counter and a code generated by electronic equipment driven by the printer. When the two codes compare, the hammer is energized. The important thing is to get the print hammer thyratron fired at the right time. As long as the sum total of all the operations you do beforehand achieves that, you get the right character.

Lt. R. S. Weinberg (Air Materiel Command, United States Air Force): Can you relate something of the service experience of the printer so far?

Mr. Rosen: Not extensively because of security problems. I can tell you this. In our experimental work the print hammer mechanism was tested to a life of 200,000,000 operations without showing any detectable wear.

The earlier units have been in use over a period of about two years, but I cannot tell you how much of that time they were actually used. We have made one batch of replacement parts. The implication is that there hasn't been much replacement.

A Survey of Analogue-to-Digital Converters

HARRY E. BURKE, JR.

A GOOD many years ago Aesop told a story about a grain miser whose horde was raided by ants that silently crept through cracks into his warehouse to extract his store, kernel by kernel. It is easy to picture the frustration of this wretched man, opening his granary doors one day to find his treasure gone. Today, engineers and scientists are frustrated by a reverse situation—they want to empty their storehouses of raw information, but succeed in doing it only “kernel by kernel,” or point by point. Raw data continue to pile up at such a rate that research laboratories and test facilities are overflowing with unreduced information. Manometer tube photographs, theodolite records, frequency-modulated carriers on magnetic tape, galvanometer deflections from recording oscillographs, strip-charted pen gyrations, and so forth, are gathering dust despite a frantic effort to reduce them to useful engineering conclusions.

There is now available a technique to help break this bottleneck, and to accelerate the tedious data reduction process to a point where it at least approaches the speed at which raw data can be generated by modern instrumentation. This technique is that of analogue-to-digital conversion, and it has already reached a point far beyond mere engineering curiosity. A wide variety of instruments has already been designed and used to prove the value of this approach.

The term ‘analogue’ is used here to describe a dependent parameter that varies by some ratio in the same manner as does some independent parameter.

For instance, the voltage generated by a thermocouple is analogous to the temperature differential experienced by the couple, and is hence an analogue voltage. In the same manner, the deflection of a galvanometer, the shift of a carrier frequency, or the rotation of a shaft can be continuously proportional to some other varying physical quantity, to become analogue functions. Figure 1(D) is a curve describing some such function, and is essentially an analogue plot. Analogue functions are characterized by being continuous in nature, with an infinite number of values.

The term ‘digit’ implies discontinuity, that is, the presence or absence of some finite symbolism describing the phenomena. Figure 1 illustrates a typical function by means of an analogue plot and by certain digital presentations. Figure 1(A) describes the function of Figure 1(D) by means of familiar Arabic symbols, while Figures 1(B) and 1(C) are typical binary records of the same information. Roman numerals or Egyptian pictures could have been shown with equal significance. The term ‘binary’ (or 2-state) here means the presence or absence of one type of symbol in a geometric location coded to some special significance. For instance, a hole may be punched in a card. This hole is a binary mark, in that either there is a hole or there is not a hole. This hole can then be made to take on a decimal-digital form by its location on the card. If datum points are to be assimilated by the human brain with the minimum of effort the presentation should be in a tabular Arabic form, as this best matches the brain’s previous training. On the other hand, machines do not have the versatility of the brain, and they can best work on a binary signal. Machine assimilation of data is therefore usually carried out through some binary-coded data-handling system.

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Figure 1. Typical digital presentations
The analogue-to-digital converter is a device interposed somewhere between the analogue input information and the tabular, or binary-stored, output information. Digits result in uniform, rapid, and accurate data processing. In the past, equipment data have often been considered to be accurate only to ±1 per cent of the full-scale capabilities of the data-handling system. A good part of this feeling has arisen from the knowledge that an analogue system tends to shed some accuracy each time the data is processed, or each time it passes from one instrument in the system to another. One-per-cent system accuracy is then about all that can be economically attained in an extensive analogue system. Digital information, however, can be processed and reprocessed with no loss in accuracy, and systems capable of handling data accurate to ±0.1 per cent of full scale can be economically assembled.

