An Automated Semi - Random Storage/ Retrieval System

Occasional Paper

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BUREAU OF TRANSPORT ECONOMICS

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AN AUTOMATED SEMI-RANDOM STORAGE RETRIEVAL SYSTEM

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FOREWORD

Since its formation, the Bureau of Transport Economics has presented the results of its completed studies in the form of project reports. There have also been a number of ancillary studies which have created a need for other types of publication.

The most pressing need has been for a series of short reports, each on a single topic, and it has been decided that these should be presented in a series of Occasional Papers. This first paper by Mr. W. P. Egan presents the solution to a materials handling problem; his paper stands at the engineering extremity of the range of topics. Subsequent Occasional Papers will deal with economic and operational research aspects of transport, as well as with engineering aspects.

J. H. E. TAPLIN
Director

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Canberra, A.C.T.

March 1973

PREFACE

The system described in this paper is a result of an investigation carried out by the Bureau of Transport Economics and the National Materials Handling Bureau for the Australian Wool Testing Authority. The primary objective of the investigation was to determine the characteristics of a materials handling system capable of storing and retrieving very large numbers of wool core samples.

In view of the number of samples involved and the need for high speed and random access, it appeared unlikely that a conventional materials handling system could be provided at acceptable cost, for this particular task. Consequently, the Bureau examined the problem to determine whether there might be some novel system which might be more appropriate. This led to the concept of an automated, semi-random storage/retrieval system based on computer control.

The system developed for the particular problem of wool core sample storage has general application in the materials handling field, and accordingly is described as a general system in the paper.

CAUTION: The system described in this paper is subject to patent provisions.

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SUMMARY

The materials handling system described in this paper is intended for use in the storage and retrieval of large numbers of relatively small items, where a high and random turnover is anticipated.

The system is based on the controlled selection of uniform containers, and has the intrinsic property that a particular container need not be restored to the position from which it was taken. The system includes a digital computer as an integral part, and does not attempt to simulate any existing type of manual storage/retrieval system. The major advantages of the proposed system are that it is very efficient in terms of storage area and storage volume, and the storage and retrieval operations are unusually rapid. In suitable applications, there may also be a significant cost advantage over alternative systems.

The paper describes the principles of the system, the design of the containers and two particular storage/retrieval machine designs. The system is compared with conventional systems and some practical limitations are noted.

INTRODUCTION

This paper describes the design and operation of a fully-automated materials handling system which differs in many respects from conventional systems. The system is intended to fulfil requirements for automated semi-random storage and retrieval of non-fragile uniform containers, and has several major advantages over other systems. Although it is well suited to a particular class of handling problem, the proposed system could also be used in other applications.

A materials handling system can be considered as comprised of four separate parts:

- the containers used to store the material in the system;
- the physical storage of the containers;
- the mechanisms required to deploy and retrieve the containers;
- the control system which organises, records and actuates movements of containers within the system.

The system description in this paper does not deal with operations peripheral to the central storage and retrieval system, since these will vary with different applications. However, the question of compatibility with peripheral operations is considered where it affects the design of the central system.

Since materials handling systems fall into many categories, it is desirable that the scope of the system described in this paper should be stated explicitly. The proposed system is intended to be applied to fully-automated storage and retrieval operations, and in particular to operations which have the following characteristics:

- uniform container sizes and shapes, with no external constraints on the shapes (i.e. the container shape may be selected to fit in with other system requirements);
- automatic identification of containers as a peripheral function;
- random arrival and departure order of the containers (i.e. the order in which the containers are stored or retrieved is immaterial);
- a large scale of operations, for which a typical system would require at least a small digital computer for satisfactory automation;
- limited single-pass selection or storage proportions (i.e. the number of containers to be stored or retrieved at one pass should be fairly constant).

Although this definition of the scope of the system may appear rather restrictive, there are many storage and retrieval problems falling into this category. It is also likely that future increases in the use of automatic handling systems will unearth many more problems of this general nature. A further feature is that the type of system proposed is adaptable to problems with different constraints from those listed.

Design parameters

In general, the design of materials handling systems involves consideration of many design parameters. Some of the desired characteristics are common to most systems, but the proposed system offers significant opportunities for efficient design in the following specific areas:

- efficient use of available space (both volume and area);
- use of the digital computer's logical capacity as an alternative to mechanical complication;
- predictability (i.e. low variance in the time taken to store or retrieve a given number of containers);
- comparatively low initial operating and maintenance costs.

Computer control

The effectiveness of a digital computer in a storage/retrieval system will not be fully realised if the automated system merely duplicates manual operations. The entire system should be based on maximum utilisation of the computer's logical capacity and, even more important, the system's machinery should be designed for 'digital' (i.e. step-wise) operation. The basic rationale of the proposed system is that any manual-simulation system which involves a digital computer is not likely to be nearly as effective as one which is fundamentally designed with the computer as an integral part. Therefore, many operations which would normally be performed manually have been integrated into the control system, or have been eliminated altogether.

CONTAINERS

Description

The containers are an integral part of the system. As well as providing a convenient storage unit, the containers are functional. The system requires that the containers should be cylindrical, and also that they should be sufficiently rugged to be stacked on top of one another to some considerable height. The number to be stacked will vary with different applications, and would be determined as a result of optimisation studies.

The form of the container is shown in Figure 1. The lid is screwed on, or, alternatively, some form of quick-locking device could be used. The base of the container is recessed, and contains an identification disc, which is a machine-readable coded device. The containers are identical in size and shape, and would, therefore, be produced in quantity.

Identification

One of the main problems encountered in storage/retrieval systems is container identification. A major cause of this problem is that efforts are usually made to mark the container according to its contents. This means that the machine-readable marking on the container is temporary, and is usually some form of optical or magnetic code. In either case, the marking is not very substantial, and a high proportion of errors results from rough handling.

In the proposed system, this difficulty is overcome by generating a *conceptual* correspondence between the container and its contents. Each container in the system is marked with a substantial, rugged and unique code, and the central computer maintains correspondence tables of container numbers and contents. There is a minimum of clerical effort involved in this operation and error rates can be reduced dramatically by its implementation.

As the identification disc is located in the recessed base of the container, it is protected from rough handling. Since each disc has a different code, the discs would probably be produced separately, and then bonded to the containers. It is proposed that each disc would be coded with the Binary-Coded Decimal (BCD) equivalent of the container's reference number. The mechanical implementation of this code would be in the form of holes drilled in the disc for binary 'ones', as shown in Figure 2. The parity bits referred to in that diagram are a further insurance against error, since they ensure that the sums of the binary 'ones', both along and across the code, are odd numbers. The decimal reference number could also be stamped on the disc for easy reference.

It can be seen that this system results in a truly substantial numerical code, which will withstand very rough handling outside the system. The BCD code is widely used, and inclusion of parity bits reduces the possibility of error due to aggregation of dirt or other foreign material in the code holes. The correspondence between this permanent code and the contents of the container is recorded in the computer, where it may be changed or updated as required.

Reading operations

Identification of the containers as they enter or leave the storage/retrieval system can be performed by a comparatively simple machine. As each container passes through a reading machine, its longitudinal orientation can be checked by a simple probe which identifies the recessed base. If a container is disoriented, it may be turned around automatically or rejected for manual orientation. The reading machine would then read the code on the identification disc, and the central computer would determine the action to be taken. Incorrect parity would result in rejection of the canister.

The 'index tab' shown in Figure 2 is intended to ensure correct alignment of the 'read head' with the code on the disc. For convenience, this tab is shown as a raised area on the disc, but, in practice, it would probably be another hole. The functions of checking container orientation (both longitudinal and rotational) and code parity could be performed by the central computer. However, they are simple logical processes, and might be incorporated in the reading machine. Both possibilities have some advantages, and the choice depends on the economic considerations involved in the alternatives. Treatment of rejected containers would depend on the requirements of particular installations.

Summary

The essential features of the storage container for use in the proposed system are:

- cylindrical shape for rolling action;
- recessed base for protection of the identification disc and ease of detecting orientation;
- individual identification discs for container numbering;
- robust coding system to eliminate errors as far as possible.

STORAGE

There are significant benefits to be obtained from the use of a storage system which does not involve an individual physical support for each container in the system. The obvious advantage is that cost will be reduced, but an even greater advantage arises from the fact that clearances between containers may be reduced, with a significant reduction in system volume and space requirements. However, to gain these advantages, it is necessary to consider the concept of variable-length stacks.

If a single column of containers is stacked one on top of the other to a height of, say, ten containers, it is possible to consider each container by its stack address as well as by its intrinsic reference number. If one or more containers are removed from various positions in the stack, the total number of containers in the stack is obviously reduced. A more important consideration, however, is that the addresses of the other containers in the stack will have changed (except in certain special cases). The address of a container is, therefore, dynamic (with an operation on one container affecting the status of other containers). Similarly, addition of containers to the stack may affect the addresses of other containers in the system. An example is shown in Figure 3.

Obviously, a manual system would not be able to cope with the positional changes resulting from manipulation of containers in such a stack. However, it is a simple matter for a computer-controlled system to record the changes involved.

The conceptual design of the storage is therefore based on a matrix of stacks (or columns). Each column can contain a number of containers arranged sideways on top of one another. If there are only two rows of such columns, access to any container in the system can be obtained from the sides, but there is a penalty in wasted space. In the system proposed, each column would have a bottom door, which would retain the containers in the column. An individual canister would be accessible only by removing those below it. This system leads to complication in the selection machinery, but has the advantage that more than two rows may be stored together.

A diagram of a typical storage module is shown in Figure 4. In this case, the module contains eight columns longitudinally and three laterally. Each column can contain up to about six containers. The total storage capacity of the system is, therefore, 144 canisters. While this is far too small for a practical system, it illustrates the type of system proposed, and shows a typical storage structure.

The storage module consists of a structural frame, with a matrix of column dividers. The dividers consist of standard metal sections, and need only be very light, since they do not carry substantial loads. If the lateral loads on the dividers are significant, the structure can be stiffened by partial cladding of the columns. In either case, the storage module is constructed of low-cost, readily-obtainable materials. The doors at the bottoms of the columns are simple, and would be provided with a latch mechanism which can be operated by the selection machinery situated under the columns. Figure 4 shows two containers located in one of the columns.

In any particular application, the size of each storage module must be determined by considerations of cost, speed and space. However, the basic principles underlying the storage system design remain unchanged. The height of the bottom of the columns above floor level depends on several factors, but the major consideration is the type of selection machinery. As an alternative to stacking the containers on their sides, as in Figure 4, they could be stacked vertically. This arrangement would, however, lead to a considerable increase in the amount of material required to construct the storage module. Nevertheless, this alternative arrangement might lead to simpler selection machinery in some cases.

