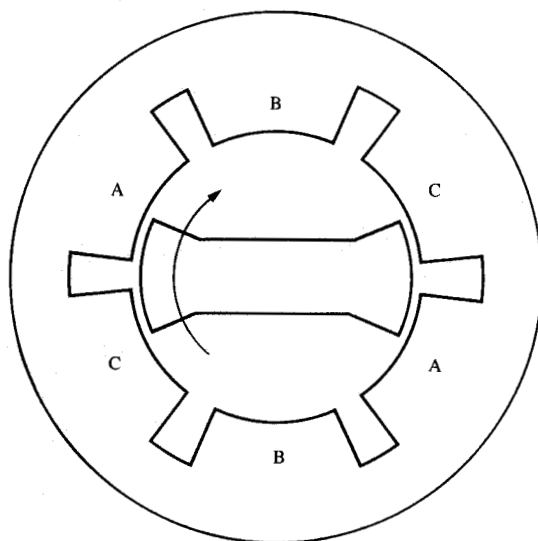


Figure 5

Simplified schematic drawing of a stepper motor.

as printwheel selection. In these applications (large inertia load and low friction) stepper motors frequently run erratically. Figures 2 and 3 show the response of a stepper motor to a single input step with a simple inertia load for two different drivers. Figure 2 is the system response with a constant current driver and with a lightly damped response.

In this system, even subtle variations in motor torque, supply voltage, or system friction can lead to unacceptably large oscillations. Figure 3 shows the response of the same system with a damping driver and shows the large increase in system damping as compared with the system oscillations in Fig. 2. This system is more tolerant of variations and is able to reduce quickly any oscillations that are induced.

The selection and escapement motors use the damping driver and are driven in an open-loop mode. In the selection system, the microprocessor sends a signal to the driver which increases the driver damping after the final motor step to quickly reduce any oscillations.

Figure 4 provides a simplified schematic drawing of the damping driver. The drive transistors are turned on and a voltage proportional to the current is produced across the sense resistor. This signal is compared to the reference voltage to determine when the phase is turned off. The reference is cyclic at a frequency of 20 kHz. Under microprocessor control, the reference signal can be switched to give either full torque and low damping or enhanced damping, as shown in Fig. 3. The reference signal is gated; only the downward-sloped portion of the reference is used for current control.

The damping is generated from the motion of the motor. As the motor runs and back-EMF voltages are generated, the duty cycle, or percentage of on-time, changes to maintain the required average voltage. For a specified back-EMF voltage, the change in duty cycle is nearly constant. For a given duty cycle and on-time, the value of current is set by the value of the reference at the end of the on-time. Since the reference is sloped, the changes in duty cycle due to the back-EMF voltages result in changes in current. By changing the slope of the reference waveform, the amount of current change for a given amount of back-EMF can be controlled. These changes in current produce the motor damping, and the microprocessor controls damping by controlling the reference.

In practice, a phase which is producing a positive accelerating torque generates a positive back-EMF and its current decreases. When a motor move ends with two phases energized but with a final velocity, the rotor oscillates about the final detent position. Figure 5 shows the rotor aligned in its detent position with phases A and C energized but with a clockwise velocity toward A and away from C. Since the rotor is aligning itself with phase A, it is being pulled toward phase A with a positive accelerating torque. Therefore, the current in phase A decreases because of the positive back-EMF and the torque decreases by a comparable amount. Conversely, phase C has a negative back-EMF and has an increase in its current and torque. The decrease in the torque of phase A and the increase in the torque of phase C are both incremental torques induced by the rotor velocity that oppose the rotor velocity. These incremental torques are the source of the electromechanical damping.

• *Print hammer*

A novel mechanical design for the hammer and solenoid system eliminates adjustments when the carrier is installed. To control the energy delivered to the hammer and ultimately the printed character, the working stroke of the solenoid is gauged during assembly and set to a predetermined value. **Figures 6 and 7** compare the standard hammer design approach with the WHEELWRITER typewriter approach. Figure 6 illustrates a force-versus-displacement curve for a typical solenoid energized for a set period of time while moving from point a to point b at some nominal current. In this system, an increase in current causes the missile to move from point a to point c while energized. In contrast, Fig. 7 shows a typical curve for the WHEELWRITER typewriter design. Since the solenoid is always energized over the entire working stroke, a change in current produces less than half the change in energy delivered.