The accuracy of a digital system is almost entirely a function of the accuracy of the creation of the original digits, and once the digits are available, the problem of processing is a relatively minor one. Digital information is being transmitted now over radio links, through computers, into recording devices, and the like, with excellent reliability. The key to such a system is, then, the analogue-to-digital converter.

Characteristics

A survey of analogue-to-digital converters shows that many exceedingly ingenious ideas have led to the development of useful instruments. A casual examination of these instruments might lead to the impression that they share few features in common, but there are certain characteristics that apply to all of the converters discussed here.

The measurement of an unknown quantity generally establishes its relationship to some known standard reference quantity. The process of analogue-to-digital conversion is essentially a measurement, so somewhere in every converter there must be a standard. Of necessity, this standard will have the same physical characteristics as has the quantity to be digitized. Precision components such as resistors or condensers, precise units of distance or rotation, and standard voltages are all used as references where appropriate. Some functions are more readily standardized than others, so they are probably easier to digitize. No converter will perform with more accuracy or stability than is demonstrated by its standard.

The output signal of all of these converters falls into one of three categories. The first of these is that of mechanical coded-contact closures. This is exemplified by the type of signals produced by relays or commutators. The advantage of such a signal form lies in its universality, as there is generally no problem of synchronization, impedance matching, or signal level matching between the converter and the device accepting the digits. For higher speed applications, one disadvantage is that it takes more time to operate a mechanism than it does to energize a purely electronic device. The second category is that of coded busses. Here a vacuum tube can control the presence or absence of a signal on a bus wire. This sort of system has speed advantages, but requires careful matching of the output signal into the receiving instrument. The third category is that of a pulse code, such as is used by telegraphers to transmit information of all kinds. Here, simplicity of transmission equipment is important but the transmitted signals must be stored somehow before they can be decoded. The first two coding techniques might be considered to be space codes, while the third is a time code.

All of the converters described on these pages operate from some form of binary signal, that is, a contact is closed, or it is not; a bus line is energized, or it is not; a specific period of time is occupied by some event, or it is not. The presence or absence of a particular binary condition in space, time, or space and time is then...
arranged to have the intended significance. If Arabic decimal information is desired, it can be accomplished by binary coding 10 bus wires in such a way that only one of 10 is ever designated at one time. These bus wires are then used in some manner to energize the proper阿拉伯 symbol. This action is typified by where the binary pressure (there is either pressure or there is not) on a key produces a plus or minus direction. This is a space-time event that must correctly toggle if correct read-out information is to be available. In a decimal system, carry-toggle action of this kind is accomplished by an interchange of information between the decimal digits.

A description of an analogue data-processing device usually includes some discussion as to its frequency response characteristics. This method of comparing similar devices is so useful that attempts are often made to couple the terms 'frequency response' and 'digit' together. In defining the frequency response of such a system, the number of samples required per cycle to describe the input signal must first be determined. It has been shown that only two samples per cycle, at the highest frequency of interest, are actually needed, but there is a general feeling that more than this is usually desirable. It is suggested that the term 'samples-per-second' be used in reference to devices of this type, instead of applying a cyclic caption to a sampling process. Some analogue-to-digital converters are constructed so that they can actually follow an input signal through its various changes with time, if the changes are not too rapid. Under these conditions, it is possible to sample the signal each time it changes by one digit, or to sample in equal time intervals which are short enough to give the information desired. Another type of converter searches the entire range of possible values for the correct answer, and requires the same period of time for any sample of the analogue signal, regardless of its value. If comparisons are made between converters as to their maximum sample rates, it should be noted whether this is a rate based on the digit-to-digit speed or on the zero-to-full-scale speed.

