The Notched-Disk Memory

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The notched-disk memory appears to be a very significant development in electromechanical information storage techniques. Its possible applications are manifold, including such diversified automatic information processing activities as electronic computing, telephone switching, ticket reservations, optical recording, and business accounting.

As the operations of government and private business become more varied in nature and larger in scope, the problem of adequate record keeping is continually becoming more acute. Not only is the volume of records rising to unprecedented magnitude, but also the time required to store and later reach this information is becoming continually of greater importance. There is little reason to doubt that modern advances in electronics will greatly modify the handling of information in large enterprises, both governmental and private. In all systems of automatic handling of information, one of the key elements is the device for storing information.

A magnetic information-storage device now being developed at the National Bureau of Standards (NBS) combines advantages of large storage capacity and rapid access time. The new "memory" stores data in the form of magnetic pulses on both sides of thin metal disks, which are mounted in a doughnut-shaped ring with the planes of the disks vertical. Each disk has a deep notch, and the notches are normally aligned so that a bank of magnetic recording-reading heads can be quickly rotated into position at any desired disk. Test results demonstrate that stored data can be reached in times of the order of 0.5 second. This memory was devised at NBS by request of the Ballistic Research Laboratory of Aberdeen Proving Ground, Md. Two models are nearing completion.

It has long been recognized that 3-dimensional storage of information, as in a book, utilizes space most efficiently. Previous 3-dimensional storage systems, however, have had the disadvantage of relatively long access time. The usual method of storing information in three dimensions has been to record it on a film strip, or on magnetic wire or tape. The difficulty is that the whole reel may have to be played in order to reach a particular bit of data; thus while the storage is 3-dimensional, the playback is either 1- or 2-dimensional, and is sequential. Short bits of magnetic wire can be used to reduce access time, but then the amount of machinery required becomes very large.

THE NOTCHED DISKS

The storage of information on magnetically coated disks appeared to be attractive from several points of view when the problem was approached at NBS, but the known methods of selecting and playing each disk did not seem promising. Disk-record changing mechanisms are old, and disks can be selected and played in many ways, but if a machine is to have as many as several thousand disks old mechanisms are inadequate, particularly from the standpoint of rapid access.

The solution arrived at was a design in which a deep notch extends most of the way to the center of each disk. The disks are arranged on a common shaft, and the notches are aligned so as to permit the magnetic heads that are to scan the disks to pass through the channel formed by the notches. This makes it possible to move the heads rapidly to the desired disk.

It soon became apparent that a more effective arrangement of the disks is to mount them on a circular shaft in the form of a toroid or "doughnut." The magnetic heads then can be rotated on a central shaft instead of being moved in a straight line. This design, which results in a simple and rugged machine, was therefore adopted.

When the heads are in position, the disk is rotated past them while information, in the form of coded magnetic pulses, is recorded or read out. A large number of heads, spaced along a radius of the disk, are used so that the whole useful area of each disk can be read or written upon in a single revolution of the disk. The bank of heads is divided into two halves, with a narrow slit between them through which the disk passes. The general arrangement of the machine is shown in Figure 1. Thin aluminum disks, coated on both sides with magnetic material, are being used in the experimental models at NBS.

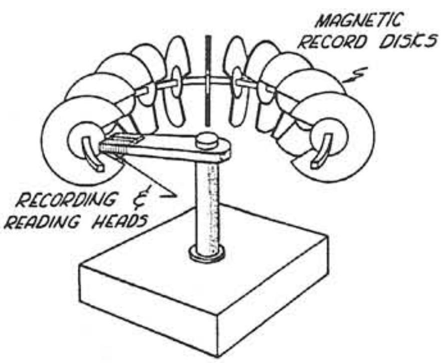

Figure 1. Schematic diagram of the notched-disk memory

The notched-disk memory "doughnut" can be thought

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The magnetic heads employed in the first two models of the notched-disk memory were developed by the Raytheon Manufacturing Company, Waltham, Mass. The small machine was built entirely in the National Bureau of Standards (NBS) Ordnance Division laboratories, while the large machine was built jointly with the Shepard Laboratories, Summit, N. J. The Aluminum Company of America supplied much helpful information as well as the aluminum sheet. Special thanks are due many members of the staff of both the Computer Laboratory and Ordnance Division of the NBS who contributed so many ideas and so much effort to the improvement of the machines described.

