HANDBOOK - Non Servo Dedicated Automation
In the past, robotic elements were introduced to perform operations on hostile environments such as pick and place functions inside radioactive chambers.

More recently, robots have been applied to perform work in undesirable environments and in applications which are dull and monotonous.

More effective use of robotics and other forms of automation is now evident as technical staffs develop new manufacturing processes in parallel with new product development, resulting in improved quality, increased productivity and lower costs for everyone’s benefit.

Proponents of robotics point with pride to benefits of early forms of automation in the U.S. agricultural industry. They point out that efforts of 3% of our population can now produce enough food to feed us well and allow us to share the surplus.

An interesting sidelight to automation is the countless variety of parts which can be handled efficiently with robotics and automated devices. An example is an automobile -- we often think of an automobile as a large four-wheeled assembly weighing in excess of a ton without realizing that the majority of these parts are processed as small bits and pieces weighing less than a few pounds. A new car would probably cost the wages of a lifetime without present levels of automation.

“Robotics” is probably best defined as a subdivision of the science of “automation” as shown here:

PROCESS (a)

MANUAL

AUTOMATED

FIXED (b)

REPROGRAMMABLE (C)

(ROBOTS)

Perhaps the most comprehensive definition of an industrial robot is the one established by the Robotic Institute of America in 1979. It reads, “An industrial robot is a reprogrammable multifunction manipulator designed to move materials, parts, tools or specialized devices through variable programmed motions for the performance of a variety of tasks.”

“Reprogrammable” is a key word.
OBJECTS AND LOCATIONS IN THREE DIMENSIONS:

In spite of living and working in a three dimensional world, it is often difficult to describe an object or define its position in three dimensional space. Describing three dimensional features on two dimensional paper is even more difficult.

Technical people used a method called "perspective drawing" to describe an object in three dimensions. They also use a system called "coordinates" to define locations in three dimensional space.

The letter "Z" identifies the vertical axis in a "CARTESIAN COORDINATE SYSTEM" and yet, the letter "Y" identifies the vertical axis in two dimensional work. The apparent conflict is no problem to those accustomed to working in this area.

However, in the interest of simplicity and uniformity, the B•A•S•E® COORDINATE SYSTEM is used here, where the letter "Y" identifies the vertical axis in all cases.

POSITION:

The idea of "motion" contains two primitive concepts, those of "position" and "time".

Strictly speaking, we should refer to "position" in some primary reference system which relates to a location in the Universe. However, for practical reasons, we may do this by noting its distance from three mutually perpendicular planes, which we take as a fixed reference system. An example would be the lines of intersection of two adjacent walls and the floor of a room. The position of an object in a room is found by measuring its distance from the walls and floor. See Figure 1.

ROBOT MOTION:

A full six component robot will have capability for translating motion in three axes and rotations about each axis.

Many automation applications do not require full six component capability and products are available for structuring only as much robot as needed for the job.

Further, many applications do not require controlled path transfer or an infinite number of stop locations. Non-Servo Robots provide practical solutions for this class of work.

TYPES OF ROBOTS:

Technically, a "ROBOT" must have reprogramming capability. Devices not capable of reprogramming are better defined as "DEDICATED AUTOMATION".

There are only two basic types of robots: "SERVO CONTROLLED & NON-SERVO CONTROLLED". Non-servo robots are inexpensive, easy to understand and easy to set up, have good precision with high reliability and can be a logical choice for point to point transfer. Non-servo robots usually operate along the axes of a coordinate system with one or more rotations. Motion is controlled through the use of a limited number of stops and the actual path between points may be difficult to define. Programming involves setting stop locations at the manipulator and determining sequence and duration at the controller. Control can be as simple as a cam or drum timer for applications involving robots in dedicated service while programmable controllers or desk top computers with simple non-servo software are more practical where reprogramming is required.