The term 'digit' is inextricably coupled with the term 'toggle.' It has already been pointed out that a digital system is a discontinuous one, and it is usual that some kind of toggle action provides the required discontinuity, or the rapid change from one state to another. Relays, vacuum tubes, detents, and so forth, can be used to furnish this required toggle action. If the analogue input signal changes in value over one full unit, the digital output signal should flip, or toggle, from one digit to the next at some point during this change. This toggle action is one of the factors that prevent ambiguity in the number read from the converter, as only one number should be readable at any one instant. Toggle action is required for each digit-to-digit step but in a decimal-digital system it is also required at a carry point, such as experiences in changing from a count of 99 to 100 or from 30 to 29. Here the toggle action becomes more complicated, as several digits

Figure 4. Commutator and brush techniques

Figure 5. Forced nonambiguous techniques—star wheel

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Accuracy, stability, linearity, and resolution are all subjects that apply to the process of analogue-to-digital conversion in much the same way that they apply to an analogue process. For this reason it is not felt that they need be discussed in detail here, except in connection with two special cases. Assuming that a converter has been constructed so that the input and output signals are reasonably compatible, the stability and resolution of the conversion process will be about one-half of one digital step. This ambiguous half step, combined with the toggle action which occurs between steps, usually means that the output reading of an analogue-to-digital converter is accurate to no better than ±1 digit in the number of digits read out. For maximum accuracy, it is then desirable to digitize the analogue input signals as near to the system full scale as is possible. If noise is present in the analogue input signal, the problem of conversion may be extremely difficult. Some converters are completely useless in the presence of cyclic noise because of their inability to stabilize on any single reading. Others will read out the sum of the signal and the instantaneous noise, while still others will read the peak or the average noise plus the signal. In any case, for maximum accuracy, frequency components in the analogue input signal that exceed the maximum frequency that can be digitized must be damped to the point where they do not interfere with the digital conversion.

Examples

At present, development effort in the field of analogue-to-digital conversion is quite intense and very fluid. It is probable that over 100 different devices have been demonstrated in breadboard form in the last 3 years, although very few of these have reached the stage where they can be purchased commercially. This survey covers about 50 of these devices in particular, and it is believed that the ideas expressed here would also describe the majority of those not included. Seventeen techniques have been chosen as illustrations. Although these are grouped together as nine different figures, for convenience as much as anything else, it is not felt that this is necessarily the best classification. Perhaps devices competing for the same application would have made a more interesting grouping, but the problems of explanation would have been much more complex. The reason for this is that many specific analogue-to-digital converters are, or could be, combined with an analogue-to-analogue converter in such a way that all techniques could be essentially competitive.

Two direct-counting techniques are shown in Figure 2. For this application, the converters are arranged to generate some kind of repetitive event which can be counted. The revolution angle of a shaft can be broken into finite segments by slotting a disk attached to the shaft. With reasonable machining care, one revolution can be digitized to an accuracy of plus or minus one count in several thousand counts. The slots can be sensed magnetically or photoelectrically, and counted in an electronic counter. Special arrangements of the sensing device can be used to detect the phase of the count, and the counter can be made to count up or down, depending on the direction of the rotation. The instantaneous count in the counter is then the digital measurement of the shaft position in relation to its position at a zero count. In much the same way, the relative motion of the two conductor grids generates nulls and peaks in the detector circuit which can be counted. This technique tends to average the dimensional location errors and may be potentially the more accurate of the two. The output signal from both of these converters is a time code.

Figure 3 describes two incremental-step techniques. The step-matrix voltage indicator is essentially the electrical equivalent of the multicontact displacement indicator. In this device a crystal is biased at each of the desired voltage increments. When the input voltage is equal to one of the bias voltages, the current through that circuit will suddenly...
change, and can be used to actuate an indicator. It is probable that this technique can have the highest possible speed of response, as the speed limitation is primarily a function of circuit capacitance. Each of these converters produces a space code.

