The rapid development of business systems during the past few years has at the same time called attention to some rather serious limitations in mechanical and photographic methods for the production of printed copy. Modern electronic computing machines can process data and produce results in tremendous quantity. Moreover, the operation of large business organizations creates a problem in the dissemination of information within themselves that is not always economically solved by existing equipment.

There has accordingly been much interest in new methods of producing printed copy, both for the recording of original data created by computing processes and for multicopy reproduction of existing data for distribution. The technical literature (1) reveals that considerable development work has been done on equipment of this type in the last few years. Devices have been designed for rapidly recording the results produced by electronic computers. These devices have, for the most part, been improvements and extensions of well known mechanical principles. The inherent speed limitations of mechanisms have generally been overcome by utilizing a high degree of parallelism. For example, printing tabulators may employ upwards of one hundred independent printing units, each capable of printing the entire font of symbols it is desired to record (2). These parallel or "gang" printers have utilized relief type mounted on reciprocating bars or rotating wheels. Means are then provided to bring the paper and the type into engagement when the desired character is in position in each column. The large amount of equipment involved, not only in one hundred or more printing stations, but in the devices required for storing information and feeding it to them, results in a bulky and expensive piece of gear.

The subject of this paper is a printing process and equipment which is inherently fast enough so that serial printing methods can be used and still permit reasonable speeds to be attained. The process depends on the attraction of a magnetic ink to selectively magnetized areas on a printing plate. Setup of the printing plate is rapidly accomplished by magnetic recording techniques while development and transfer of the recorded image to paper is effected at printing press speeds. This process we have generically named "Ferrography," a title which has also been used by more independent investigators of the art (3).

The Ferrographic process, like the older printing methods, is fundamentally one having three steps: first, the recording of a magnetic printing plate by one of several methods; second, the inking of the plate to develop the latent magnetic image; and third, transfer of the developed image to paper or other receiving surface. The process is thus fundamentally similar not only to the Xerographic electrostatic process (4) but to all commonly used printing methods. The differences lie in the type of materials employed for the printing plates, the methods used for registering images on them and techniques for inking or developing the images. Processes generally transfer the image to paper by
pressure contact, but some require preprocessing or postprocessing of the paper.

The first step in the Ferrographic process is the recording of a latent magnetic image on a magnetizable drum or plate. A number of materials have been used successfully for Ferrographic plates. These include iron oxide dispersions, electrodeposited films of cobalt-nickel alloys and sheets of magnetic alloys such as Cunico and Cunife. It is important that the material chosen has as high an energy content as is consistent with the definition desired and practical recording head design. Strong magnetic images can be readily inked while weak ones produce "noisy" prints.

There are a number of ways in which magnets can be impressed on a magnetizable surface. Perhaps the most commonly used method of recording is called longitudinal, in which the magnets are oriented parallel to the motion of the recording head. This method is used on sound recorders and on most pulse recording equipment. For recording on Ferrographic plates, however, the magnet orientation produced by longitudinal recording is the least suitable. The magnets produced on the surface of the plate by a longitudinal head tend to produce only outlines of desired images. It will be recalled that the flux path or magnetic "ghost" of a bar magnet can be revealed by laying a piece of paper over the magnet and then sprinkling iron powder on it as shown in Figure 1. It will also be remembered that the flux pattern so developed consists of heavy agglomerations of powder at the poles of the magnet and progressively lighter powder deposits at more remote distances, even along the magnet itself.

The same phenomenon occurs on a developed Ferrographic plate. The magnetic ink is attracted only to magnetic poles on the plate and not to intermediate points as shown in Figure 2a, even though the material at these points is magnetized. This means that if a video signal is applied to a longitudinal magnetic head which is scanning a plate, then the ink will develop only the outline or flux changes of the recorded image. A true picture will be developed only if the head records a modulated carrier which will apply a series of poles to surfaces which must attract ink. The result of recording such a series of poles is shown in Figure 2b.