Servo controlled robots have a wide range of capabilities. They can perform multiple point to point transfers and move along a controlled path. Most servo controlled robots use jointed arm mechanism and can be programmed to avoid an obstruction. Programming can be rather sophisticated and the price tag for a complete servo controlled robot system is relatively high.
Regardless of type, an "Industrial robot" must include the combination of "manipulator" and "control system". The manipulator is the portion which goes through the motions and performs work. It can be as simple as a gripper on the end of a cylinder or so complex, it takes a full time staff of professional people to install and maintain a single system. The control system directs the manipulator in performing its work. A control system can be as simple as a clock driven timer or so complex that practical solutions for the shop environment are still under development.

Robot size is not a limitation. In many applications, smaller robots are mounted on gantrys or tracks in the floor to increase operating range. See cover.

Larger robots usually operate on hydraulics while smaller sizes operate electrically or on air.

END EFFECTORS:
End effectors are devices which pick up or otherwise handle objects for transfer or while being processed. Selecting an end effector early in a program involving robotics is usually not difficult since characteristics of the object to be handled are known.

End effectors come in all types and sizes. Many must be custom made to match special handling requirements.

Some typical examples are shown in Figure 3.

GRIPPERS:
Angular closing and parallel closing grippers are perhaps the most common of all end effectors. Simple angular closing grippers are nothing more than air operated pliers while simple parallel closing grippers are essentially air operated vises.

The style shown in Figure 4 is basically a short stroke, double-acting, double-ended cylinder with finger attachment and drive mechanism.

In most cases, reprogramming involves only a change of fingers.

FIGURE 3

GRIPPERS:
Angular closing and parallel closing grippers are perhaps the most common of all end effectors. Simple angular closing grippers are nothing more than air operated pliers while simple parallel closing grippers are essentially air operated vises.

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In most cases, reprogramming involves only a change of fingers.

FIGURE 4

Stock grippers with blank fingers are easily modified to fit a part as suggested in Figure 5.

FIGURE 5

Two finger models simulate the motions of the thumb and index finger for reaching into channels, grasping parts within closely spaced components or picking and placing any object with simple geometry.

Three finger models duplicate the motions of the thumb, index finger and a third finger for grasping bodies of revolution and objects of spherical or cylindrical shape.

Four finger grippers provide a means for grasping square or rectangular parts. One pair of opposing fingers are wide for angular orientation of the part as the combination of four fingers close simultaneously to position the centroid.

Two, three and four finger grippers have the self centering feature of universal two, three and four jaw chucks with good repeatability.

Pneumatic grippers using double acting pistons are able to grip internally and externally with pinch force proportional to operating pressure. Operating pressure can be reduced for handling delicate parts.

Further, pinch force is essentially constant in the range of travel which allows the gripper to grasp objects of different size with uniform pinch force.

LINEAR MOTION DEVICES:
Several types of pneumatically actuated transporters are available within the industry.
One type is basically a single ended, double-acting cylinder with improved piston guides for better reaction to side loads and overhanging moments.

Special features may include adjustable travel stops, pistons keyed against rotation and speed control.

Installing a gripper in line or perpendicular to the piston rod and mounting the body to a fixed structure or to another linear transporter is common. Examples are shown in Figure 6.

Another type consists of a sliding motion pad attached to a base plate and driven by a conventional pneumatic cylinder.

Reaction to transport loads and moments is taken in guide rods or other means and the cylinder drives the motion pad.

Special features may include adjustable and remotely controlled travel stops, speed controls and shock absorbers.

Typical installation includes mounting a gripper or another transporter to the motion pad and attaching the entire assembly to a fixed structure or to another motion device. See Figure 7.

Air operated, non-servo, rotating devices are usually vane or rack and pinion operated with a choice of 90° or 180° rotation in pitch, roll or yaw. Adjustable stops provide close control over angular position, however, stopping at multiple intermediate angles is not practical without remotely controlled stops.

Many production processes and parts transfer involve a tilt of 90° or flip of 180° and non-servo, pneumatic rotators provide a reliable solution for this class of work.

Flow control valves serve well to dampen over-running loads and provide shock control.

REMOTEly CONTROLLED INTERMEDIATE STOPS:

Adding one or more remotely controlled double-acting, single-ended air cylinders is an example of intermediate position control.

