2 AUTOMATED FLOW LINES

An automated flow line consists of several machines or workstations which are linked together by work handling devices that transfer parts between the stations. The transfer of workparts occurs automatically and the workstations carry out their specialized functions automatically. The flow line can be symbolized as shown in Figure 1 using the symbols presented in Table 1. A raw workpart enters one end of the line and the processing steps are performed sequentially as the part moves from one station to the next. It is possible to incorporate buffer storage zones into the flow line, either at a single location or between every workstation. It is also possible to include inspection stations in the line to automatically perform intermediate checks on the quality of the workparts. Manual stations might also be located along the flow line to perform certain operations which are difficult or uneconomical to automate.

![Figure 1 In-line configuration](image)

![Figure 2 symbols used in production systems diagrams](image)
The objectives of the use of flow line automation are, therefore:

- To reduce labor costs
- To increase production rates
- To reduce work-in-process
- To minimize distances moved between operations
- To achieve specialization of operations
- To achieve integration of operations

Configurations of automated flow line.

1) **In-line type**

The *in-line* configuration consists of a sequence of workstations in a more-or-less straight-line arrangement as shown in figure 1. An example of an in-line transfer machine used for metal-cutting operations is illustrated in Figure 4 and 5.

![Figure 4 Example of 20 stations In-line](image)

![Figure 5 Example of 20 stations In-line configuration](image)
2) Segmented In-Line Type

The segmented in-line configuration consists of two or more straight-line arrangements which are usually perpendicular to each other with L-Shaped or U-shaped or Rectangular shaped as shown in figure 5-7. The flow of work can take a few 90° turns, either for workpieces reorientation, factory layout limitations, or other reasons, and still qualify as a straight-line configuration.

Figure 5 L-shaped configuration

Figure 6 U-shaped configuration

Figure 7 Rectangular-shaped configuration
3) **Rotary type**

In the *rotary* configuration, the workparts are indexed around a circular table or dial. The workstations are stationary and usually located around the outside periphery of the dial. The parts ride on the rotating table and are registered or positioned, in turn, at each station for its processing or assembly operation. This type of equipment is often referred to as an *indexing machine* or *dial index machine* and the configuration is shown in Figure 8 and example of six station rotary shown in figure 9.
METHODS OF WORKPART TRANSPORT

The transfer mechanism of the automated flow line must not only move the partially completed workparts or assemblies between adjacent stations, it must also orient and locate the parts in the correct position for processing at each station. The general methods of transporting workpieces on flow lines can be classified into the following three categories:

1. Continuous transfer
2. Intermittent or synchronous transfer
3. Asynchronous or power-and-free transfer

The most appropriate type of transport system for a given application depends on such factors as:

- The types of operation to be performed
- The number of stations on the line
- The weight and size of the work parts
- Whether manual stations are included on the line
- Production rate requirements
- Balancing the various process times on the line

1) Continuous transfer

With the continuous method of transfer, the workparts are moved continuously at constant speed. This requires the workheads to move during processing in order to maintain continuous registration with the workpart. For some types of operations, this movement of the workheads during processing is not feasible. It would be difficult, for example, to use this type of system on a machining transfer line because of inertia problems due to the size and weight of the workheads. In other cases, continuous transfer would be very practical. Examples of its use are in beverage bottling operations, packaging, manual assembly operations where the human operator can move with the moving flow line, and relatively simple automatic assembly tasks. In some bottling operations, for instance, the bottles are transported around a continuously rotating drum. Beverage is discharged into the moving bottles by spouts located at the drum's periphery. The advantage of this application is that the liquid beverage is kept moving at a steady speed and hence there are no inertia problems.

Continuous transfer systems are relatively easy to design and fabricate and can achieve a high rate of production.
2) **Intermittent transfer**

As the name suggests, in this method the workpieces are transported with an intermittent or discontinuous motion. The workstations are fixed in position and the parts are moved between stations and then registered at the proper locations for processing. All workparts are transported at the same time and, for this reason, the term "synchronous transfer system" is also used to describe this method of workpart transport.

3) **Asynchronous transfer**

This system of transfer, also referred to as a "power-and-free system," allows each workpart to move to the next station when processing at the current station has been completed. Each part moves independently of other parts. Hence, some parts are being processed on the line at the same time that others are being transported between stations.