Two other recording methods exist which do not require such a carrier. These methods are commonly called perpendicular and transverse recording. In the first method, shown in Figure 3, magnets are recorded which are oriented normal to the surface of the plate. In the second, the magnets are in the plane of the plate but at right angles to the motion of the recording head.

The simplest type of perpendicular recording head, as shown in Figure 4a, consists only of a pencil shaped bar of soft magnetic material having a coil wound on it for the reception of video signals. If the point of such a recording element is brought in contact with, or slightly spaced away from, a Ferrographic plate, then the high flux concentration at the point as a result of current flowing in the coil, will mark the plate magnetically. The flux returns through the air to the far end of the bar. This is, of course, an inefficient magnetic structure and can be improved by providing an iron return path for the flux. The area of the return bar should be large compared to
that of the pencil point of the marking bar or the plate will also be marked at the flux return point. Such an arrangement is shown in Figure 4b.

Of course, a recording head which impresses purely perpendicular magnets, or for that matter longitudinal, or transverse, is a theoretical possibility only. The magnetic flux lines emanating from a point or developed across a gap always fringe out in broad curves which result in magnetic components in all three axes. Thus, for example, perpendicular heads produce some recording both transverse and longitudinal. The transverse component becomes larger if a return bar is brought down to the surface of the Ferrographic plate and becomes the primary component if the return bar is brought to a point and located close to the marking bar point.

Now the important criteria in recording on a Ferrographic plate is the creation of poles. It will be recalled that longitudinal recording of a video signal was unsuitable because of the small number of poles produced. The deficiency could only be corrected by modulating a carrier so that enough poles would be produced to effectively attract ink to dark areas. Perpendicular recording overcomes this objection by rendering such a surface a large pole as a result of the orientation of the magnets produced. Noticeable washout in the center of large areas will still be encountered, however, due not only to self demagnetization over the surface of a large pole but also to the lack of magnetic gradients on the surface.

It has been found that transverse recording has none of these shortcomings. The magnetic pattern produced in an area which is recorded to print dark will resemble a ploughed field where the head has scanned across it as shown in Figure 5. Strong flux lines fringe out from the plate to join the crests and valleys of each furrow. The magnetic gradients are sharp and the magnetic return paths in air are short to give strong external fields. Ink powder is attracted strongly to such a surface. No modulated carrier is required for the driving signal and thus the circuits required are simpler.

Several problems exist in the formulation of inks suitable for Ferrographic printing. In the first place, the ink must be strongly attracted to the magnetized areas of the plate. They must, therefore, have a high initial magnetic permeability. The attraction and adherence of the ink depends on its providing a better or lower energy flux path than air. Almost any magnetic powder satisfies this criteria but soft magnetic materials are superior to hard ones from the point of view of permeability.

The ink may be either a liquid or a powder. Successful printing has been done with each type. Liquid inks usually consist of unstable colloidal dispersions of iron powder or iron oxide powder in a low viscosity fluid. Such an ink is a dispersion of Fe₃O₄ in alcohol or carbon tetrachloride. A Ferrographic plate immersed in such an ink draws the magnetic material from solution to adhere to the magnetized portions of the plate. Similar liquid inks can be made with soft iron powder of Fe₂O₃. In each case the vehicle should be colorless and have a very low viscosity. High viscosity vehicles do not permit sufficient mobility of the magnetic particles and, of course, colored vehicles stain the plate.

The image so developed can be transferred at once while still wet or can be
dried before transfer. In the latter case, of course, the vehicle should be highly volatile. When wet transfer is made, smearing of the image and loss of definition result unless an offset technique is used.

Dry inks can be made from mixtures of magnetic powders with pigments, dyes and fixing resins. These inks can be applied to a spinning Ferrographic cylinder to develop an image. One feature which distinguishes Ferrography from other printing processes is that, although inks are attracted to selected areas, there is no magnetic mechanism to repel them from unselected portions of the plate. In Xerography, for example, there is some repulsion as well as attraction of charged ink particles. Relief printing plates effectively deny adherence of ink in low areas, while Lithography is essentially a negative process, depending for its operation entirely on inhibition of ink adherence on wet portions of the plate.