Figure 4 demonstrates some of the things that can be done with a commutator and a brush. The phased-binary presentation of Figure 1(B) is produced by bussing every third commutator bar to actuate three indicators in a space-time code. It is not even necessary that the brush span the distance between two bars, as the absence of a signal can carry significance in this case. An ambiguous space code can be prevented if the commutator bars are spaced very close together and the brush is equal to one half the width of one bar. In this case a relay matrix can unscramble the code into decimal significance, as is shown. One other commutator-brush converter has an exceedingly clever method of actually toggling the brush itself so that it jumps from bar to bar, and never stops on or between two bars.

The principle illustrated by Figure 5 is a relatively simple one, but it requires a rather complex drawing, so only one example is shown. In this case the analogue input information is in the form of a shaft angle. A star-wheel-and-commutator combination is elastically coupled to the shaft, so that its position duplicates the shaft angle until read-out is desired. Just before read-out, a solenoid-operated plunger forces the star wheel to align the brush directly onto the nearest commutator bar, which then provides the desired digital signal.

If the oscillations of a frequency-modulated signal are counted for a fixed period of time, the count can be made to describe the modulating function. Figure 6 shows two well-known methods for changing the frequency of an oscillating system. The vibrations of a wire under tension can be sustained at the natural frequency, or some harmonic, by magnetic-electronic means, and the frequency can be varied by changing the tension. In much the same way, changes of resistance, capacitance, inductance, or voltage can be made to change an electronic oscillator’s frequency. These methods are generally nonlinear, and require some technique of zero suppression, but can be made to give useful results.

Figure 7 describes the converse of Figure 6. Here chronometric pulses are generated, and gated into a counter by one event, and the counter is stopped by another event. The resulting count in the counter is a measurement of the elapsed time between the two events. A linear saw-tooth voltage, coinciding with a zero signal and an input voltage, can be made to digitize the input voltage. In much the same way the phase relationship between two alternating signals can be measured. This is a very old approach and has been used in ballistic studies and in timing races.

Figure 8 shows two ways in which a raster can be used to provide the digital signals. Example A makes use of holes in a disk to control the passage of light from a source to a group of photoelectric cells. The holes and photoelectric cells are then mutually coded to give a space binary code. This device would not actually work very well as shown, because the particular code used has a tendency to become ambiguous if there is any instability in the system. Other codes have been used that will accurately divide one shaft revolution into several thousand parts. The same raster is capable of producing a time code if the so-called flying spot is used to develop a time axis. Example B makes use of the beam in a cathode-ray tube driven by a saw-tooth voltage on the horizontal axis. The vertical voltage is then digitized by the interruptions of the beam caused by that part of the raster over which the flying spot passes. A galvanometer driven with a saw-tooth current and a single photoelectric cell could accomplish the same effect with the coded disk of example A.

Two methods using continuously rotating drums are pictured in Figure 9. In
both of these examples there are two information areas on the drum that are mutually synchronized by their physical locations. Example A requires a hollow drum whose cylindrical surface is perforated by two types of symbols. Inside the drum, in back of some small slits, is a photoelectric cell, while in back of the appropriate Arabic numbers is a flash tube. The photoelectric cell and flash tube do not rotate with the drum. If light ever impinges on the photoelectric cell the flash tube will be energized and the number that is currently passing in front of the flash tube will be illuminated. The slits are then arranged around the circumference of the drum in such a way as to synchronize with the proper symbol, and along the axis of the drum to break up a linear distance into incremental steps. If the spot of light from a galvanometer's mirror is then reflected onto the area of the drum which includes the slits, it will fall on only one of the slits per drum revolution and only one number will be illuminated, indicating the galvanometer's deflection. Example B makes use of a magnetic drum on the periphery of which are recorded two pulse tracks. The first of these has a multiplicity of pulses which break up the circumference of the drum into the desired number of digits. The second pulse track has only one pulse recorded on it. There is a fixed head reading each of the two tracks and a movable head reading the single pulse track. An electronic counter can then be used to count the number of pulses on the drum between the fixed head and the movable head in such a way that the angular distance between the two heads is indicated.