General

The basic function of the selection machine is that it should operate on each column in a storage module and remove from that column any containers required. The machine should then restore the column to its original state (except for the containers removed). A further function of the machine is that it should be capable of placing new containers in the system. The machine functions are:

- open the column door;
- remove containers one at a time, during retrieval operations, and separate out containers required in the current pass through the system;
- return unselected containers to the column in their original order after retrieval operations have been completed;
- store containers at the bottom of each column during storage operations; and
- close the column door.

There are several ways in which these operations could be performed mechanically, and only two of them are described in this paper. These machines are particularly suited for operation in conjunction with digital computers, since they are essentially stepping machines (i.e. all mechanical elements are actuated in an 'on-off' manner). The main advantage of machines of this type is that the electrical/mechanical interface equipment can be very simple. A further advantage is that feedback requirements are virtually eliminated.

It would obviously be inordinately costly to have one machine for each column in a storage module, while a single machine operating on each column in turn would probably not meet most speed requirements. The compromise selected is a machine which would operate on each bank of columns in the module at one time. In the module in Figure 4, the machine would operate on three columns simultaneously. The machine would step between banks along rails under the module. Selection of the appropriate bank of columns would be simply a matter of providing the appropriate number of stepping pulses to the machine control. It would not be necessary to have any positional indicator on the machine, since the central computer would be capable of recording the machine position by logging the stepping pulses.

In addition to the positioning mechanism, each type of machine would have a temporary storage chute and an ejector chute. The ejector chute would be used to store selected containers, while the temporary storage chute would perform the following functions:

- during storage operations, serve as a 'magazine' in which containers to be stored are loaded and held until the machine is located under the appropriate column;
- during retrieval operations, hold unselected containers for subsequent return to the column from which they were unloaded.

The basic machine operation would therefore consist of controlled transfers of containers between the storage column, the ejector chute and the temporary storage chute. The temporary storage chute would be attached to the machine, but the ejector chute could, in fact, include no storage, and could merely deposit the selected containers on to a fixed conveyor system. In the two machines described, the ejector chute would contain storage space. In this case, if the ejector chute were full, the machine would step to some unloading location, unload the selected containers, and return to the next column to be treated. This system would eliminate the need for a fixed conveyor system. The appropriateness of providing storage in the ejector chute would depend on the application of the system.

The machine descriptions given below are merely illustrative. Within the framework suggested, there are many variables which could be altered to optimise the design. The fundamental feature of both designs is that the machines can be totally 'unintelligent', since they merely perform mechanical functions in response to computer-generated instructions. There is no need for sensors to determine whether an ejector chute is full, for instance, since the computer could record the chute loading far more quickly and reliably by keeping a record of the number of containers selected.

Type I Storage/Retrieval machine

The major functional components of the Type I machine are shown in Figure 5. In this machine, transfer of containers between the column, the ejector chute and the temporary storage chute is performed by a slotted drum. Apart from the drum, the machine contains only three moving parts:

- the ejector flap, which permits containers to fall out of the drum if they are to be selected;
- the drop controller, which controls transfer between the storage column and the drum;
- the hold controller, which controls transfer between the temporary storage chute and the drum.

The machine shown in Figure 5 operates on one column at a time. The mechanism used to open and shut the column door is not shown, since it can be of virtually any type. The traversing mechanism for movement of the entire machine under the storage module is also not shown. In a multiple-bank machine, many of the control functions would be common to all banks—although some optimisation of the independence of the banks is desirable (for instance, common control of the drop controllers in each bank could result in excessive handling of some containers).

Operation of the Type I machine can be best illustrated by an example. It is assumed that a storage column contains six containers which have reference numbers 79, 56, 43, 17, 39 and 12 (in order of their positions counted from the bottom of the column). The requirement is that containers 56 and 39 should be retrieved from the stack. The steps in this process are shown in Figures 6A to 6G. The ejector flap and the drop and hold controllers are binary devices (i.e. having only two controlled states). The increment of drum rotation is 45°, and is not a continuous action.

Storage operations with this type of machine involve loading the temporary storage chute from its outer end (i.e. the end away from the drum). The machine stores the containers in the column in exactly the same way as in the retrieval operation (i.e. steps 28 to 37 on Figures 6E to 6G). Combined storage and retrieval operations may be carried out by loading the containers to be stored into the temporary storage chute before the retrieval cycle commences. Although this might be desirable in some cases, it may cause the design length of the temporary storage chute to become excessive. It should be noted that the ejector flap plays no part in the storage cycle.

A flow chart of one way of operating the Type I machine is shown in Figures 7A to 7D. The logic shown is not optimised, and differs slightly from that used in the example (particularly at the change between the unloading and reloading cycles in a retrieval operation).

Some concern might be felt at the reliability of the drive mechanism for the drum, since intermittent drives are notoriously unreliable. However, this device will operate in a relatively unhurried manner, and the accelerations induced should not be high. A further point is that the loads on the various components are fairly low (the maximum load being approximately the weight of a column of loaded containers).

Type II Storage/Retrieval machine

This machine performs the same functions as the Type I machine, but the functional components are of a somewhat different type. A diagram of the Type II machine is given in Figure 8. As shown on this diagram, the machine has drop and hold controllers, together with an ejector flap. However, the functions which the drum performs in the Type I machine are performed by column retainers and temporary storage retainers. These devices ensure that only one container is released from the column or the temporary storage chute at a time. A feature of this machine is that it has two temporary storage chutes, one on top of the other. This feature results in a considerable reduction in the length of the chutes, at the cost of slight additional complication in the design. This particular feature could also be incorporated in the design of the Type I machine, but it would be more difficult, due to the rotary nature of the transfer process. Either machine could be fitted with multiple ejector chutes, although only one is shown in Figure 5 and Figure 8.

Since the underlying principles of the two types are very similar, the operation of the Type II machine is not described in detail. Descriptions of the steps involved in various transfer operations are given in Tables 1 to 3. The steps involved in storage operations (transfers from either temporary storage chute to the column) are effectively the reverse of the corresponding retrieval operations.

CONTROL SYSTEM

The basis of the storage/retrieval system is that as many functions as possible should be performed within the central control system. In this way, the impressive logical capabilities and reliability of modern digital computers may be used to the greatest advantage. All of the functions described in previous sections can be controlled with ease by a quite small computer. The scale of the installation will be the major determinant of computer size. Speed should be no problem, except in cases where a large number of storage modules is to be controlled by one computer.

Clerical operations

A most important feature of the system is that as many clerical operations as possible are performed by the computer. Some of these operations are:

- generating and maintaining correspondence tables which show the relationship between the physical reference number and the contents of each container;
- generating and maintaining correspondence tables for the reference number and the physical location of a container within a storage module;
- recording status changes in the addresses of containers in each column;
- recording arrivals and departures from the system, so that system operations are recorded on a regular basis;
- accepting and implementing operator instructions.

Peripheral operations

It is obvious that there are many operations which must be performed before incoming containers can be physically stored in the system, or after outgoing containers have left the system. Virtually all of these operations can be performed under computer control. They include:

- control of reading machines at entry and exit;
- directing operations involved in routing containers from an external entry point to the appropriate storage module;
- directing operations involved in routing containers from a storage module to the exit area;
- control of peripheral loading, unloading and sorting operations;

- control of alarm devices and indicators which alert operators of malfunctions or important status changes.

Storage/Retrieval operations

Most of the control functions involved in storage/retrieval operations may be summarised as:

- maintain records of containers in the ejector chutes and temporary storage chutes of each storage/retrieval machine;
- initiate remedial action if abnormal conditions are detected in container records;
- position the storage/retrieval machine under areas of the module from which containers are to be retrieved;
- control the mechanical operations involved in the storage and retrieval of containers;
- control position of the machines after storage or retrieval passes have been completed;
- monitor any feedback information and provide the operator with indications of malfunctions;
- in sophisticated systems, control 'on-condition' maintenance procedures (in which maintenance requirements are assessed by analysing machine performance).

It is useful to compare the characteristics and operation of the proposed system with alternative methods of performing the same tasks. The conventional storage and retrieval systems usually consist of banks of double-sided shelving, with aisles between each bank. Storage and retrieval machines operate in each aisle, and can store or retrieve containers located on the shelves on each side of the aisle. This system is illustrated in Figure 9.

The conventional system varies fundamentally from the proposed system in having a specific physical position for each container. While this certainly simplifies the logic involved in storage and retrieval operations, it incurs a very heavy penalty in wasted space. On the other hand, storage/retrieval logic is not a major problem in virtually any system which contains a digital computer. The wasted space in a conventional system is a result of two major causes. One problem is that shelves may only be grouped in pairs, with an aisle between each pair, which results in immediate area and volume overheads which may exceed 100 per cent. The second is that each container on a shelf must have sufficient clearance from its neighbours to permit manipulation by the storage/retrieval machines—with small packages, this could introduce area overheads of up to 400 per cent and volume overheads up to 800 per cent.

Both area and volume overheads are minimised with the proposed system. The magnitudes of the savings would vary widely, but overheads should almost always be less than about 100 per cent (allowing for maintenance aisles between storage modules).

Another problem which can be encountered with conventional systems is somewhat more insidious, and is best described by example. If a storage/retrieval system of the design shown in Figure 9 contains, say, 100,000 containers arranged in ten aisles, each storage and retrieval machine will operate on 10,000 containers. If a particular retrieval operation involves retrieval of 10,000 containers, then under 'average' conditions, each machine might be expected to retrieve about 1,000 containers. However, there are small (but not negligible) probabilities that:

- many more than 1,000 containers (and even the whole 10,000) might have to be retrieved by one machine;
- the containers to be retrieved from one aisle might be arranged in an extremely unfavourable manner;
- both circumstances might occur simultaneously.

These considerations lead to a very delicate balance between the number of aisles and the probability that a conventional system will not be able to cope with its speed requirements. The result is usually that the system is designed with more aisles and machines than are needed to handle average conditions. This particular short-coming is intrinsic in random storage/retrieval systems in which each machine is assigned to a large number of containers. The proposed system reduces this problem, because it can be designed to operate on *all* containers in the system. The extent of improvement cannot be estimated intuitively, since it is a function of many variables. It is possible that there may even be a disadvantage in using the proposed system in some cases.

The major penalty involved in gaining the advantages of reduced space and improved predictability is that containers which are not required are handled in the course of selecting other containers. The significance of this penalty cannot be evaluated without a thorough analysis of particular applications.

Table 4 summarises comparisons between the conventional systems and the proposed system.

CONCLUSIONS

This paper provides a broad description of a semi-random materials storage/retrieval system which differs radically from conventional systems. Some of the fundamental properties of the system make it unsuitable for use in certain applications, whilst leading to significant advantages in others. It is strongly emphasised that intuitive judgments of the applicability of this system are not adequate, and that it should be properly studied before use in any particular materials handling task.

The advantages of using the system stem from a re-arrangement of control functions between mechanical equipment and a digital computer. In effect, the system is designed around the computer, and uses the computer's logical capabilities to simplify mechanical functions and to save storage area and volume. The system is deliberately designed so that it does not attempt to automate conventional manual procedures.