One mechanism which has been used successfully in Ferrography to deny adherence in unselected portions is centrifugal force. This technique works satisfactorily with dry powder inks. Cylindrical plates are used and rotated rapidly during inking. The ink is poured on the top of the spinning cylinder and centrifuges off the unmagnetized portions. In this manner, plates can be inked so that unselected areas are extremely clean.

After the image has been developed by inking, it can be transferred to paper by pressure contact. If liquid inks are allowed to dry partially, then they will transfer to paper on contact without smearing. Similarly, dried liquids inks and dry powder inks can be contact transferred to a dampened sheet of paper. If this is done, almost complete transfer of the developed image will be accomplished. A pressure sensitive adhesive on the surface of the paper will also effectively strip the image. It also serves the function of holding or fixing the ink particles to the paper surface.

Three other methods of fixing the image have been used. The first is to include in the ink formula a soluble adhesive resin. The paper is then dampened with its solvent as a stripping agent which also softens the adhesive to fix the image. The second method incorporates a thermo-setting resin or wax in the ink formula. Application of heat from an infrared lamp after transfer then fuses the image to the paper surface. In addition, dyes can be included in the ink formulation which are soluble in the solvent and which will mark the paper surface to increase the intensity of the print or produce some desired color. The iron powder can then be magnetically removed from the paper surface so that only the dye pattern remains.

The third fixing method is to spray the paper surface with a fixer such as is used on charcoal or pastel drawings. These fixers are usually thin shellacs or lacquers. The fixer also imparts to the paper a superior finish or gloss and also tends to prevent ink dyes from fading.

The Ferrographic process has been employed in the design of a duplicating machine. This equipment produces Ferrographic duplicates of copy up to $8\frac{1}{2}$ by 13 inches. The material to be duplicated is facsimile scanned by a photo-cell while a magnetic head receiving the signals sets up a Ferrographic plate. This plate is cylindrical and, after development by a dry powder ink, the image is transferred to paper and fixed.

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The process has also been studied for use in a high-speed-data printer. Here two methods of application have merit. One method employs a multichannel head to receive and record parallel facsimile signals to create images of character shapes on a Ferrographic drum. The other employs direct magnetic transfer from a type face.

Multichannel heads for use in the first process have been produced having upward of one hundred channels per inch. Such a head structure is shown in Figure 6 and 7. These heads can be fed from a letter forming function table or switching circuit through an electronic distributor to record character images in response to an input in code. Preliminary tests show recording speeds in excess of 10,000 characters per second with such a head. Since a single recording element can set up printing plates at these speeds, serial equipment becomes practical. This simplifies the design from a logical standpoint and reduces the amount of equipment required. The transfer to paper, of course, can proceed at printing speeds until the desired number of copies have been produced. The plate is then erased and new copy set up on it.

Direct magnetic transfer from soft iron type faces can also be done serially. The type faces can be mounted on one or more rotating wheels which are mounted on an axle parallel to the Ferrographic drum axle. A magnetic circuit is pulsed when the desired character is in position next to the drum to effect magnetic image transfer. The use of a plurality of such type wheels has been considered, both by the writer and by Berry (3), providing one wheel for each column of the copy to be produced. A single type wheel can be operated rapidly enough, however, to scan a drum surface at acceptable speeds with simpler circuitry.

The Ferrographic process has an economic advantage over many existing printing processes. This advantage is the use of ordinary sheet paper. Special stock is not required in most cases and carbon paper is eliminated. The high cost of pin-fed multipart forms represents a major part of the cost of operating tabulating equipment. Such a high speed printer can consume its own cost in paper in a year's time. This high cost is the result not of using very high grade paper but rather of the high cost of carbon paper, of interleaving it between the sheets of the form, punching the tractor holes along the side of the form and stapling the sheets together. Since such specially prepared papers are not required for Ferrography, a tremendous reduction in the operating cost of the equipment can be expected. High speed printing processes employing "teledeltos" or other electrosensitive papers are uneconomical for the same reason. These papers are very high in area cost and are not generally available.