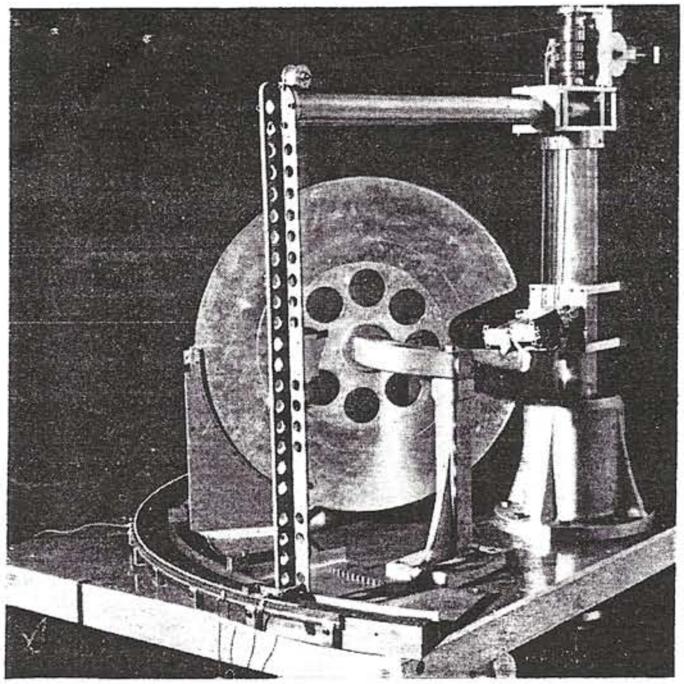

Figure 2. The large notched-disk memory

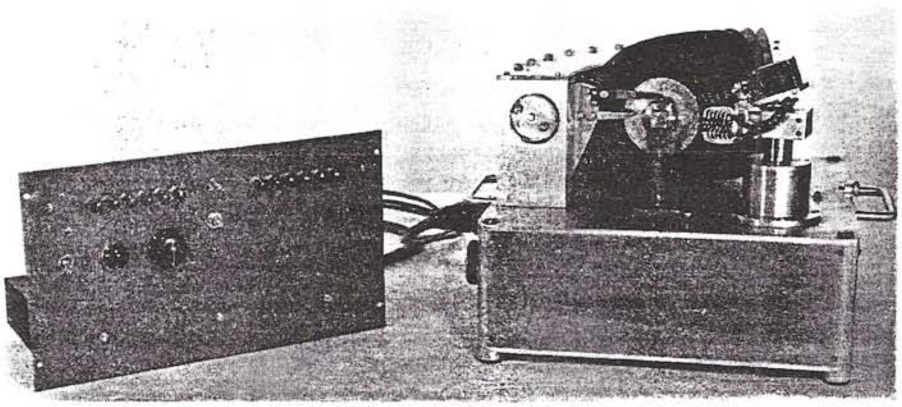

Figure 3. Small notched-disk memory and control unit

of as a kind of book in which round pages are slotted in such a manner that each line on each page can be read by merely spinning the page for one revolution; the notches in the pages provide the "windows" through which the selected page can be read. In other words, the book can be read without being opened.

THE TWO MODELS

THE FIRST EXPERIMENTAL MODEL of the new memory was designed to have 250 disks, each 20 inches in diameter, arranged in a quarter circle. Merely to simplify construction, the design was subsequently modified to call for only 147 disks (this particular figure has no special significance). Construction of this model, shown partially assembled in Figure 2, is now well along. Following satisfactory proof tests, the machine can be expanded to 588-disk full-circle form.