Although the mechanical equipment used is simple, reservations may be expressed about its reliability, and the ability of the containers to withstand the stress of repetitive handling. These factors are clearly important. However, the basic characteristics of the system can be exploited using a wide range of materials and mechanical devices, so it should be practicable to design a satisfactory system for any particular application.

TABLE 1: TRANSFER FROM COLUMN TO LOWER TEMPORARY STORAGE CHUTE (TYPE II MACHINE)

Step		*Operation or Status*	
1	Initial conditions:	Ejector flap	: UP
		Chute selector	: IN
		Drop controller	: DOWN
		Hold controller	: IN
		Column retainers	: IN
		Storage retainers	: IN
2	Drop controller raised until it is supporting containers in column.		
3	Column retainers: OUT.		
4	Drop controller lowered until bottom container is clear of the column.		
5	Column retainers: IN (supporting remainder of column).		
6	Drop controller lowered until container is resting on continuation of lower temporary storage chute (drop controller then proceeds to DOWN position).		
7	Hold controller moved OUT — pushing container towards others in chute.		
8	Lower storage chute retainer: OUT.		
9	Hold controller moved fully OUT — pushing container into lower chute.		
10	Lower storage chute retainer: IN (supporting entire set of containers, including the one added, in the chute).		
11	Hold controller: IN.		
12	Final conditions: as for Step 1.		

TABLE 2: TRANSFER FROM COLUMN TO UPPER TEMPORARY STORAGE CHUTE (TYPE II MACHINE)

Step		*Operation or Status*	
1	Initial conditions:	Ejector flap	: UP
		Chute selector	: OUT
		Drop controller	: DOWN
		Hold controller	: IN
		Column retainers	: IN
		Storage retainers	: IN
2 to 5	As in Table 1.		
6	Drop controller lowered until container is resting on temporary storage chute selector (drop controller moves to DOWN position).		
7	Hold controller moved OUT — pushing container towards others in chute.		
8	Upper storage chute retainer: OUT.		
9	Hold controller moved fully OUT — pushing container into upper chute.		
10	Upper storage chute retainer: IN (supporting entire set of containers, including the one added, in the chute).		
11	Hold controller: IN.		
12	Final conditions: as for Step 1.		

TABLE 3: TRANSFER FROM COLUMN TO EJECTOR CHUTE (TYPE II MACHINE)

Step		*Operation or Status*	
1	Initial conditions:	Ejector flap	: DOWN
		Chute selector	: irrelevant
		Drop controller	: DOWN
		Hold controller	: IN
		Column retainers	: IN
		Storage retainers	: IN

2 to 5 As in Table 1.

6 Drop controller continues DOWN — container is caught by ejector flap and rolls into ejector chute.

7 Final conditions: as in Step 1.

TABLE 4: COMPARISON OF CONVENTIONAL AND PROPOSED SYSTEMS

Characteristic	*Conventional System*	*Proposed System*
Area and volume overheads	High	Low
Predictability	Poor	Good*
Reliability	Good	Very good*
Manual operation in case of breakdown	Yes	Difficult
Current equipment	Yes	No
Effective use of computer	No	Yes
Flexibility of container shape	Limited	No
Repetitive handling of containers	No	Yes
Low-cost storage module	No	Yes

* Based on judgement and requiring verification by investigation.

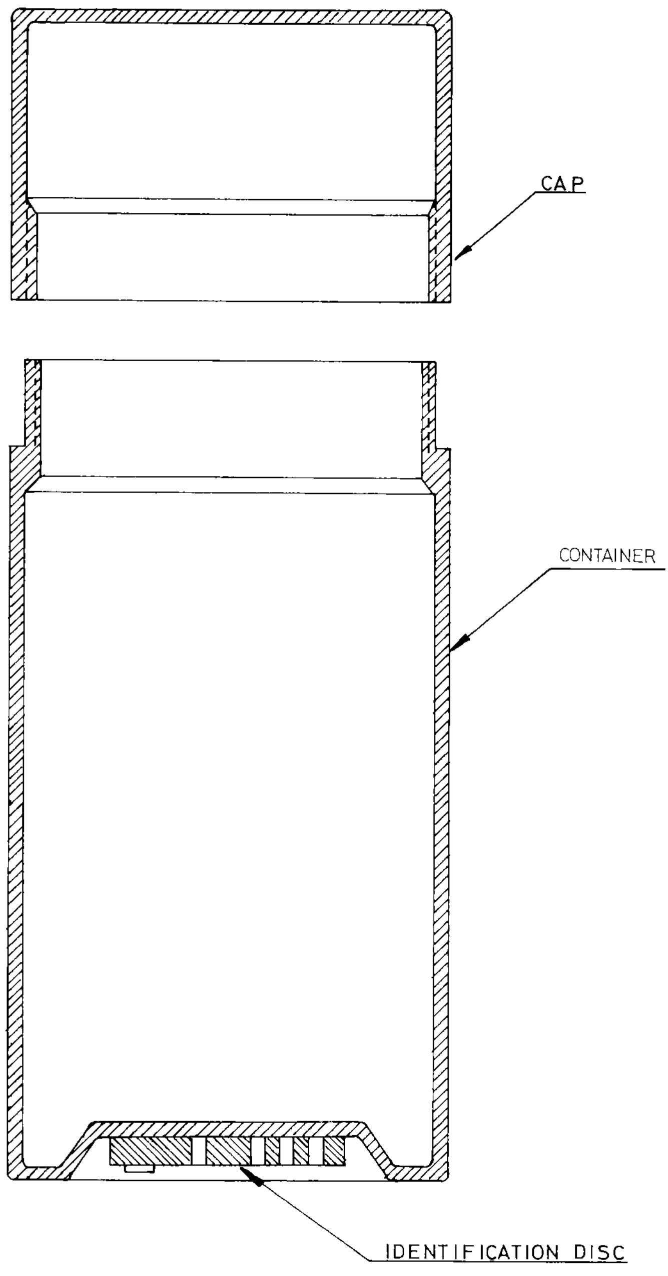
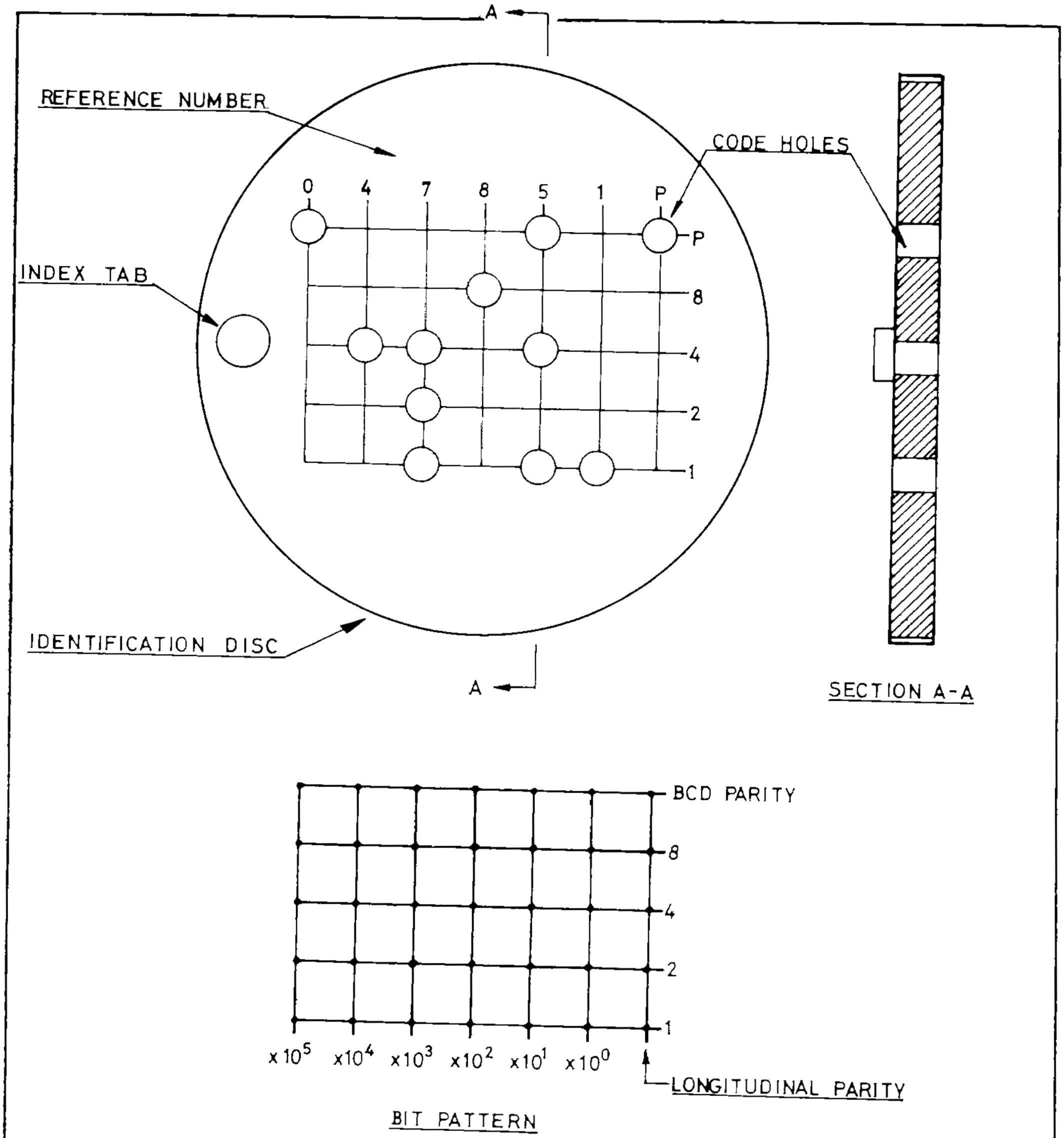


FIGURE 1. CONTAINER SECTION



BCD CODE	DECIMAL DIGIT									
	0	1	2	3	4	5	6	7	8	9
PARITY	1	0	0	1	0	1	1	0	0	1
8	0	0	0	0	0	0	0	0	1	1
4	0	0	0	0	1	1	1	1	0	0
2	0	0	1	1	0	0	1	1	0	0
1	0	1	0	1	0	1	0	1	0	1