Asynchronous transfer systems offer the opportunity for greater flexibility than do the other two systems, and this flexibility can be a great advantage in certain circumstances. In-process storage of workparts can be incorporated into the asynchronous systems with relative ease. Power-and-free systems can also compensate for line balancing problems where there are significant differences in process times between stations. Parallel stations or several series stations can be used for the longer operations, and single stations can be used for the shorter operations. Therefore, the average production rates can be approximately equalized. Asynchronous lines are often used where there are one or more manually operated stations and cycle-time variations would be a problem on either the continuous or synchronous transport systems. Larger workparts can be handled on the asynchronous systems. A disadvantage of the power-and-free systems is that the cycle rates are generally slower than for the other types.
TRANSFER MECHANISMS

There are various types of transfer mechanisms used to move parts between stations. These mechanisms can be grouped into two types: those used to provide linear travel for in-line machines, and those used to provide rotary motion for dial indexing machines.

Linear transfer mechanisms

We will explain the operation of three of the typical mechanisms; the walking beam transfer bar system, the powered roller conveyor system, and the chain-drive conveyor system. This is not a complete listing of all types, but it is a representative sample.

Walking beam systems

With the walking beam transfer mechanism, the work-parts are lifted up from their workstation locations by a transfer bar and moved one position ahead, to the next station. The transfer bar then lowers the pans into nests which position them more accurately for processing. This type of transfer device is illustrated in Figure 10 and 11. For speed and accuracy, the motion of the beam is most often generated by a rotating camshaft powered by an electric motor or a roller movement in a profile powered by hydraulic cylinder. Figure 12 shows the working of the beam mechanish.

Figure 10 Almac Industrial Systems, the Ontario-based manufacturer of material handling equipment- Walking Beam'.
Figure 11 SIKAMA INTERNATIONAL has developed a Walking beam mechanism for FALCON 1200 and 8500

Figure 12 walking beam transfer system, showing various stage during transfer stage
**Powered roller conveyor system**

This type of system is used in general stock handling systems as well as in automated flow lines. The conveyor can be used to move pans or pallets possessing flat riding surfaces. The rollers can be powered by either of two mechanisms. The first is a belt drive, in which a flat moving belt beneath the rollers provides the rotation of the rollers by friction. A chain drive is the second common mechanism used to power the rollers. Powered roller conveyors are versatile transfer systems because they can be used to divert work pallets into workstations or alternate tracks.

![Power Conveyor](image13a.png)

![Power Conveyor](image13b.png)

![Power Conveyor](image13c.png)

Figure 13 a, b and c Power Conveyor
Chain-drive conveyor system

In chain-drive conveyor system either a chain or a flexible steel belt is used to transport the work carriers. The chain is driven by pulleys in either an "over-and-under" configuration, in which the pulleys turn about a horizontal axis, or an "around-the-corner" configuration, in which the pulleys rotate about a vertical axis. Figure 14 shows the chain conveyor transfer system.

This general type of transfer system can be used for continuous, intermittent, or nonsynchronous movement of workparts. In the nonsynchronous motion, the workparts are pulled by friction or ride on an oil film along a track with the chain or belt providing the movement. It is necessary to provide some sort of final location for the workparts when they arrive at their respective stations.

Rotary transfer mechanisms

There are several methods used to index a circular table or dial at various equal angular positions corresponding to workstation locations.

Rack and pinion

This mechanism is simple but is not considered especially suited to the high-speed operation often associated with indexing machines. The device is pictured in Figure 4.6 and uses a piston to drive the rack, which causes the pinion gear and attached indexing table to rotate. A clutch or other device is used to provide rotation in the desired direction.
**Ratchet and pawl:**

A ratchet is a device that allows linear or rotary motion in only one direction, while preventing motion in the opposite direction.

Ratchets consist of a gearwheel and a pivoting spring loaded finger called a pawl that engages the teeth. Either the teeth, or the pawl, are slanted at an angle, so that when the teeth are moving in one direction, the pawl slides up and over each tooth in turn, with the spring forcing it back with a 'click' into the depression before the next tooth. When the teeth are moving in the other direction, the angle of the pawl causes it to catch against a tooth and stop further motion in that direction. This drive mechanism is shown in Figure 16.