Figure 10. Null detector techniques

Figure 11. Analogue-to-digital conversion
of the operator. For example, in the collection of data from a wind tunnel, the operator initiates the data-handling cycle when he is satisfied that the model is adjusted properly, and that conditions in the tunnel are stabilized to the point where data of some significance can be taken. After the data have been collected, the conditions in the tunnel are changed and the cycle is repeated. This particular system is chosen as an example because it contains all of the essential features of a 'complete' system.

The system illustrated consists of four channels of analogue-to-digital conversion equipment, a remote control unit, a plotting unit, a tabulating unit, a storage unit, and a program unit. After this system is set up, adjusted, and calibrated, an operator at the remote control point can examine the input channels, decide on their reasonableness, freeze these data, and initiate the readout cycle. The data collected by the system are then automatically tabulated, plotted, and punched into the cards.

For the sake of this illustration, it might be assumed that this system is operating from the output signals of four strain gauge bridges attached to a model in a wind tunnel. The analogue voltages generated by the strain gauges are amplified and converted to their equivalent digits by the action of individual digital self-balancing potentiometers. The coded-contact closure signals from these potentiometers indicate the balance points accurate to three decimal places, the polarity of the balance points, the attenuator settings, and whether or not there is an actual balanced condition in each channel. The calibration of this system will include simple analogue computations in the input amplifiers, which change the significance of the digits to some desired linear function. Zero suppression (addition or subtraction) and scale factor adjustment (multiplication or division) controls are available on the front panel of each amplifier.

The remove control unit includes 15 rotary switches that allow the introduction of arbitrary fixed constants into the tabulator and card format. These constants can be used to indicate dates, model configuration, test numbers, and other information that does not change as a result of the test. The program unit controls the flow of information from the converters and the fixed-constants on the control board into the tabulator and the card punch, and from the digital-to-analogue converter to the X-Y plotter. A plug board is provided to allow flexibility in the program and information format. A run number, generated each time the program completes a cycle, is recorded along with the other digits. A possible format might be as shown in Table I. The same information would be punched into the cards, with one card for each tabulated row. These cards can then be used to control a computer for complete data reduction.

The digital-to-analogue converter can receive two 3-digit numbers, and pass equivalent analogue signals to the plotter unit for control of the X and Y plotting axes. These digits can be programmed automatically, introduced by hand at the remote control point, or read from the punched cards, as circumstances dictate.

If the operator has control of only the start of the test and must take data at fixed intervals of time thereafter, the required system might be called a dynamic data-processing system. An application example would be that required for processing data during a rocket's flight. Here, high-speed conversion and control equipment are required, with perhaps a recording oscillograph replacing the electromechanical plotter and a magnetic-tape recorder replacing the card-punch unit. Tabulation and computation could be done at the end of the test by playing back the magnetic tape at a reduced speed. Dynamic data-processing systems usually generate a great deal of unwanted data to assure the collection of the desired data, so some method must be available for separating out the useful information at the end of the test; otherwise, the system philosophy is not much different from that of the quasi-static example.

It has been shown that an analogue-to-digital converter can be a very important part of an automatic data reduction system. Of course, such instruments are not the complete answer to all of the data reduction problems, as they furnish but one step in the process. Plotters, tabulators, storage devices, matching equipment, and computers must all be considered as a part of such a system, and the characteristics of the analogue-to-digital converter must be compatible with their characteristics as well as those of the analogue signal. At present, an analogue-to-digital converter is considered something of a novelty, but in the future its use will become commonplace. Applications that are imminent, if not current, include wind tunnels, engine test stands, telemetry, static structural tests, industrial process control, computer inputs, and so forth.