BCD CODE

FIGURE 2. IDENTIFICATION DISC AND CODING SYSTEM

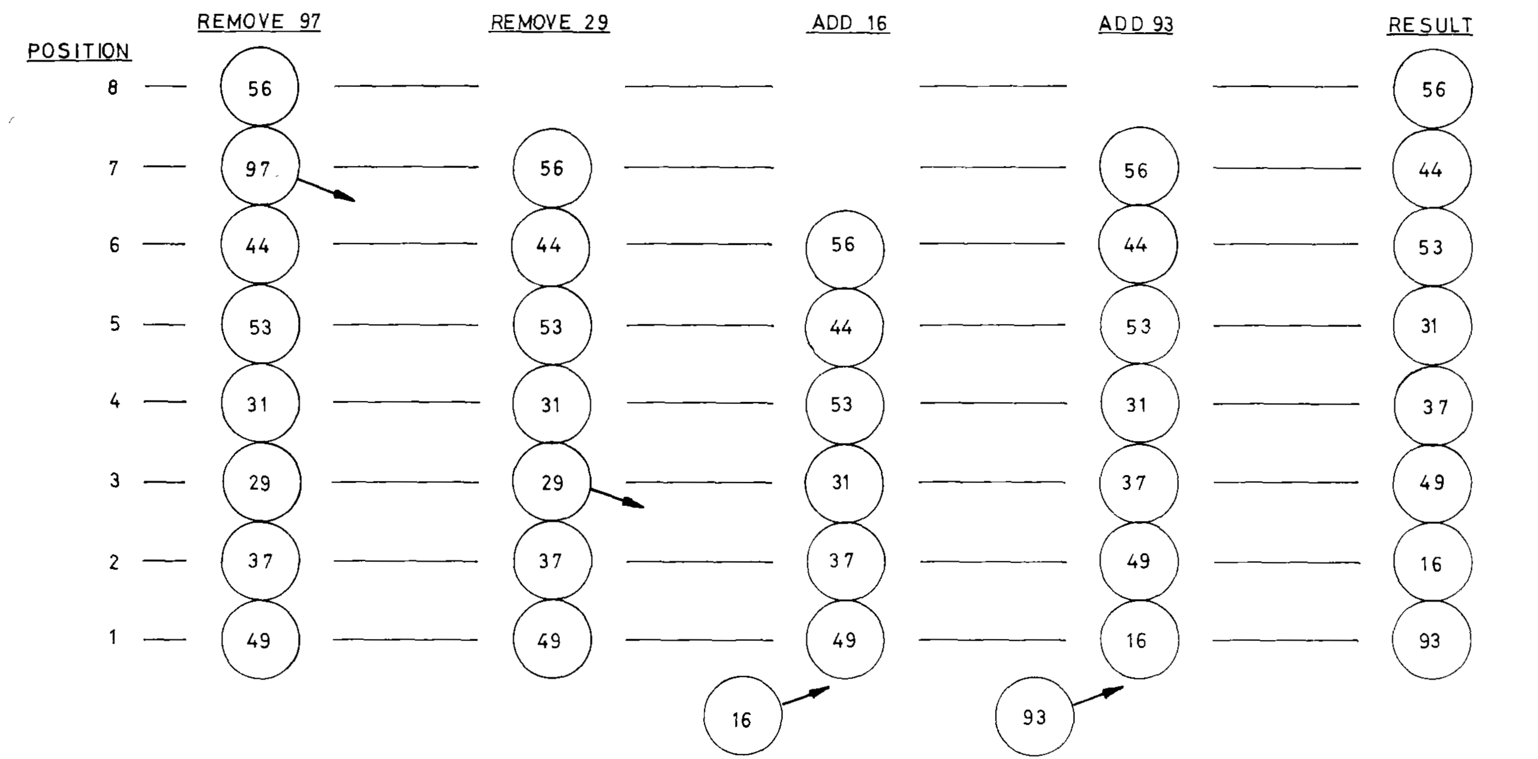


FIGURE 3. DYNAMIC STACKING CONCEPT

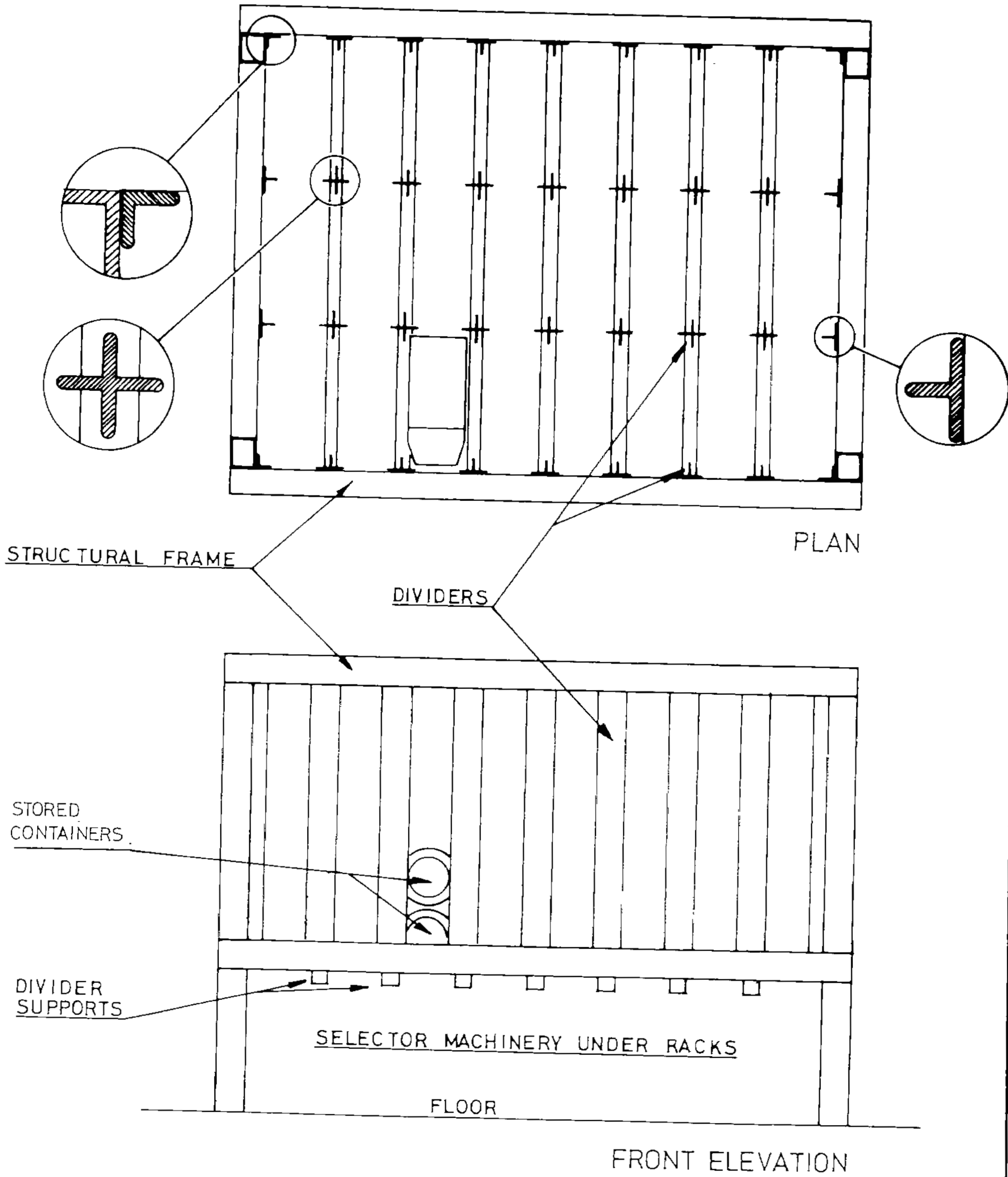


FIGURE 4. STORAGE MODULE

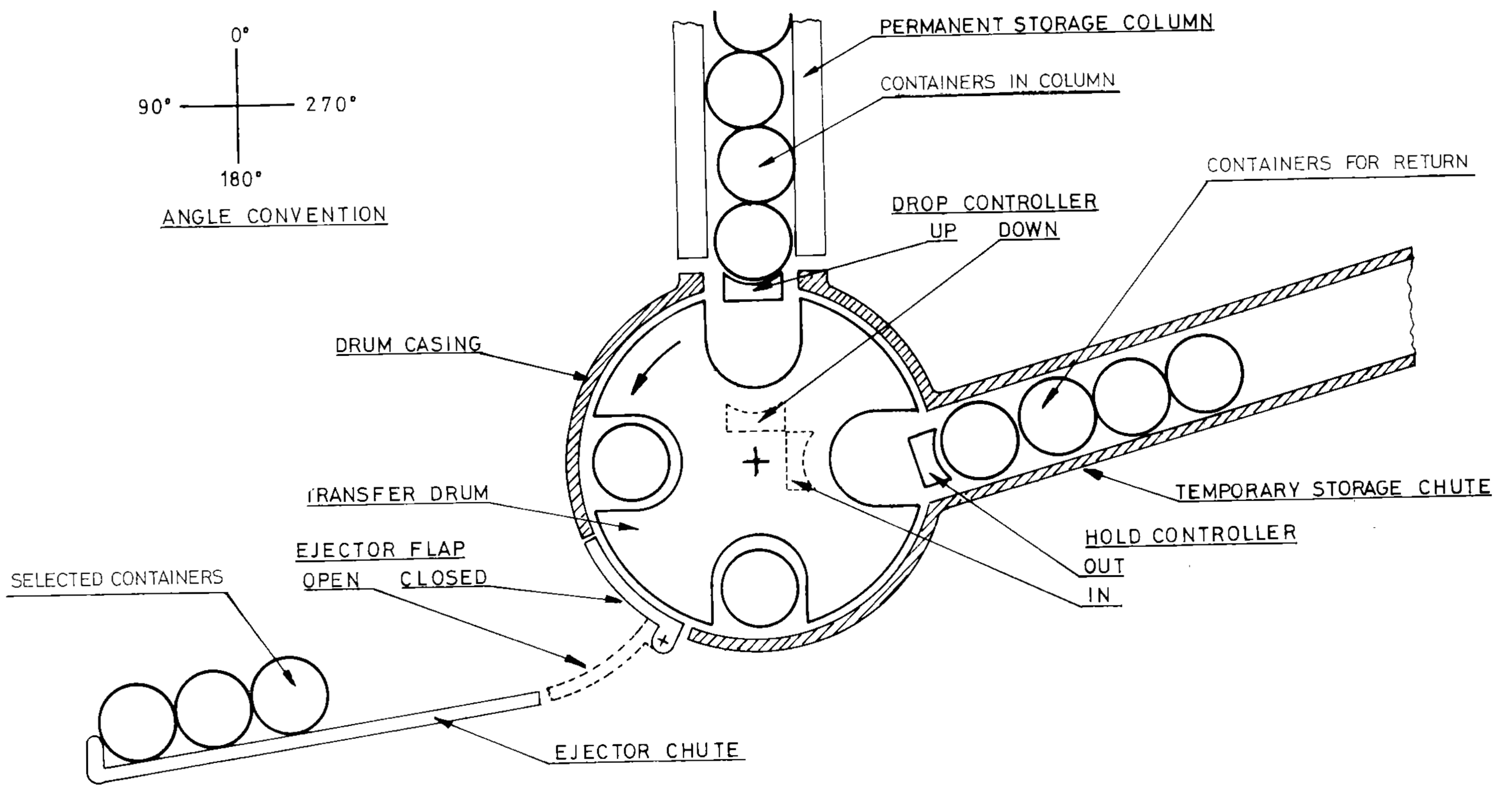


FIGURE 5. TYPE I STORAGE/RETRIEVAL MACHINE