The Ferrographic printing process appears to be superior to Xerography on several counts. First, the magnetic plate constitutes a memory for the information which is to be printed. The electrostatic charges which govern the operating of Xerographic printing are destroyed by each printing signal. They must, therefore, be restored by re-recording or recharging between printing operation. Secondly, the fact that a single recording suffices to produce a large number of copies is important from a legal point of view. The legal status of the carbon copy is well established. Microscopic examination of an original and a carbon copy can confirm that they were produced simultaneously in a printer or typewriter. The same relationship can be established for Ferrographic prints produced from the same recording. Supposedly identical
recordings of the same subject matter will differ in a microscopic sense due to magnetic noise on the plate and to minor defects in the operation of the recording process, which only such microscopic examination would reveal. Continuity of recording reflected in a family of copies can be obtained only by commercial printing processes, carbon copies and Ferrographic prints. They cannot be obtained by processes which require re-setup of the copy between printing operations such as is required in Xerography and facsimile.

In summary, the new process provides means for rapidly setting up copy on a printing plate. The information may be new data received in pulse code from a computer or facsimile signals generated by a photo scanner. The resulting printing plate can be developed and printed rapidly. As many copies as may be desired can be produced from a single setup. The plate can then be erased and new information recorded. It is believed that the process will be useful for tabulators and data printers as well as facsimile duplicators. The process is also expected to find application in commercial printing especially where setup time is an important economic factor.

REFERENCES

Figure 3  PERPENDICULAR RECORDING HEAD

Fig. 4a PERPENDICULAR RECORDING HEAD

Fig. 4b PERPENDICULAR RECORDING HEAD

Fig. 5 TRANSVERSE RECORDING

Fig. 6 MULTICHANNEL HEAD

Figure 7 Photograph of Multichannel Head
An Improved Cathode Ray Tube Storage System*

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Introduction

Several years have passed since Williams and Kilburn (1) first described their method of storing digital information as charge patterns on the phosphor screens of common cathode ray tubes.

Since then many computers have been built using this form of storage. Considerable research has been carried out to further the understanding of the storage phenomena (2,3) and to improve the storage tubes themselves. Yet this type of memory is still faced with two rather severe limitations. The first one is spot interaction or spillover. Thus if a single spot on the cathode ray tube screen is referred to repeatedly, the information in adjacent spots may be altered. A measure of the storage system's susceptibility to this type of failure is the "read-around ratio", or the number of times a single spot may be consulted before the adjacent spots have to be regenerated to avoid loss of information. Needless to say a low read-around ratio limits considerably the usefulness of a storage system.

The second type of difficulty encountered is caused by the presence of flaws or imperfections on the cathode ray tube screen, of such characteristics that they will not store information. These imperfections are usually very small even when compared with a beam diameter and it is relatively easy to position the charge pattern so that none of the flaws interacts with any of the storage spots. It is however quite difficult to maintain a high enough long term stability to insure that the raster of storage spots does not drift onto one of these flaws with a resultant loss of information.

The ability of the electrostatic memory tube to retain its information in the presence of flaws on the phosphor screen is somewhat dependent on the mode of operation of the tube.

Thus the various systems presently in use (dot-dash, double dot, defocus-focus, etc.) all show different susceptibility to flaws. As a rule, however, those systems which show a high resistance to flaws have a low read-around ratio and vice versa. Because of this, efforts to improve cathode ray tube storage systems have largely been centered on producing improved storage tubes with better focus and deflection characteristics and with storage screens free of flaws (4). A parallel effort has been carried out at the Institute for Numerical Analysis to devise a modification of the Williams' principle of storage which has resulted in improvements not only in spillover, but also in resistance to flaws. Before describing this new system, however, it is well to review briefly the principle of charge storage in the conventional dot-dash system both under normal operating conditions and as affected by spillover.

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