Appendix I. Information Sources

Company Brochures
Arthur D. Little, Inc.
Atomic Instruments Company
Beckman Instruments, Inc.
Benson-Lehner Corporation
Berkeley Scientific Company
Clary Multiplier Corporation
Consolidated Engineering Corporation
Electronic Engineering Company of California
Engineering Research Associates, Inc.
Institute of Inventive Research
Melpar, Inc.
Metrotech Corporation
Potter Instrument Company
Streeter-Amey Company
Taller and Cooper, Inc.
Telecomputing Corporation
Westinghouse Electric Corporation
Wright Engineering

Sources of Projects Not Yet Published
Benson-Lehner Corporation
Consolidated Engineering Corporation
Cornel Wind Tunnel Instrumentation Group
Electro Circuits Company
Massachusetts Institute of Technology, by Sisson and Susskind
National Advisory Committee of Aeronautics, Lewis Laboratory
National Bureau of Standards Survey, by G. G. Bower
Naval Research Laboratory, by A. M. Rothrock
Office of Naval Research Survey, by N. M. Blackman
Tally Register Company
Telecomputing Corporation
Wallind-Pierce Corporation
Wright Field Wind Tunnel Instrumentation Group

References

Burke, Jr.—Survey of Analogue-to-Digital Computers
Discussion

H. F. May (Teleregister Corporation): What speed can be achieved with 0.1 per cent accuracy in converting a voltage to digital value?

Mr. Burke: This is dependent on the signal. Voltage in itself can extend all the way from a very low to a very high level. I would say that it is possible to digitize something from 100 volts to 0.1 per cent accuracy. This is based on the Miller sweep, which is capable of sweeping over this range to an accuracy of 0.1 per cent or better.

In the case of a millivolt, I would say that less than 100 volts, two or three times a second is quite easy. For something in the order of a millivolt, once a second is possible. The reason for this lies with the problem of amplification and identification. At these low levels the only thing I know of that will do it is the mechanical chopper. There are only two choppers that I know of that will do the job; one is capable of 400 or 500 motions a second, achieving several times a second; the other, 60 times a second. The chopper determines the carrier frequency, and the carrier frequency determines the speed response of the system. Generally, the speed response is considered to be approximately 10 per cent of the carrier, but this is a holdover from 1-per-cent systems.

When talking of 0.1 per cent, it is not possible to approach that high percentage of the carrier; for example, a 60-cycle carrier gives a 1-cycle response.

J. S. Fondrik (General Electric Company): I am very much confused by your first slide. You have a nonuniform sampling rate. It looked to me as if you were not converting from analogue to digital, but really from analogue to some other analogue.

Mr. Burke: There are several conversion techniques possible. One technique is to convert digitally so many times a second. The other is to convert digitally at such-and-such an increment of the analogue signal. The slide purposely showed the latter, because most people think in terms of the former. This was a conversion that changed at increments of signal level, not in timing.

Mr. Francis A. Collins (Atlantic Refining Company): Has any work been done on converters for old or dead data which are available only as a graph?

Mr. Burke: Yes, there has been a lot of work. One technique which has been used for a long time has an operator adjust a set of cross-hairs on a projection of the graph and then convert the cross-hair position. In two cases I know of, this system has been used. It is almost like the flying-spot technique, where the position of the flying spot coincides with the zero position of the other circuit; the zero position of the flying spot can open a gate and the coincidence uses the signal on the graph to close the gate, becoming a conversion like the photographic technique known by that label.

Capt. R. W. White (Air Development Center, Wright-Patterson Air Force Base, Dayton): Would you care to comment on which of the many techniques you described best lends itself to a high accuracy, that is, a large number of digits for any given range?