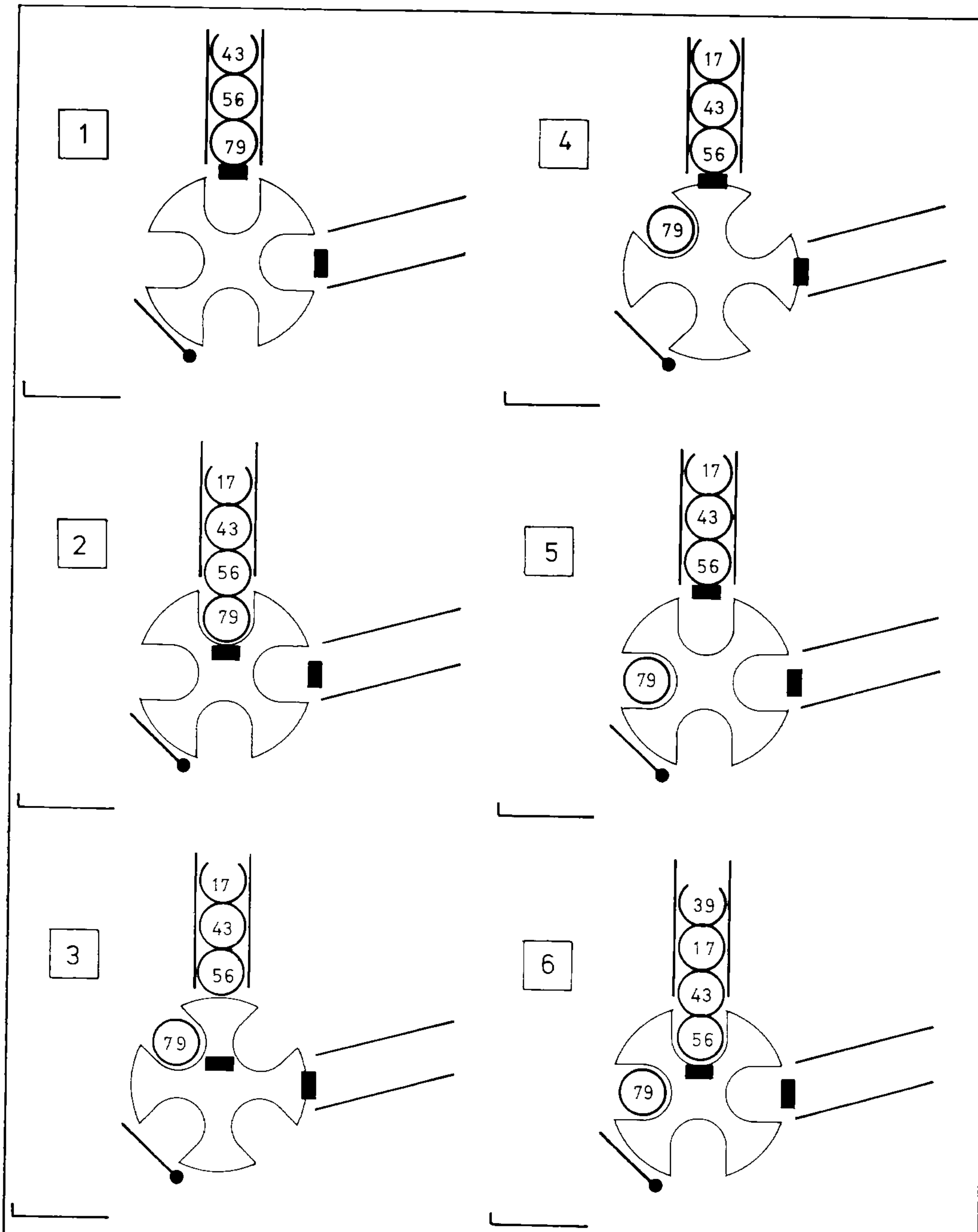


FIGURE 6A. RETRIEVAL OPERATION - TYPE I MACHINE

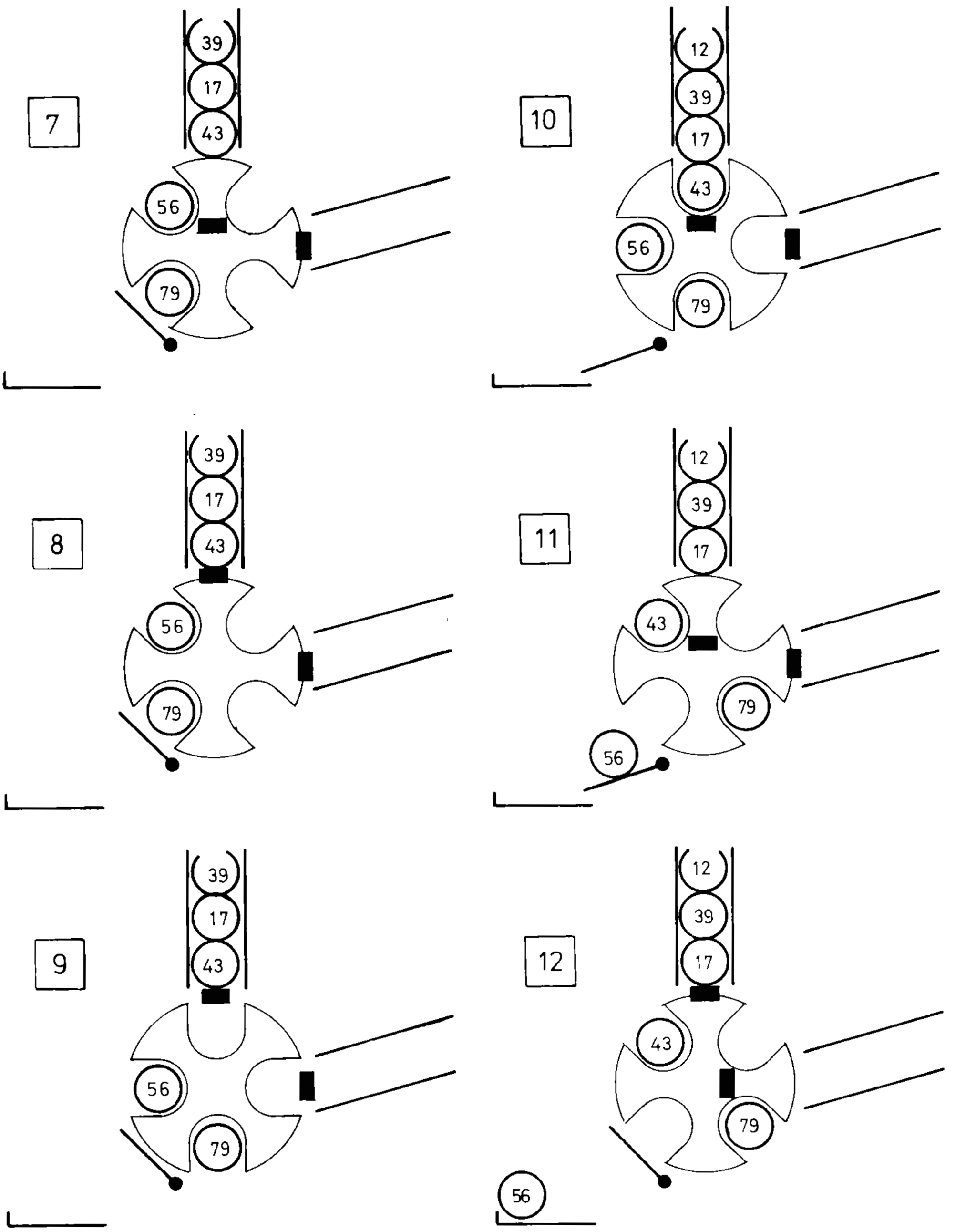


FIGURE 6B. RETRIEVAL OPERATION (CONTINUED)

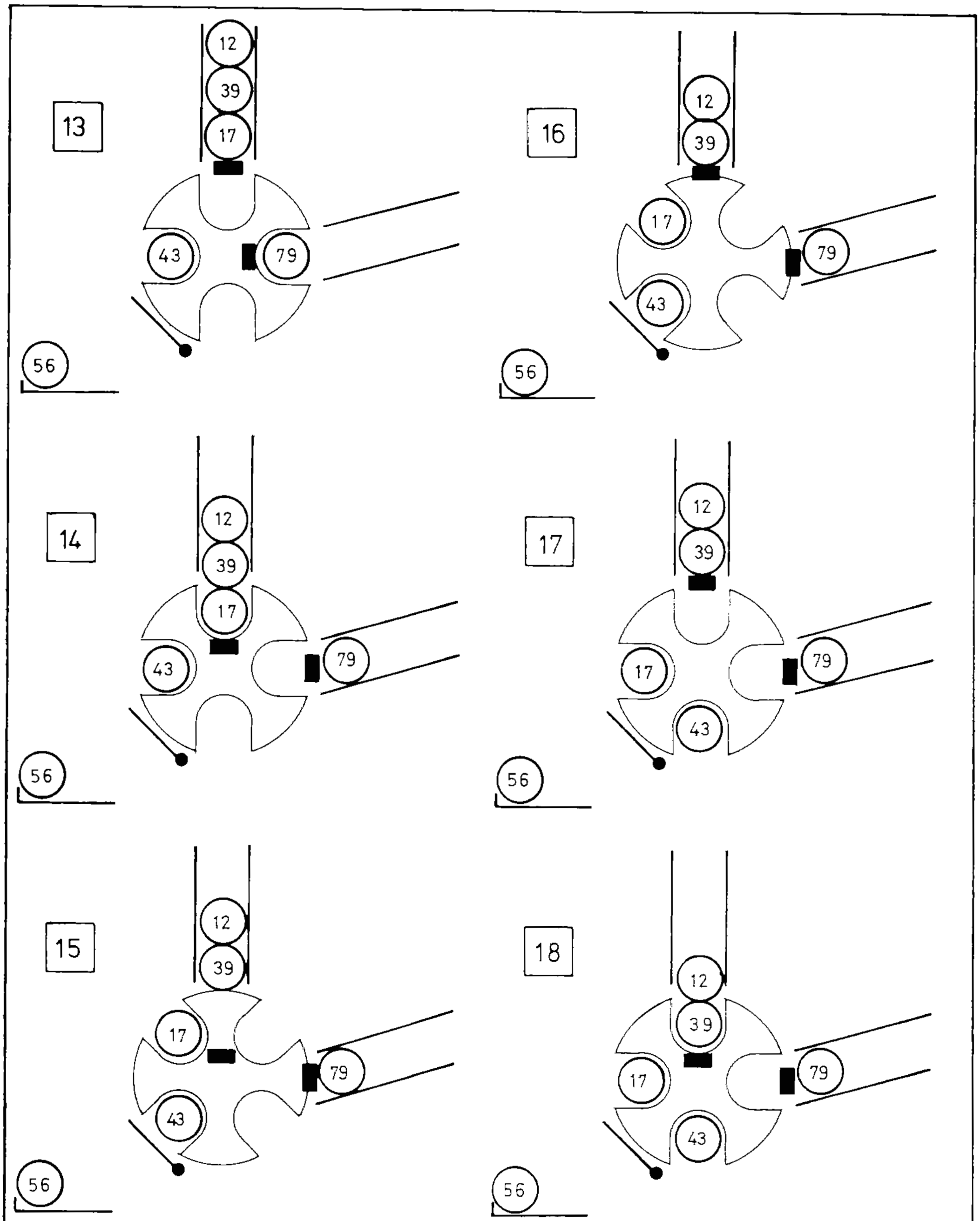


FIGURE 6C. RETRIEVAL OPERATION (CONTINUED)