To ensure that the same amount of energy is delivered by each solenoid, the hammer driver design is critical in its ability to control current. The hammer driver, similar in principle to one phase of the damping driver, has one difference. Instead of both transistors being turned on and off simultaneously to achieve current control, only the top transistor is chopped. The sense signal in this instance always represents the current in the hammer coil; this signal is averaged and compared to a reference signal. Hence, average current can be controlled instead of the peak current, as in the damping driver. This gives precise current regulation and accurate control of the various print energies. A total of seven different current levels are used to provide an array of hammer impact energies and force levels. These levels compensate for the varying print areas of different typestyles and different characters within a typestyle.

• *Printer initialization*

When the machine is initially turned on, a procedure is required for microprocessor initialization to ensure that each of the motors is in a defined state. This is accomplished by running the ribbon lift, ribbon feed, and paper feed motors through a preset sequence of motor steps.

A more involved procedure is necessary to initialize the selection and escapement motors. Traditionally, an optical sensor homes the selection printwheel and a microswitch initializes a position counter for the escapement motor. WHEELWRITER typewriters, however, use only one optical sensor to perform both tasks, as well as to read encoded pitch and font weight information from the printwheel. This novel approach makes available a wide variety of font weights without operator intervention.

An infrared (IR) LED and optical sensor are mounted in the carrier with the printwheel blocking the optical path between the two. As the printwheel rotates, holes in the printwheel hub open the optical path. These holes are sensed for printwheel homing, pitch, and font weight information.

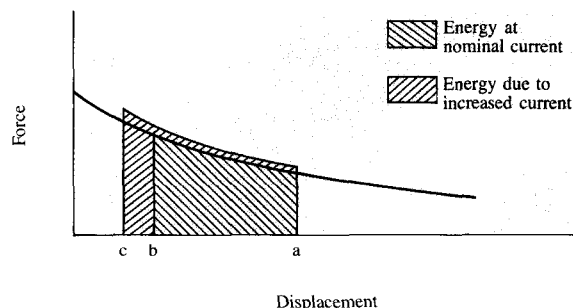


Figure 6

Standard hammer: solenoid force versus displacement.

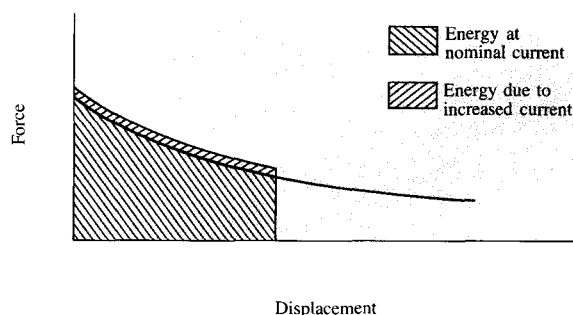


Figure 7

WHEELWRITER Typewriter hammer: solenoid force versus displacement.

A spring-loaded plunger extends from the left side of the carrier. When the carrier is moved to the left side-frame of the machine, the plunger is pushed into the optical path of the sensor. This indicates to the system that the carrier is at the leftmost position.

Before a single character can be printed or erased, an initial start-up or power-on reset (POR) of the machine must be performed. During this start-up procedure, checks are made for internal shorts or shorts to ground in the stepper motors or hammer solenoid, improper driver operation, nonfunctional homing sensor, or illegal keyboard identifier. If any of these are found, the typewriter will not function and the problem is delineated for the operator through the LED message panel.

The POR procedure for the printer is controlled by the microprocessor on the printer board. It has only one input line for detection of overcurrent for all of the stepper motors and the hammer solenoid. To isolate motor problems, the motors are turned on sequentially, and any fault signal is assumed to have been caused by the last motor energized.

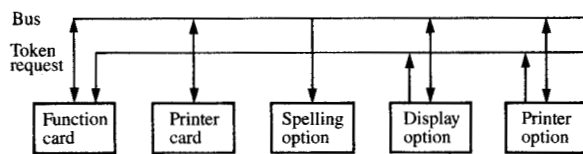


Figure 8

Serial communications.

Table 2 Interrupt structure.