Soon after work on the first machine was begun, construction was undertaken in the NBS laboratories of a smaller machine for immediate experimental and demonstration use. This smaller machine is shown in Figures 3 and 4. The disks in this machine are 6 inches in diameter. Ten disks are mounted on a shaft bent into a 90-degree circular segment. This machine is also so designed so that it can later be expanded to have a full circle of disks.

The two models, which differ in several design details, are described more fully in the following. It should be pointed out that in building the first models no effort is being devoted to maximizing all of the parameters. Many more disks could undoubtedly be used in a given volume than are being used in these first models, and more information could be stored on each disk.

MAGNETIC DISK DETAILS

IN THE LARGE MACHINE, the disks are made of 0.006-inch thick aluminum which was supplied to NBS "as drawn." The material, therefore, is quite hard and springy. Both sides of the disk are coated with an Epon plastic in which is embedded a magnetic powder. To the center section of each disk are spot welded two sheets of 0.015-inch thick dural. See Figure 5 for disk parts. The curved shaft that supports the disks has a square cross section. On this shaft are mounted circular washers with square holes. Each of these washers supports one disk. Between the disks are wedge-shaped washers which act as separators. Each of the large disks is provided with a thickened lug at a point of its circumference opposite to the position of the notch. This lug, which extends beyond the normal periphery of the disk, is employed to start the disk on its rotation and to stop it at the end of each cycle. The mechanism for doing this will be described later.

In the small machine, as in the

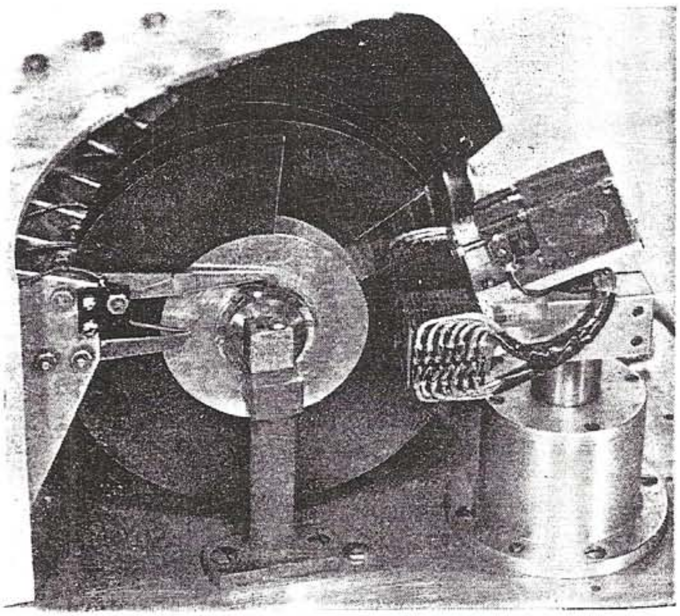

Figure 4. Detail of magnetic heads and notched disks of small disk memory

large, the disks are supported on a square-cross-section circular shaft, but they have attached to them large, thick central washers by means of which they are started in rotation. See Figure 4.

When the work was originally begun, it was hoped that materials harder or tougher than aluminum could be used for the disks. It was found, however, that very few metals are rolled in the 20-inch width required for the large machine and that aluminum provided the best solution, combining as it does lightness and strength. Although other materials are available that could have been utilized for the disks in the small machine, aluminum was used here, too.

DISK DRIVE DETAILS

THE PROBLEM OF rapidly accelerating and decelerating the desired disk presented considerable difficulty. In the large machine a clutch-driven "kicker" mechanism accelerates the disks to full speed in approximately 10 degrees of disk travel. See Figure 6. Two small rubber-tired driving wheels are located near the magnetic heads so that, after the disk is started by the kicker, one edge of the notched section enters between these rubber wheels and then is driven by friction. See Figure 7. When the disk has completed one revolution, it disengages from rubber wheels and is decelerated by a clutch mechanism that acts as a brake. The disk overshoots its final position and is returned slowly to its initial position, and the heads are then again free to travel to the next disk selected. There are both mechanical and electric interlocks to prevent the head assembly from moving toward a new disk should the previous disk not be in its proper stand-by position.