![Figure 16 Rachet and pawl mechanism](image)

**Geneva mechanism:**

The two previous mechanisms convert a linear motion into a rotational motion. The Geneva mechanism uses a continuously rotating driver to index the table, as pictured in Figure 17. If the driven member has six slots for a six-station dial indexing machine, each turn of the driver will cause the table to advance one-sixth of a turn. The driver only causes movement of the table through a portion of its rotation. For a six-slotted driven member, 120° of a complete rotation of the driver is used to index the table. The other 240° is dwell. For a four-slotted driven member, the ratio would be 90° for index and 270° for dwell. The usual number of indexings per revolution of the table is four, five, six, and eight.
CAM Mechanisms:

Various forms of cam mechanism, an example of which is illustrated in Figure 18, provide probably the most accurate and reliable method of indexing the dial. They are in widespread use in industry despite the fact that the cost is relatively high compared to alternative mechanisms. The cam can be designed to give a variety of velocity and dwell characteristics.
CONTROL FUNCTIONS

Controlling an automated flow line is a complex problem, owing to the sheer number of sequential steps that must be carried out. There are three main functions that are utilized to control the operation of an automatic transfer system. The first of these is an operational requirement, the second is a safety requirement, and the third is dedicated to improving quality.

1. Sequence control.

The purpose of this function is to coordinate the sequence of actions of the transfer system and its workstations. The various activities of the automated flow line must be carried out with split-second timing and accuracy.

Sequence control is basic to the operation of the flow line.

2. Safety monitoring:

This function ensures that the transfer system does not operate in an unsafe or hazardous condition. Sensing devices may be added to make certain that the cutting tool status is satisfactory to continue to process the workpart in the case of a machining-type transfer line. Other checks might include monitoring certain critical steps in the sequence control function to make sure that these steps have all been performed and in the correct order. Hydraulic or air pressures might also be checked if these are crucial to the operation of automated flow lines.

3. Quality monitoring:

The third control function is to monitor certain quality attributes of the workpart. Its purpose is to identify and possibly reject defective workparts and assemblies. The inspection devices required to perform quality monitoring are sometimes incorporated into existing processing stations. In other cases, separate stations are included in the line for the sole purpose of inspecting the workpart as shown in figure 19.

Figure 19 Inspection station with feedback
Conventional thinking on the control of the line has been to stop operation when a malfunction occurred. While there are certain malfunctions representing unsafe conditions that demand shutdown of the line, there are other situations where stoppage of the line is not required and perhaps not even desirable. There are alternative control strategies: 1. Instantaneous control and 2. Memory control.

**Instantaneous control:**
This mode of control stops the operation of the flow line immediately when a malfunction is detected. It is relatively simple, inexpensive, and trouble-free. Diagnostic features are often added to the system to aid in identifying the location and cause of the trouble to the operator so that repairs can be quickly made. However, stopping the machine results in loss of production from the entire line, and this is the system's biggest drawback.

**Memory control:**
In contrast to instantaneous control, the memory system is designed to keep the machine operating. It works to control quality and/or protect the machine by preventing subsequent stations from processing the particular workpart and by segregating the part as defective at the end of the line. The premise upon which memory-type control is based is that the failures which occur at the stations will be random and infrequent. If, however, the station failures result from cause and tend to repeat, the memory system will not improve production but, rather, degrade it. The flow line will continue to operate, with the consequence that bad parts will continue to be produced. For this reason, a counter is sometimes used so that if a failure occurs at the same station for two or three consecutive cycles, the memory logic will cause the machine to stop for repairs.

**BUFFER STORAGE**
Automated flow lines are often equipped with additional features beyond the basic transfer mechanisms and workstations. It is not uncommon for production flow lines to include storage zones for collecting banks of workparts along the line. One example of the use of storage zones would be two intermittent transfer systems, each without any storage capacity, linked together with a workpart inventory area. It is possible to connect three, four, or even more lines in this manner. Another example of workpart storage on flow lines is the asynchronous transfer line. With this system, it is possible to provide a bank of workparts for every station on the line.

There are two principal reasons for the use of buffer storage zones. The first is to reduce the effect of individual station breakdowns on the line operation. The continuous or intermittent transfer system acts as a single integrated machine. When breakdowns occur at the individual stations or when preventive maintenance is applied to the machine, production must be halted. In many cases, the proportion of
time the line spends out of operation can be significant, perhaps reaching 50% or more. Some of the common reasons for line stoppages are:

- Tool failures or tool adjustments at individual processing stations
- Scheduled tool changes
- Defective workparts or components at assembly stations, which require that the feed mechanism be cleared
- Feed hopper needs to be replenished at an assembly station
- Limit switch or other electrical malfunction
- Mechanical failure of transfer system or workstation