<i>Interrupt</i>	<i>Function</i>
Timer 0	Selection, hammer, paper feed
Timer 1	Escapement
Periodic timer	Ribbon feed, ribbon lift
External intr 1	
Serial bus	Serial communications
External intr 0	Fault interrupt for motor overcurrents

• *Printer control*

The electrical design consists of three functional units (see Fig. 1). The printer card controls five open-loop stepper motors and a linear solenoid. Traditionally, multiple microprocessors have been used to solve this kind of control problem. To reduce board size, parts cost, and power supply requirements, a single microprocessor, the Intel 8051, was used for this task. By using the two on-chip timers and an external clock generating a periodic interrupt, all printer functions have been incorporated into the on-chip 4K bytes of read-only memory (ROM).

The printer software is a totally interrupt/demand-driven system. Commands are sent to the printer from the function card via the serial bus. The bus activity interrupts the printer processor, which reads and decodes the commands. For each command, the printer constructs an interrupt control block (ICB) defining each motor action. Interrupt service routines use the ICB information to execute the requested motor actions. Table 2 gives a description of the interrupt system.

• *Serial communications*

Interconnecting the function card, printer card, and external features presented a challenge. Parallel buses increased bus bandwidth, but at the expense of interconnect costs and flexibility. Since the Intel 8051 microprocessor contained a universal asynchronous receiver transmitter (UART), a serial bus was selected.

Several bus topologies and protocols were evaluated. A half-duplex multidrop line with a token-passing protocol was chosen. This satisfied the functional requirements of the

product, was flexible, and though inexpensive to implement, left room for future growth. A simple two-wire interface contains the bus and token request signals to interconnect the cards and features; see Figure 8.

The token-passing protocol arbitrates communication on the bus. Only the processor having the token can initiate a bus transaction. When the machine is powered on, the function processor owns the token. Other processors request the function processor to pass the token by asserting the token request signal. When other processors are finished with the token, it is returned to the function processor.

• *Keyboard support*

IBM typewriters are required to support many keyboard layouts and character sets. Earlier typewriter products fulfilled this requirement by releasing a separate ROM for each country. Each ROM contained a unique keyboard translate table that translated key positions to printwheel positions or other internal code points.

A novel data compression algorithm was developed to allow all WHEELWRITER 5 keyboard tables to be stored in one ROM. This algorithm reduces the storage requirements from an uncompressed 4.6K bytes to a compressed 1.8K bytes, a 2.5:1 reduction.

With all keyboard tables stored in each product, the same electronics (except for power supply) can be used worldwide. The system requires a mechanism to identify the attached keyboard. This identification is accomplished by having a six-bit machine-readable code manufactured on each keyboard. The function processor reads this code at turn-on to uniquely identify the keyboard layout and character set to be supported.

An additional benefit of a complete set of keyboard tables in each typewriter is that a new function, a multilingual keyboard, can be provided to the operator. When the operator depresses the language key and enters a three-digit number identifying a keyboard, the function processor activates the requested keyboard configuration. Thus, the typewriter functions as if the requested keyboard were installed.

• *Shared motor driver*

Each stepper motor in the WHEELWRITER typewriter requires a multilevel constant current driver (a programmable constant current supply for stepper motor control). Of the five stepper motors, the paper feed, ribbon lift, and ribbon feed stepper motors have similar drive requirements; because of this similarity, it was possible to design a system so that a single constant current driver would satisfy their drive requirements. With this system the current control circuits and the drive transistors are shared, but each motor has electronic controls which allow it to operate independently. This significantly reduced the number of parts, circuit board size, and manufacturing cost.

Summary

The development of the WHEELWRITER typewriters required a number of innovations to achieve the final product. A totally new type of stepper motor driver was developed which had variable damping with the capability of being controlled by a microprocessor. A method of controlling five stepper motors and a hammer solenoid from a single microprocessor evolved during the project.

Acknowledgment

The author gratefully acknowledges the assistance of K. L. Bobart, T. H. Richards, and J. C. Castle in the preparation of this manuscript.

Received October 8, 1984; revised May 20, 1985

Randy D. Mayo IBM Information Products Division, 740 New Circle Road, Lexington, Kentucky 40511. Mr. Mayo is a staff engineer currently supporting stepper motor system design on a variety of products. He has held several positions in the development organization, working on new product design and stepper motor system design, most recently providing production engineering support for the WHEELWRITER typewriter carrier. He joined IBM in 1977 after receiving his B.S. in mechanical engineering from the University of Texas at Arlington in 1974 and his M.S. in mechanical engineering from Oklahoma State University, Stillwater, in 1976. Mr. Mayo is a member of the American Society of Mechanical Engineers.