In the small machine, the disk drive is somewhat different. In order to simplify the machine, each of the disks is provided with a washer at its hub, adapted to be driven by a pawl. An individual solenoid drives this pawl and thus drives the disk into engagement with the rubber wheels.

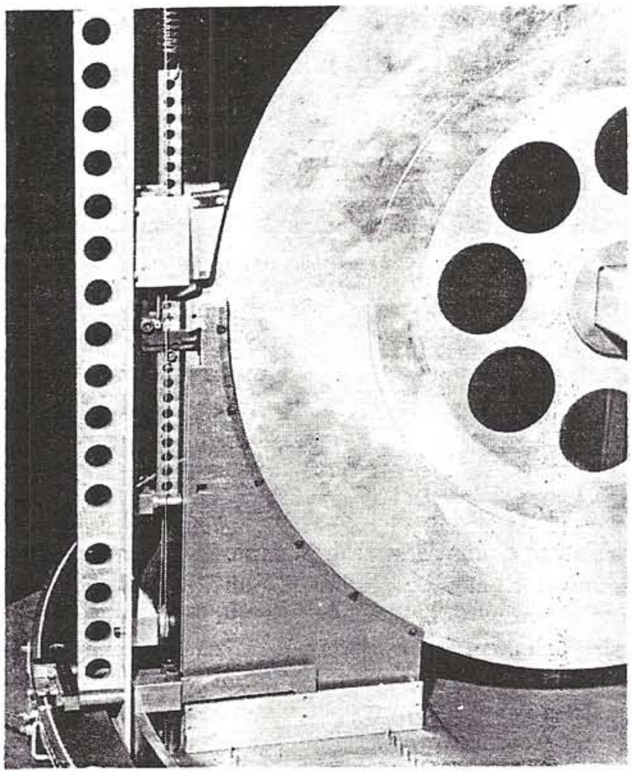

Figure 6. Large memory disk kicker

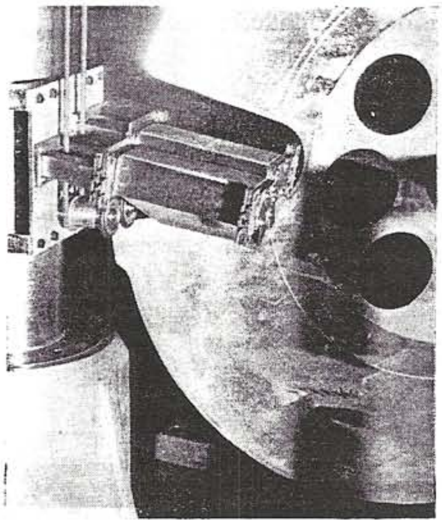

Figure 7. Large memory disk head assembly and disk drive

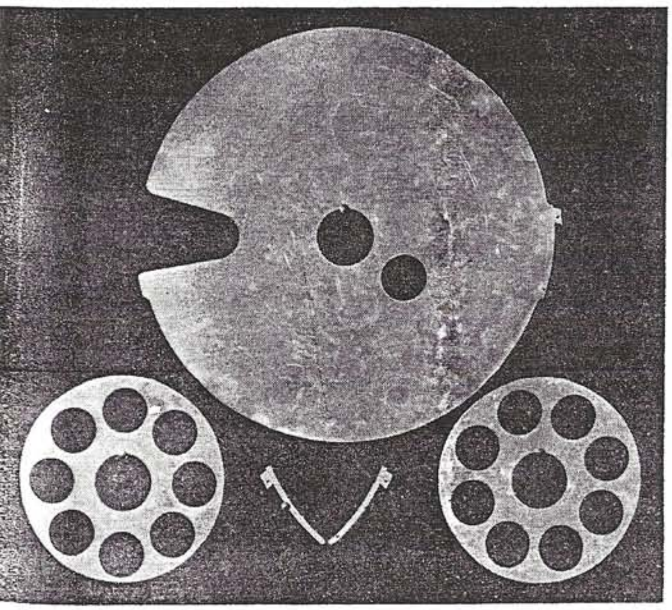

Figure 5. Large memory disk parts

When the disk is being stopped its kinetic energy is absorbed by a spring. See Figure 4.