Mr. Burke: I would rather not comment. Part of this reading again depends on what is being digitized. For instance, in my opinion, shaft position is the easiest thing to digitize because the reference is some scribe mark on the shaft bearing which can be quite precise. I have heard terms handled about all the way from 1,000 counts to 1,000,000 counts. I have never seen anything over 3,000. I am not in this area, so I don't know the whole story.

W. D. Daych (General Electric Company): It is apparent that in applying the techniques of analogue-to-digital conversion to any type of engineering or scientific test, the equipment chosen must satisfy the type of testing that is being carried on, since digitizing analogue data represents a sampling of the analogue information. The sampling periods in samples per cycle or in samples per second must be well chosen in order to represent as true as possible a picture of the analogue information.

In any type of test work, each test will have its own time rate for such things as stabilization and transient conditions. These considerations will be important in proportion to the type of test which is being performed. Consequently, the selection of equipment must be guided by the test performed as to the necessary speed of the equipment, the accuracy required, and as to whether or not digitizing the information is warranted.

In many cases, analogue presentation of the data in the form of graphs, and so forth, represents the desired end point in a test. In other cases numerical results are called for, and we should look into these cases in particular for the application of analogue-to-digital conversion techniques.

As Mr. Burke has pointed out, it is possible either to parallel (space) code or serial (time) code a digital word. It should be noted that for high-speed work, space coding is definitely required because time coding will reduce the available amount of time for each digitizing operation, and hence result in less possible samples per cycle than could the space-coded method.

In the seminar discussions, it was noted that for large-scale fixed slow-speed tests such as running wind tunnels and in engine development, relatively low speed digitizing equipment could be applied, and this equipment might be of a fairly large and heavy nature. In other words, chair-borne equipment. However, for flight testing, it is obvious that much lighter and smaller equipment would be necessary. It was generally agreed in the seminar that at present, analogue techniques are far superior to present-day digitizing techniques for the telemetering of parameters such as temperature and pressure. Therefore it would seem that the most promising solution for high-speed data from flight testing would be to telemeter analogue data and to make the conversion of the data after they are once recorded and correlated to reduce redundancy.

For that reason, equipment is required for the conversion of already recorded or dead data to the digital form. Equipment of this type, should it be developed, would find wide use in the missile test field and in flight test of manned and unmanned aircraft.

It should be remembered that for optimum utilization in any specific type of testing where data is to be digitized, the conversion system should be designed as a system, not as a series of unrelated black boxes or gadgets which, taken together, will work, but not as effectively as a properly designed co-ordinated over-all system.

Of the 33 people who attended the Thursday evening seminar on the subject of digitizing scientific and engineering data, some 10 were manufacturers, and it is hoped that these people will return to their laboratories and produce the desired and necessary equipment for the fulfillment of the requirements of those who are performing such tests.
Survey of Mechanical Printers

J. C. HOSKEN

B Y THE time computers become really sophisticated, they will communicate their findings to other machines in machine language and they will only produce the most concise progress reports in typewriter form. However, until this comes about, it is unfortunately necessary that computers shall have large outputs which their masters must read. By the time clerical machines are really well-developed they will produce bills in machine language which we shall put directly into our private check writers which will then prepare the checks and address the envelopes for us in machine language suitable for the automatic accounting machines and the automatic mail-sorting machines. But until that time we shall need high-speed printers to deal with the enormous output of clerical machines.

Many people have ideas about how high-speed printers might work but there are not many of these desirable devices available in the hardware stores. Because we all have more things to read than we can possibly cope with, I have been instructed to prepare a short and easily digestible summary of the high-speed mechanical printers now available or in embryo. The subject of this paper is mechanical printers in which, generally speaking, something solid hits a piece of paper to transfer ink to it. Lt. R. J. Rosheim is to deal with flying ink spots, magnetic powders, electrical and chemical discolorations, and photographic devices.

Requirements for High-Speed Printers

Consider first the form of the input, then the form and speed of the output required from a high-speed printer. Then look at the various classes of printer which have been developed. Table I illustrates the approach.