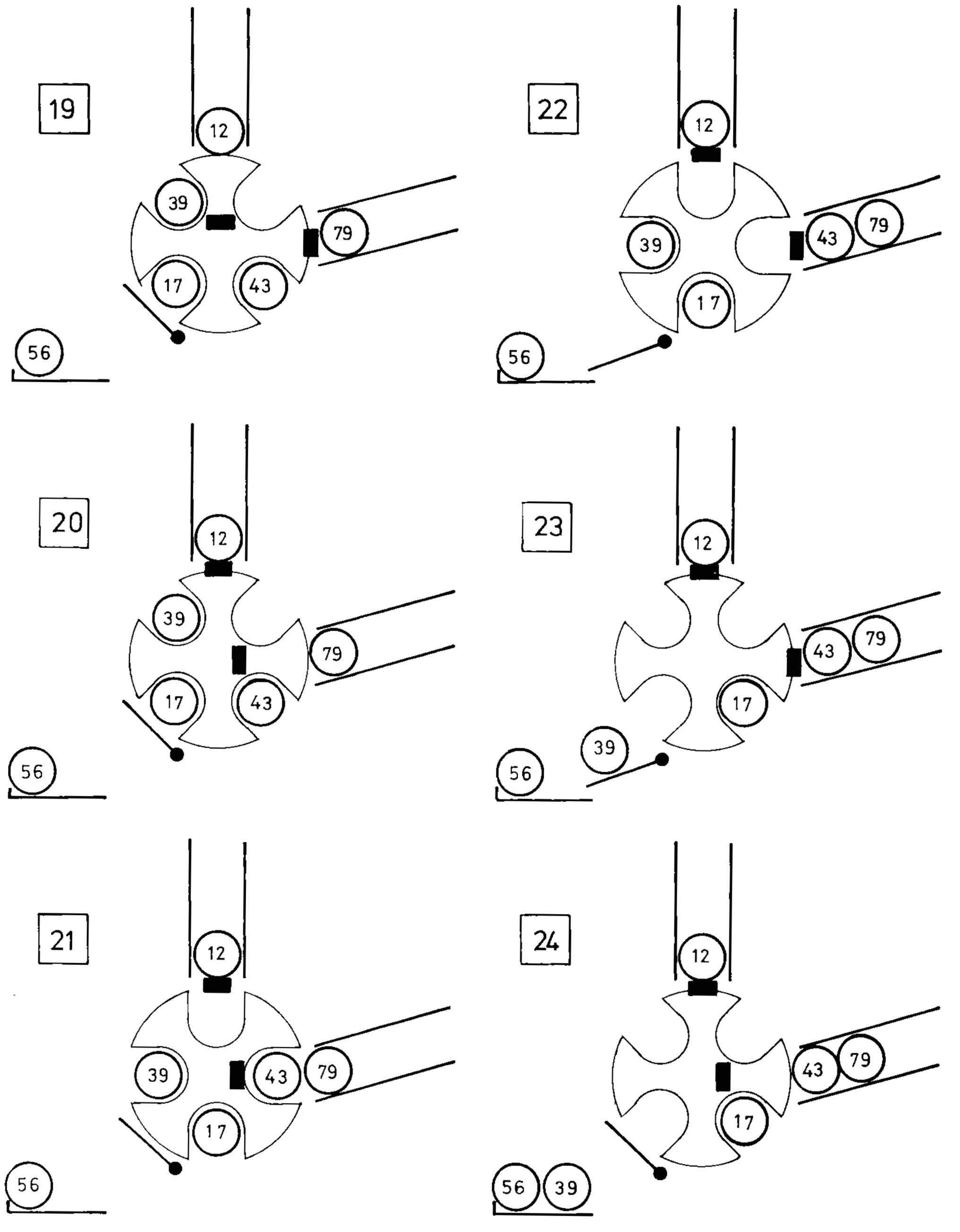


FIGURE 6D. RETRIEVAL OPERATION (CONTINUED)

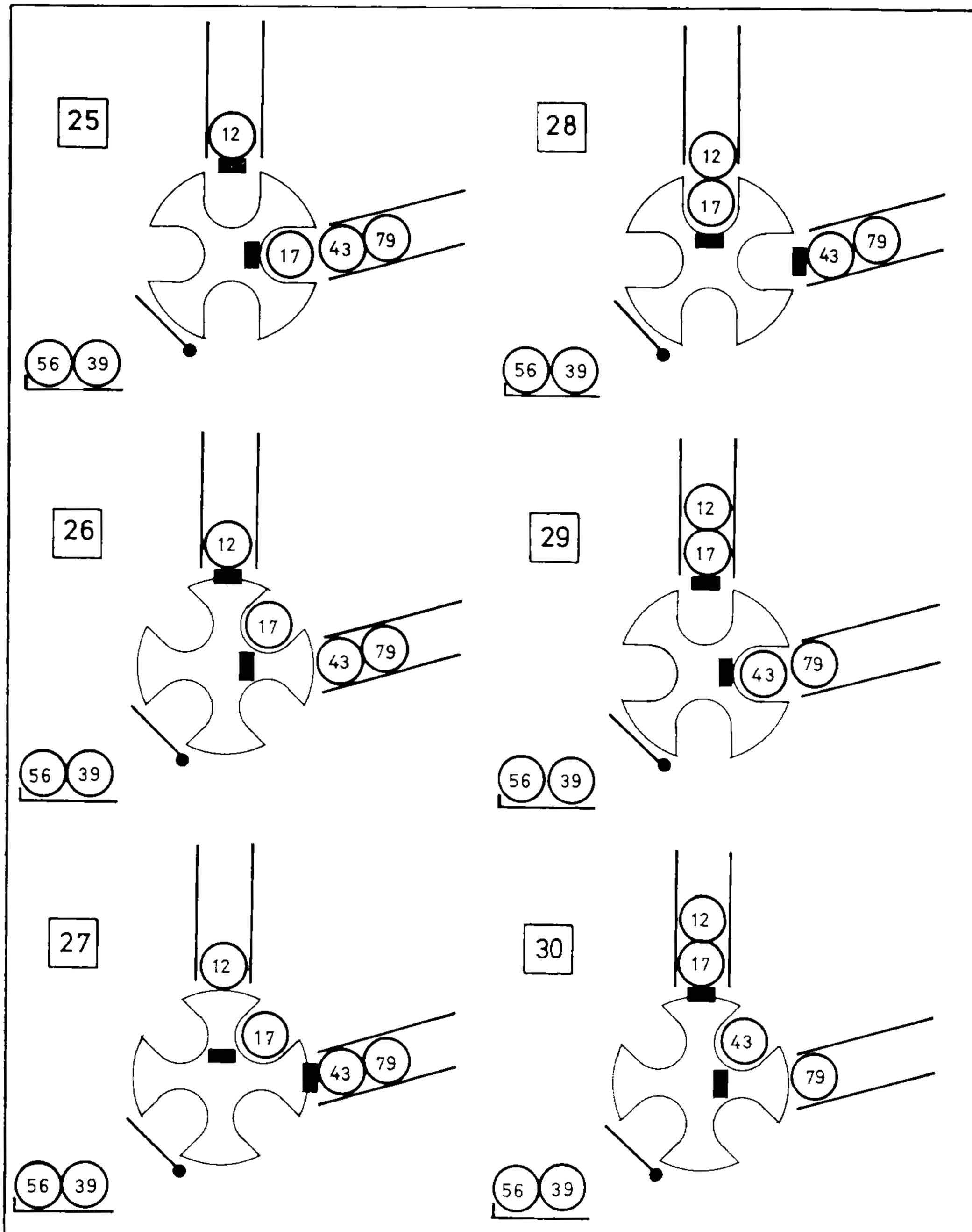


FIGURE 6E. RETRIEVAL OPERATION (CONTINUED)