When a breakdown occurs on an automated flow line, the purpose of the buffer storage zone is to allow a portion of the line to continue operating while the remaining portion is stopped and under repair. For example, assume that a 20-station line is divided into two sections and connected by a parts storage zone which automatically collects parts from the first section and feeds them to the second section. If a station jam were to cause the first section of the line to stop, the second section could continue to operate as long as the supply of parts in the buffer zone lasts. Similarly, if the second section were to shut down, the first section could continue to operate as long as there is room in the buffer zone to store parts. Hopefully, the average production rate on the first section would be about equal to that of the second section. By dividing the line and using the storage area, the average production rate would be improved over the original 20-station Mow line. Figure 20 shows the Storage buffer between two stages of a production line.
Reasons for using storage buffers:

- To reduce effect of station breakdowns
- To provide a bank of parts to supply the line
- To provide a place to put the output of the line
- To allow curing time or other required delay
- To smooth cycle time variations
- To store parts between stages with different production rates

The disadvantages of buffer storage on flow lines are increased factory floor space, higher in-process inventory, more material handling equipment, and greater complexity of the overall flow line system. The benefits of buffer storage are often great enough to more than compensate for these disadvantages.

AUTOMATION FOR MACHINING OPERATIONS

Transfer systems have been designed to perform a great variety of different metal-cutting processes. In fact, it is difficult to think of machining operations that must be excluded from the list. Typical applications include operations such as milling, boring, drilling, reaming, and tapping. However, it is also feasible to carry out operations such as turning and grinding on transfer-type systems.

There are various types of mechanized and automated machines that perform a sequence of operations simultaneously on different work parts. These include dial indexing machines, trunnion machines, and transfer lines. To consider these machines in approximately the order of increasing complexity, we begin with one that really does not belong in the list at all, the single-station machine.

Single-station machine

These mechanized production machines perform several operations on a single workpart which is fixtured in one position throughout the cycle. The operations are performed on several different surfaces by work heads located around the piece. The available space surrounding a stationary workpiece limits the number of machining heads that can be used. This limit on the number of operations is the principal disadvantage of the single-station machine. Production rates are usually low to medium. The single station machine is as shown in figure 21.
Figure 21 single-station machines
**Rotary indexing machine**

To achieve higher rates of production, the rotary indexing machine performs a sequence of machining operations on several work parts simultaneously. Parts are fixtured on a horizontal circular table or dial, and indexed between successive stations. An example of a dial indexing machine is shown in Figure 22 and 23.

![Figure 22 Example of 6 station rotary configuration](image1)

![Figure 23 Five station dial index machine showing vertical and horizontal machining centers](image2)
Trunnion machine

Trunnion machine is a vertical drum mounted on a horizontal axis, so it is a variation of the dial indexing machine as shown in figure 24. The vertical drum is called a trunnion. Mounted on it are several fixtures which hold the work parts during processing. Trunnion machines are most suitable for small workpieces. The configuration of the machine, with a vertical rather than a horizontal indexing dial, provides the opportunity to perform operations on opposite sides of the workpart. Additional stations can be located on the outside periphery of the trunnion if it is required. The trunnion-type machine is appropriate for work parts in the medium production range.

Figure 24 Six station trunnion machine
**Center column machine**

Another version of the dial indexing arrangement is the center column type, pictured in Figure 25. In addition to the radial machining heads located around the periphery of the horizontal table, vertical units are mounted on the center column of the machine. This increases the number of machining operations that can be performed as compared to the regular dial indexing type. The center column machine is considered to be a high-production machine which makes efficient use of floor space.

![Figure 25 Ten-station center column machine](image)

**Transfer machine**

The most highly automated and versatile of the machines is the transfer line, as explained earlier the workstations are arranged in a straight-line flow pattern and parts are transferred automatically from station to station. The transfer system can be synchronous or asynchronous, work parts can be transported with or without palle fixtures, buffer storage can be incorporated into the line operation if desired, and a variety of different monitoring and control features can be used to manage the line. Hence, the transfer machine offers the greatest flexibility of any of the
machines discussed. The transfer line can accommodate larger workpieces than
the rotary-type indexing systems. Also, the number of stations, and therefore the
number of operations, which can be included on the line is greater than for the
circular arrangement. The transfer line has traditionally been used for machining a
single product in high quantities over long production runs. More recently, transfer
machines have been designed for ease of changeover to allow several different but
similar workparts to be produced on the same line. These attempts to introduce
flexibility into transfer line design add to the appeal of these high-production
systems.

Figure 26  Example of 20 stations Transfer line

Figure 27  Example of Transfer line