The kinds of input which most concern us are typescript, punched tape, punched cards, magnetic tapes, and drums, and pulse signals directly from computers. The output required may be tabular, address labels, forms of various sizes used for bills, orders, notices or reports; and any number of copies may be required.

The speed requirement varies widely. The output from a computer may be small and intermittent. This can obviously be dealt with by storing the information on a magnetic tape and feeding the tape slowly but continuously into a relatively slow printer. On the other hand, it may be necessary to tabulate for reference a large amount of information, as in census work, or in mathematical tables. Clerical machines may have an enormous output of bills, premium notices, orders or reports and the speed-limiting factor may be the movement of the paper or the speed at which the input can be sensed. A punched tape can be read at 200 characters a second, a magnetic tape at 10,000 or 12,000 characters a second. Punched cards can be read at 10 or 15 a second which means about 1,000 characters a second. Continuous paper feeds of 20 or 30 feet per second are used in newspaper printing, so continuous paper speed is not a serious limitation; but intermittent paper feeds are limited to the order of 15 or 20 lines or controlled movements a second. There are probably few cases where continuous output speed greater than 15 or 20 lines a second is warranted. For very large outputs it is always safer to have several relatively small units rather than one very large one which, if it fails, holds up production completely.

Printers Developed to Fulfill These Requirements

Five general kinds of mechanical output printer have been developed so far:

1. The single-action typewriter variety with solenoid or pneumatic control.
2. The line-at-a-time printer used for printing calculators and punched card tabulators.
3. The on-the-fly machines with continuously revolving type wheels and accurately timed hammers.
4. The matrix machines which form characters by selective operation of a matrix of dot-producing hammers.
5. The bar and helix machines which use the same principle as facsimile devices.

Single Action

These printers usually consist of typewriters controlled by solenoids or pneumatic bellows. Ten characters per second is the usual speed limit, though Underwood claims 20 characters per second for the typewriters used as the output for the Harvard Mark III computer. Several firms have fitted solenoids to standard typewriters and the Autotypist and Robotyper use a conventional ‘Pianola’ mechanism with a motor-driven crank.

For many years Teletype machines have been made using typewriter mechanisms operated from punched tape or line signals through mechanical decoders. The principal makers are Teletype Corporation and Kleinschmidt Laboratories. Teletype Corporation is now bringing out a new kind operating on a rather different principle but still single-acting and in the same speed range of 10 characters a second. In this, their model 28, a light, rectangular type box containing separate pallets for each character, is substituted for the regular type basket. The type box provides the shift function so that the normal typewriter carriage carrying the platen is not needed.

The Flexowriter is in the same speed range but its design provides greater flexibility for use outside the normal communications field. It consists of an extra rugged International Business Machines (IBM) electric (that is, electric motor-driven mechanical) typewriter with various optional units attached. These include a tape punch, a tape reader, a mechanical encoder, a mechanical decoder, and justifying equipment (with this attached it is called the Justowriter). The tape used can be 5-, 6-, 7-, or 8-hole, and the encoder and decoder can be easily changed to any code needed.

Line-at-a-time printers were developed for desk computers and punched card tabulators. Most use a type bar with a complete set of pallets opposite each character position in the line. In the usual mechanism the type bars are mechanically returned to the home position and then allowed to rise under spring tension as far as a set of individual stops actuated by the signal through a mechanical decoder. A set of hammers strikes the pallets against the paper which is held on a platen roll. For greater speed, type wheels are used instead of type bars. Type bars are used in IBM and Remington Rand tabulators and Engineering Research Association (ERA) printer. Type wheels are used in the IBM type 407 accounting machine and the Bull tabulator. These tabulators are designed around punched card input and include a number of mechanical devices necessary in punched card accounting systems. The decoding systems are tied in with the particular punched card codes used. Electrical or mechanical patchboards are used to enable information

Hosken—Survey of Mechanical Printers

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