THE MAGNETIC HEADS

THE MAGNETIC HEADS used in the two machines were developed by a commercial concern under contract with the NBS. They were originally designed for use with magnetic tape to record and read several parallel channels. Each head, as shown in Figure 8, is 1.3 by 1.0 by only 0.073 inch thick. The heads are stacked with thin soft magnetic shields separating them. The over-all thickness of each head and its shield is 0.077 inch. A 28-head bank is mounted on the central shaft of the small machine: 128 heads will be used in the larger version.

Experiments indicate that the heads will perform satisfactorily despite their closeness to each other. Writing

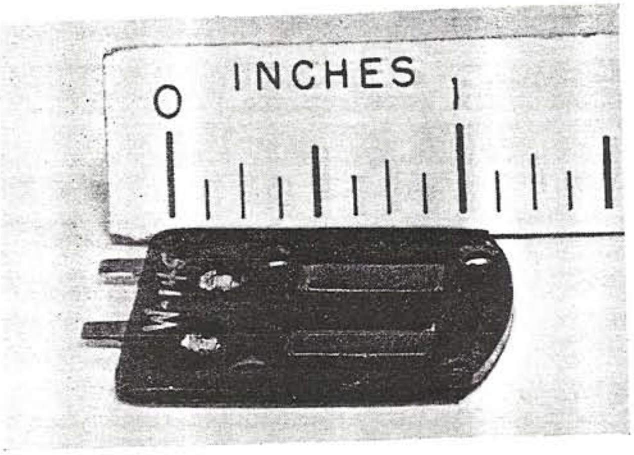

Figure 8. Magnetic head

in one channel does not produce any appreciable record in adjacent channels, and there is no crosstalk except that a channel cannot be read while an adjacent channel is being recorded. This is because the current in the recording channel is large enough to cause pickup by the heads of the adjacent channels. This normally does not give rise to any difficulty since it is not expected that reading and recording will be done simultaneously in adjacent channels. The heads on opposite sides of the disks are staggered by the distance of half a head width so that the magnetic gaps do not face each other. This is done in order to minimize crosstalk.

In the small machine, the two head assemblies on opposite sides of the disk are so spaced that there is more than sufficient room for the disk to pass between them: hence the disk is free to oscillate slightly from one side of the gap to the other. In the original experiments this caused some difficulty with modulation of the recorded pulses. However, it was found that if a large excess of current was used during recording so that saturation of the disk, and perhaps of the head, is always reached, this slight variation in spacing between the disk surface and the heads is of little importance, and the modulation is within acceptable limits.

In the large machine, the two stacks of heads are displaced slightly relative to each other, so that the disk can make contact with each stack without being pinched. See Figures 2 and 7. The head stacks can be adjusted to overhang slightly so that the disk is made to flex slightly in passing between them. This expedient results in a definite pressure between the disk and the working surfaces of the magnetic heads.

Various proposals also have been made for pressing the disks against the heads by means of supplementary springs and for arranging the head assemblies so that air pressure or vacuum could be employed to control the spacing. These expedients are not expected to prove necessary. A great deal depends on how uniform in thickness the disks can be made, and experience so far at the NBS indicates that adequate uniformity can be achieved.

With the heads available, 100 pulses to the linear inch have been recorded without much difficulty. This means that some half-million pulses can be recorded on a single 20-inch disk. If 588 disks are used in the large machine, a total capacity of a quarter of a billion binary digits would result, or somewhat less than one-third as many decimal digits. Maximum information could be stored on each disk by varying the frequency of pulse recording from the inner to the outer line; if the spacing were maintained at 100 pulses to the linear inch, more total pulses could be recorded on an outer groove than on an inner groove. This would require that the frequency of recording be made some function of the radial position of the groove, and this could be done electronically. Whether this complexity is desirable or not depends upon the economics of the over-all system design.