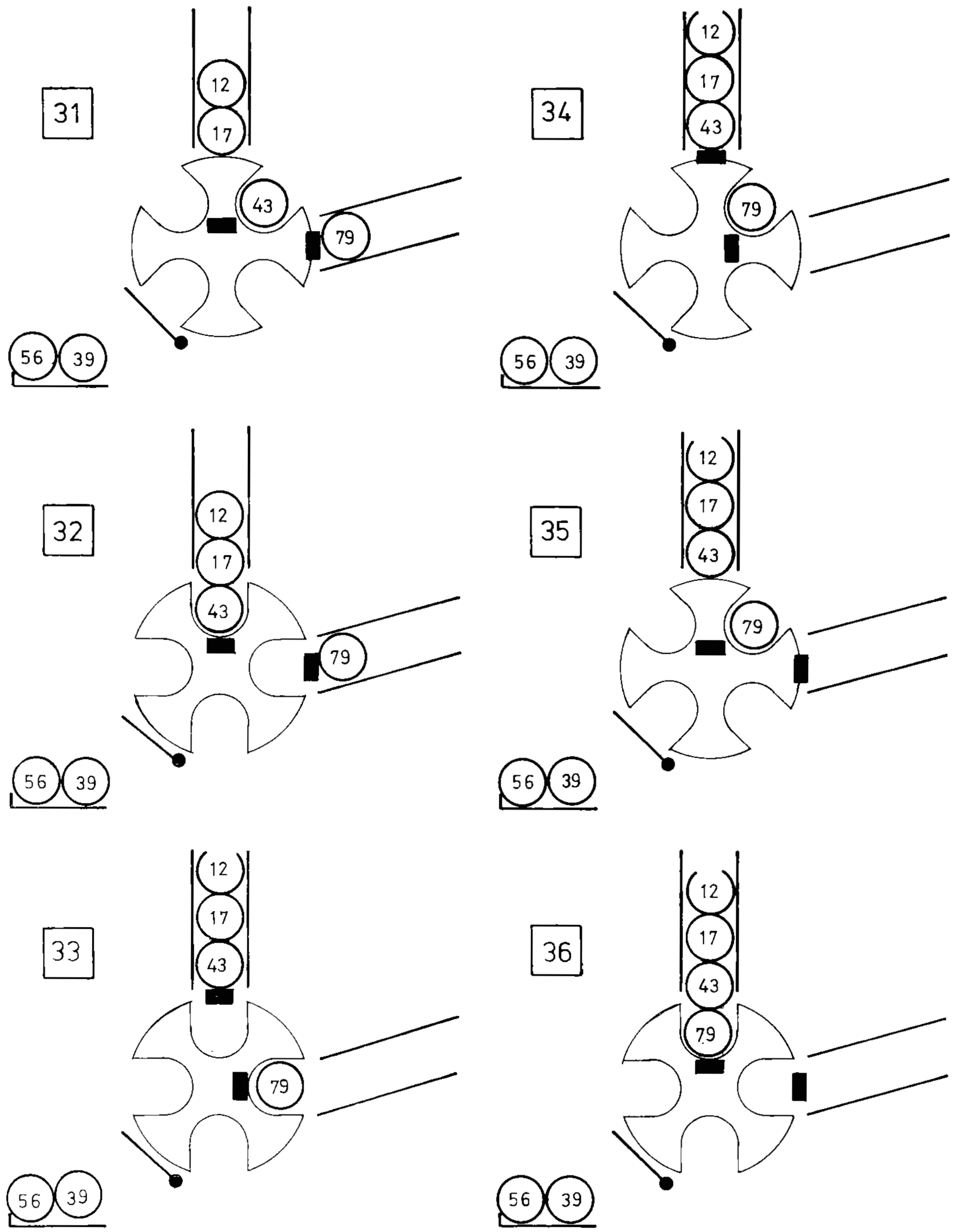
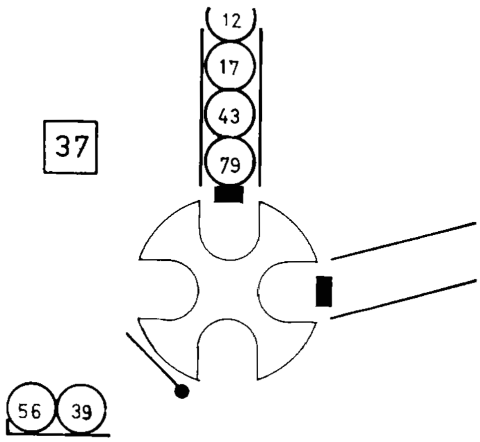


FIGURE 6F. RETRIEVAL OPERATION (CONTINUED)



STATUS OF STACKS

Column Position	Start	Finish
1	79	79
2	56	43
3	43	17
4	17	12
5	39	-
6	12	-
Exit Position		
1	-	56
2	-	39

FIGURE 6G. RETRIEVAL OPERATION (CONTINUED)

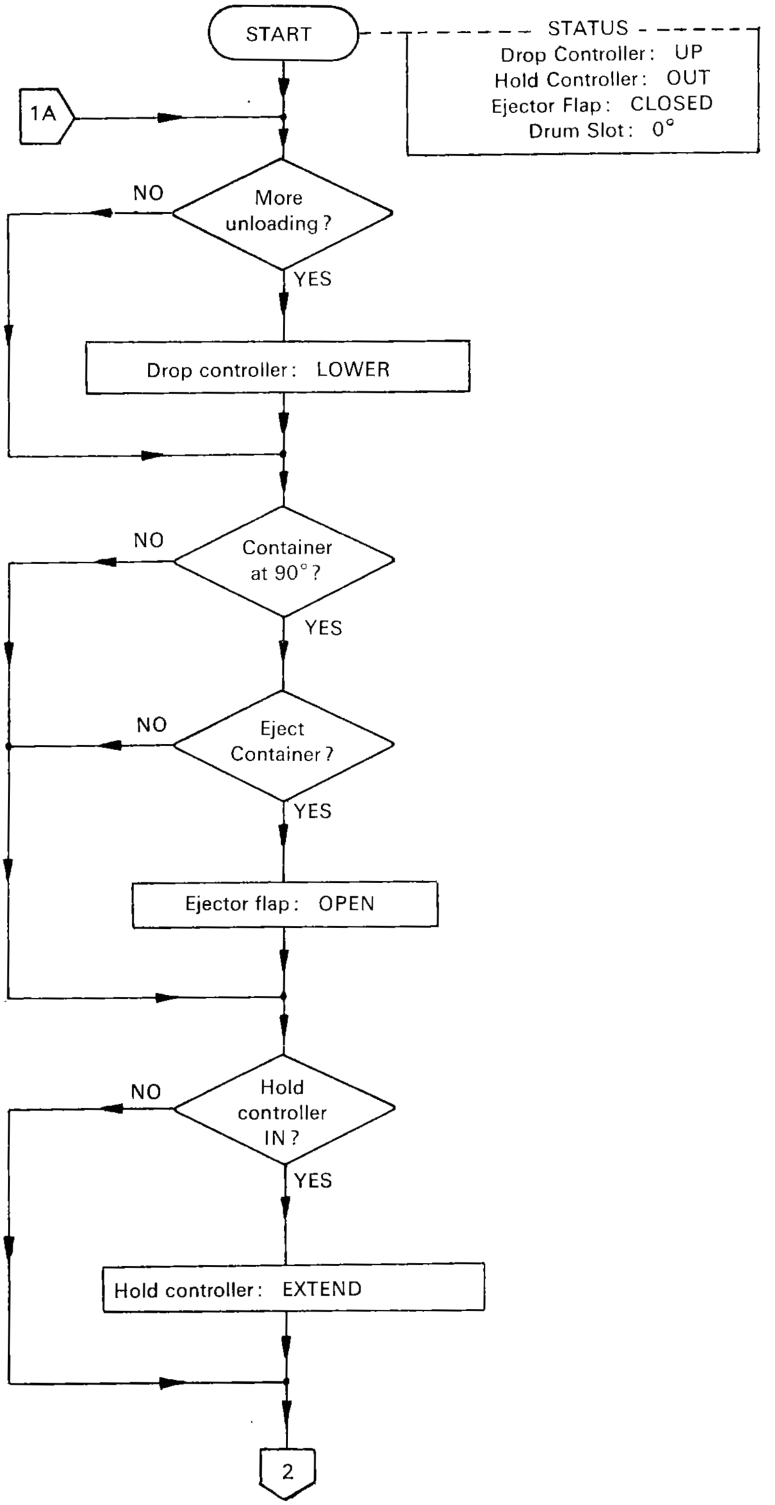


FIGURE 7A. RETRIEVAL FLOWCHART - TYPE I MACHINE

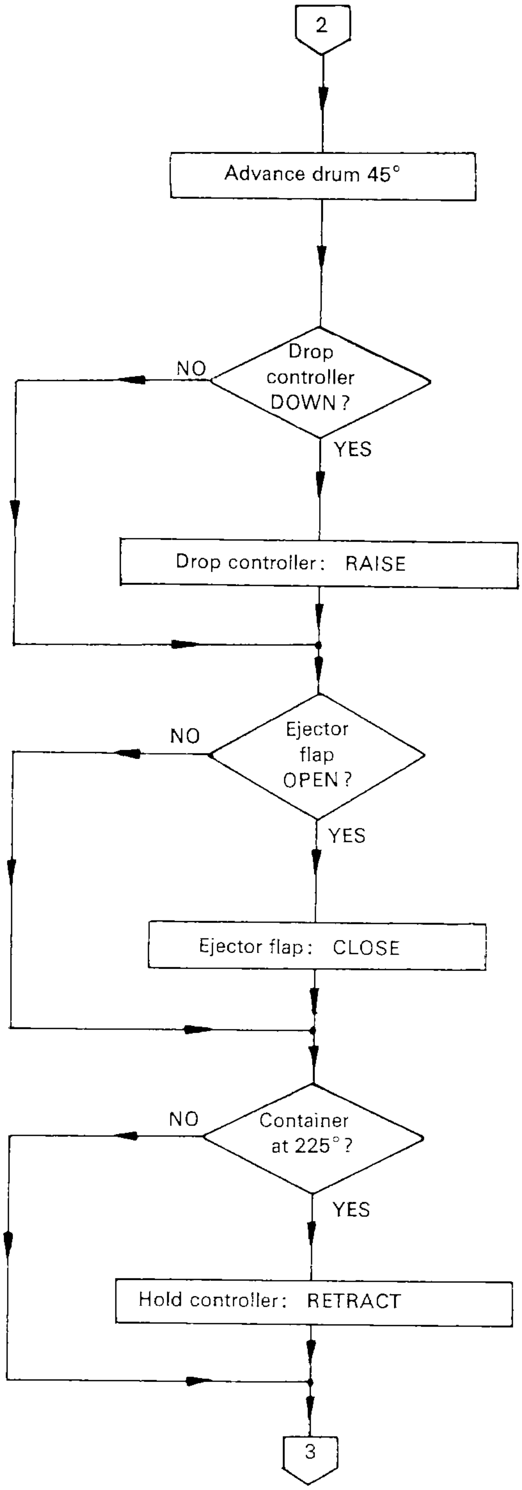


FIGURE 7B. RETRIEVAL FLOWCHART (CONTINUED)