No data are as yet available as to the wear of the heads or of the disks. Preliminary tests made incidental to magnetic studies indicate that wear will not be a serious problem. Some consideration, however, is being given to expedients such as lubrication of the disks and coating them with a protective layer of nonmagnetic material. This last expedient would not only minimize the wear of the disks, and perhaps the heads, but also would provide a fixed gap-spacer so that variations in the air gap would have less effect on the amplitude of the pulses. Attempts are being made to develop methods of keeping fixed, noncontacting, disk-to-head spacing by air-bearing techniques.

HEAD SELECTION AND POSITIONING

No provisions are being made in either of the machines for any mechanism to select a particular head. The connections to all of the heads are being fed out on a cable, and the computer used with the memory will have provisions to select the proper head electronically. Slip rings have been considered, but it is believed at present that a flexible cabling system is preferable. If the head-selection mechanism itself were mounted directly on the head supporting arm, then the number of slip rings required could be greatly reduced. In that case, their use might prove advantageous.

One of the most important problems in the development of these machines is that of positioning the heads rapidly and accurately to line up with the desired disk. In the small machine, the device being used consists

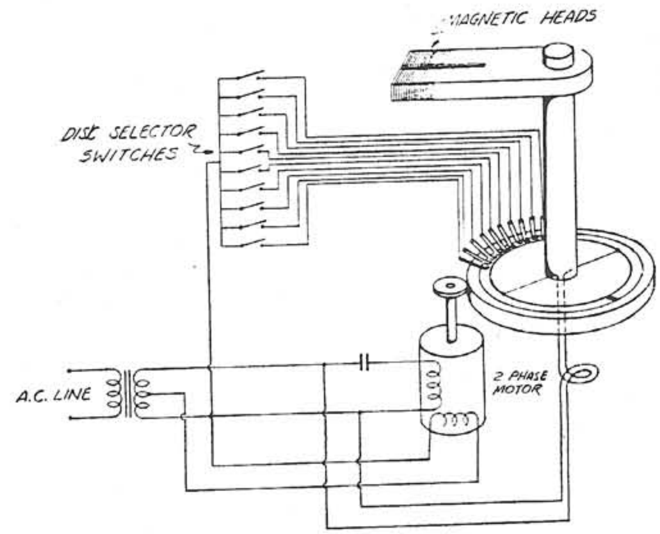

Figure 9. Schematic diagram of head positioning mechanism in small disk memory

essentially of a mechanism familiar to the radio industry for the remote control of radio receivers. See Figure 9. This device suffers from several limitations. One is that there is no provision for decelerating the heads just before they come to the right position; if high speeds are employed, the heads overshoot their correct position and oscillate a few times before coming to rest.

A much more sophisticated head-positioning device is used in the large machine. It consists essentially of a clutch-driven servomechanism which rotates the arm to a position indicated by a slide-wire potentiometer. A "Christmas Tree" decoder is employed to ground various points along the potentiometer wire, and a servomechanism positions the kicker arm, and with it the heads, by moving the slider to the grounded point. See Figure 10. This positioning mechanism has been tested and found satisfactory.

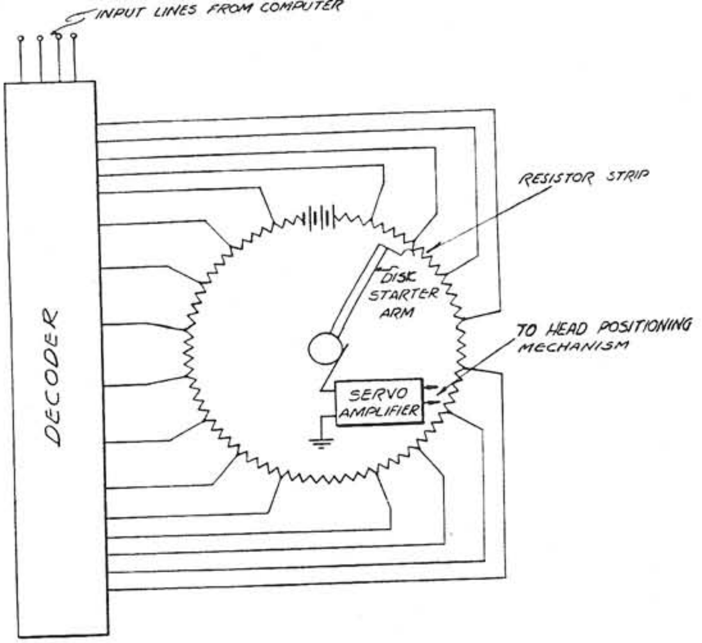

Figure 10. Schematic diagram of head positioning mechanism in large disk memory

TECHNICAL POSSIBILITIES AND APPLICATIONS

MANY SUGGESTIONS have been received for other possible forms of the notched-disk memory, and for improvements in some details of the present designs. For instance, use of more than one set of heads in order to increase the speed of access has been suggested. Four sets of heads could be used, spaced 90 degrees apart with the machine arranged to drive the nearest set of heads to the required disk. It seems doubtful that the saving of time would justify the increased cost and complexity.

By using less than an essentially complete disk, a somewhat simpler disk-driving mechanism could be used. Instead of having the disk make a single revolution and then come to a stop, an oscillating type of motion could be employed. A disk sector could be made to swing through the heads and then return to its original position without completing a unidirectional motion. This would simplify the driving mechanism to some extent since it would not have to be disconnected from the disk.

To insure that the velocity of disks through the heads will not appreciably affect the position of the pulses, a marker channel of fixed pulses could be permanently recorded onto one of the lines of the disk so as to serve as a magnetic sprocket for all of the other recording heads. The pulses on the other heads could then be synchronized with this marker channel and the marker channel could be used as an index to a desired pulse or a group of pulses. This would be particularly advantageous where only a small section of recording line is necessary to record a particular amount of data.

Work with the notched-disk memory suggests the possibility that certain intermediate memories in electronic computers, such as those that now use magnetic drums, could be replaced by memories using a single unnotched disk. A single thin, flexible disk driven continually between two sets of heads could be used to record a large amount of information and would have the advantages of being relatively inexpensive and not requiring the mechanical precision needed in a magnetic drum. Due to the rigidity of the drum, the heads are usually mounted very close to it, but avoid actual contact. This calls for a very high degree of mechanical precision. As the disk is light and flexible, it can be permitted to touch the heads without serious harm.

While the foregoing description of the notched-disk memory has been confined to magnetic recording, it is obvious that other recording techniques can be adapted to the mechanical principles of the notched-disk memory. Optical recording and playback could be used with photosensitive materials, using both variable-density and variable-area record tracks. Notched disks of the phonograph type could be used, with the information cut, pressed, or embossed into their surfaces. Perforated disks could be used; the perforations could be punched into the disks either before assembly into the machine or in place, and read by techniques familiar to users of the common business machine cards. Magnetic recording is easily erasable; but this is also its great weakness. In permanent records where erasure is undesirable or unnecessary, other forms of recording might be advantageous.

The availability of suitable information-storage devices is important to progress in the use of automatic information-processing techniques. Desirable features of such devices would seem to include large storage capacity, rapid access time, ruggedness, dependability, and reasonable economy. Since the notched-disk memory principle appears to combine these advantages in unusual degree, information-processing systems using this principle for storage may well come to find important applications in enterprises which must handle, store, and have access to large amounts of routine information. Such systems could be particularly valuable for large organizations, such as the Armed Forces or major distributing firms, where stock control, inventory, and procurement are major problems. Other possible users might include banks, insurance companies, libraries, and certain government agencies, particularly those concerned with such matters as bond issues, taxes, social security accounts, and census.