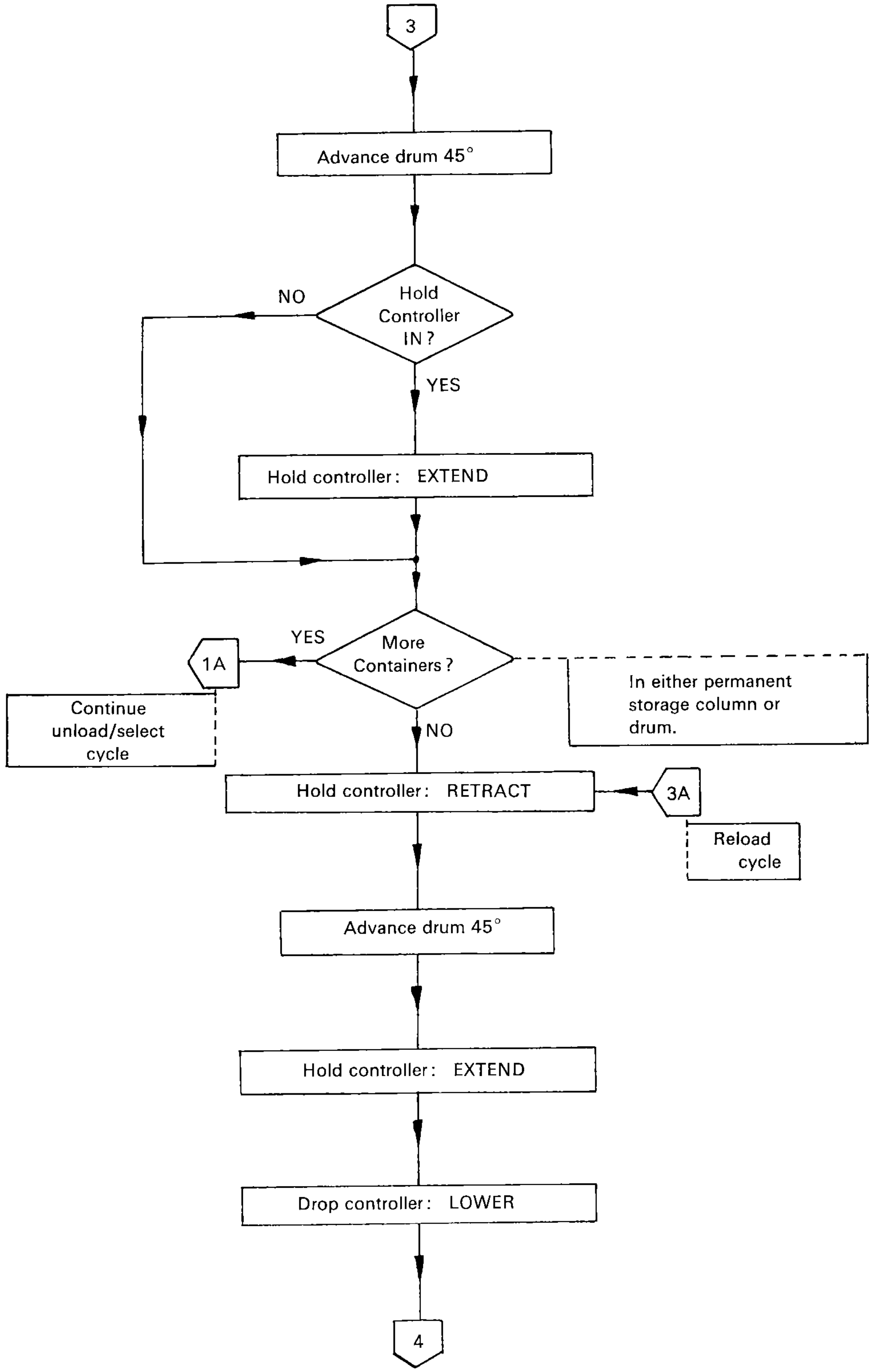


FIGURE 7C. RETRIEVAL FLOWCHART (CONTINUED)

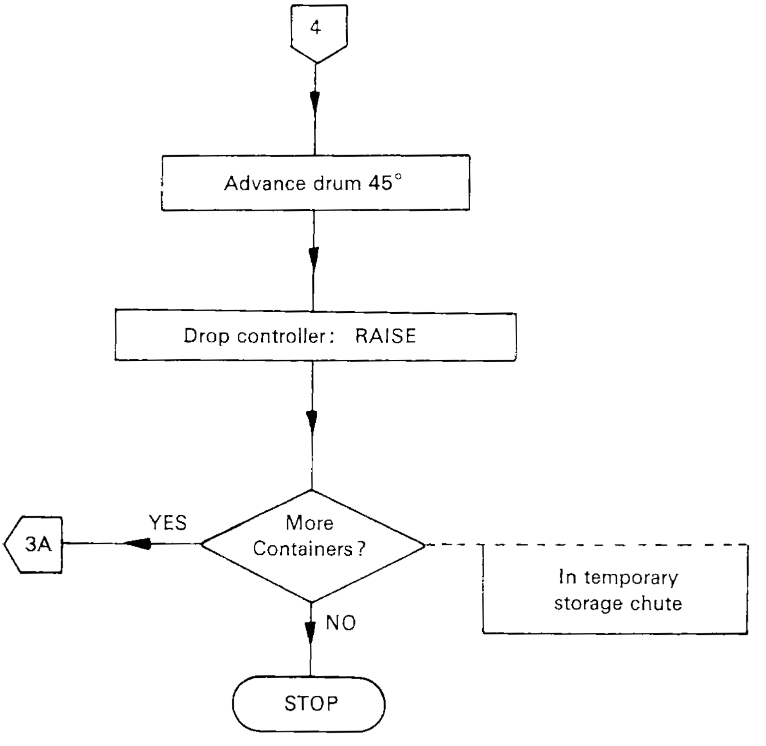


FIGURE 7D. RETRIEVAL FLOWCHART (CONTINUED)

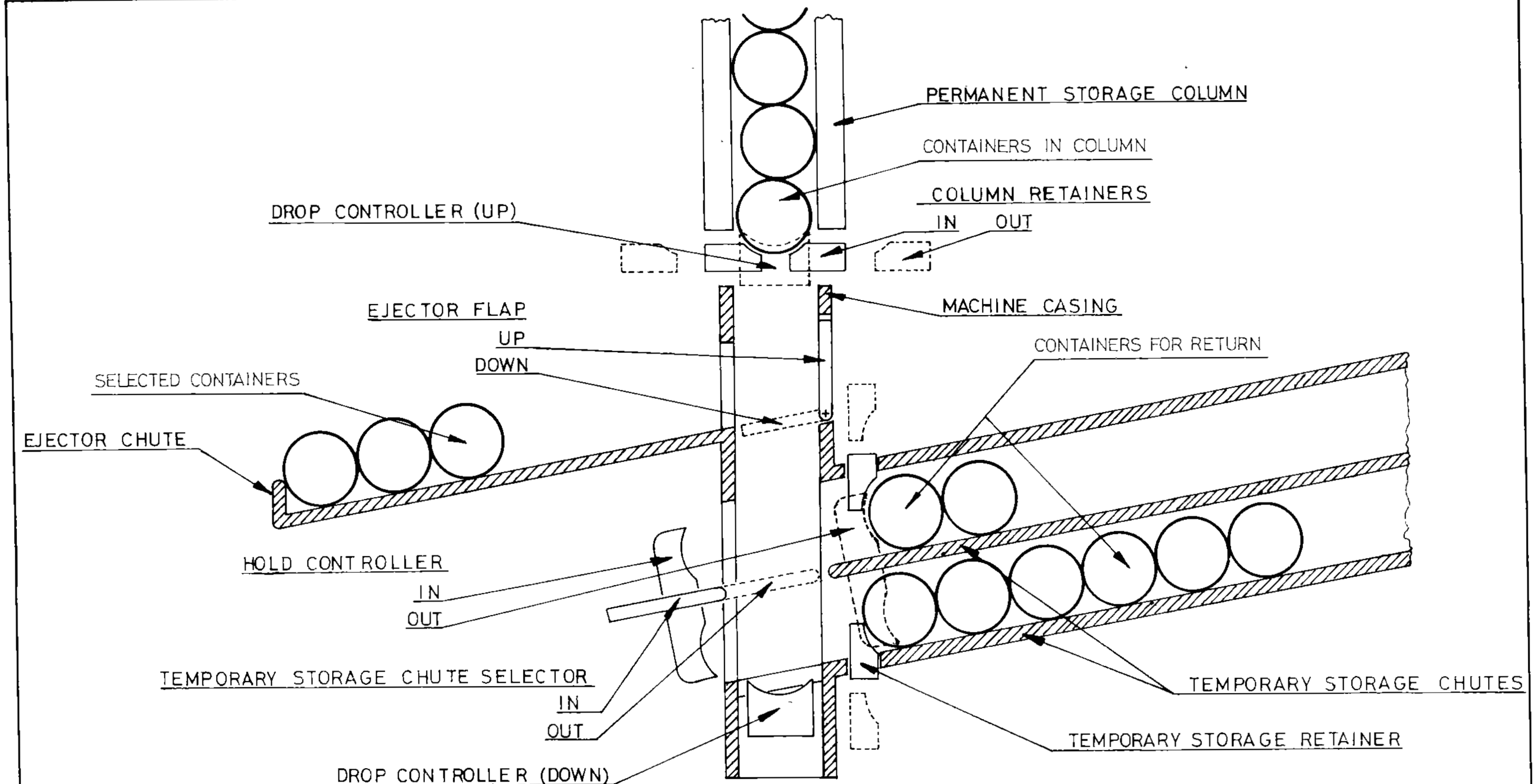


FIGURE 8. TYPE II STORAGE/RETRIEVAL MACHINE

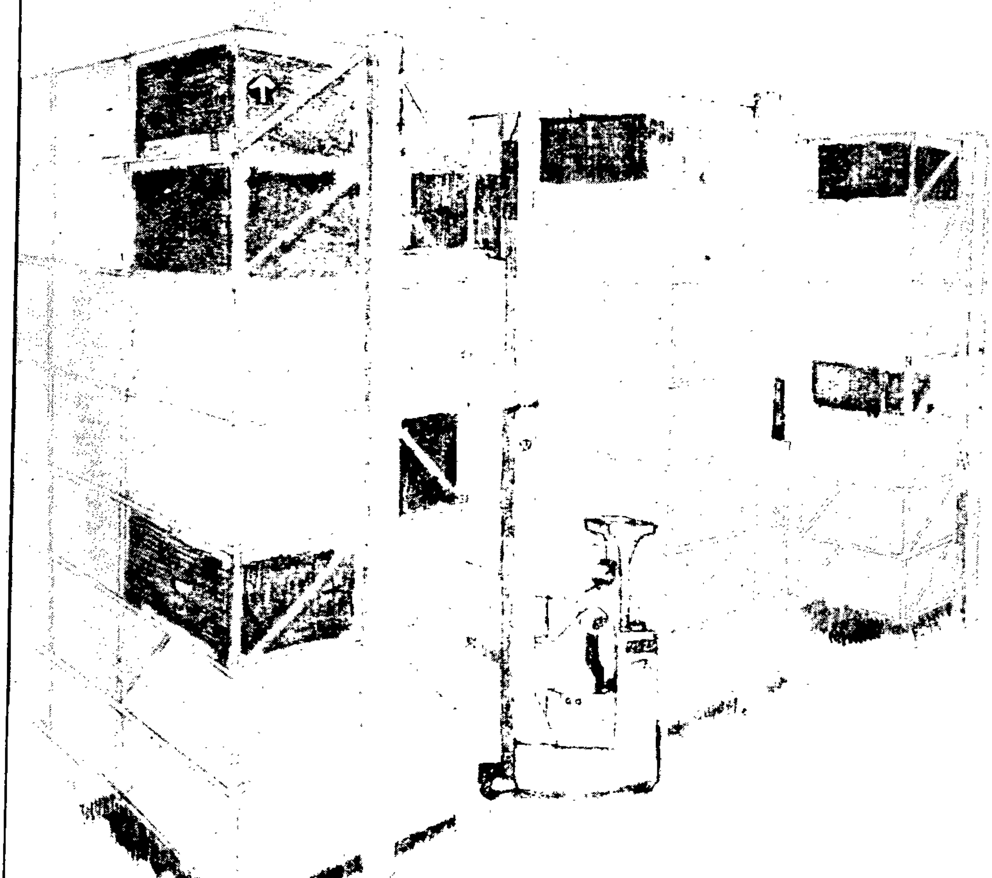


FIGURE 9 CONVENTIONAL STORAGE/RETRIEVAL SYSTEM