Output force of the intermediate stop cylinder must be higher (larger piston at the same pressure) than the driving force within the motion devices.

Extending an intermediate stop cylinder halts the motion of the sliding member until the program calls for retraction.

Incorporating two intermediate stop cylinders into a linear motion device provides four stop locations as shown in Figure 9.

Increased numbers of stop positions enhance the flexibility of non-servo robots and is the subject of much current patent activity.
An example of a recent patent is shown where a slide mechanism incorporates an indexing mechanism similar to that of a turret lathe. See Figure 10.

Theoretically, an infinite number of controlled stop positions would duplicate servo control.

STRUCTURING A NON-SERVO, PNEUMATIC ROBOT:

Structuring a non-servo, pneumatic robot is relatively simple and leads to a clean design where integrated components are available.

Where integrated components are not available, many successful automation systems are assembled as pick and place units (without reprogrammable features) using minor modifications to standard pneumatic components.

Limiting components to only those motions required for an application reduces initial costs and simplifies the entire project including programming.

Structural characteristics of this class of automation depends primarily on motion patterns. If the motion is very simple, a gripper mounted to a cylinder might do. A cylinder keyed against rotation would maintain gripper alignment. If the motion is simply to transfer something in a plane, a gripper and two slide mechanisms might do.

If motion requires transferring something within a coordinate system, a gripper and three linear motions might do. Adding rotation would allow angular orientation of the work piece.

In some cases, starting with rotation as the first component in the main frame works best. Adding a short stroke lift cylinder and gripper increases its potential.

Adding reprogrammable features turns any of these units into a robot.

A variety of robot structures can be put together in "erector set" style using standard components as suggested in Figure 11.
EXAMPLE OF STRUCTURING:

Assume a simple automation plan is to pick up something at a feeder station, process it at a work station and drop it at a conveyor station per motion pattern A in Figure 12. Also assume that changes in the product or processing might require reprogramming to one or any combination of patterns shown.

An elementary, non-servo pneumatic robot may be assembled with five B-A-S-E® robotic components consisting of a gripper, a single ended cylinder (keyed against rotation), two linear slides and one intermediate stop cylinder as shown. Picture No. 2 shows a working model of Figure 12.

A programmable controller or equivalent is required to initiate and control the duration of each step in the sequence.

An example of further flexibility in structuring a robot is shown as an inset where a B-A-S-E® wrist rotator is added for angular orientation about the vertical axis.

MOUNTING:

Pneumatic devices operate well in any position leading to many options in positioning a robot to a mounting situation.

By design, the most rigid element in a pneumatic robot, generally becomes the attaching member and mounting from above, on a side wall or upright in the plane of the work are all common. Mounting, in many applications, is self evident. An example is approaching the work station perpendicular to open dies in a press.

When there is a choice, mounting in a position which reduces time in transit and distance traveled is obvious. Other mounting considerations include rigidity, environmental factors, access for service and safety.

NON-SERVO ROBOT CONTROL:

Non-servo control of a single pneumatic motion is relatively easy since a command is either "ON" or "OFF". Control of a multi-motion robot is slightly more complex since there are several motions running in sequence.

Programming is a matter of sequencing ON/OFF commands in a pattern with respect to time in order to perform some useful task.

Control in the ON/OFF mode (without servo) usually restricts the flexibility of robots, however, a non-servo control is often the only system with economic justification. A full servo controlled six component robot system is "overkill" in many simple automation applications.

MOTION CONTROL WITH FOUR WAY AIR VALVES:

Non-servo pneumatic robots operate on plant air and are controlled remotely with four way valves in the ON/OFF mode similar to control for a double acting cylinder. Each component has two inlets. Pressure to one inlet ("ON" command) provides motion in one direction and pressure to the other inlet ("OFF" command) reverses the motion.

Operation of a single motion element with a solenoid actuated, four way valve is familiar to many and is described schematically in Figure 13.

OPERATING & ENVIRONMENTAL CONSIDERATION:

Aside from the usual industrial applications, non-servo, pneumatic robots have other interesting possibilities. With minor modifications, they can operate underwater, in explosive or hostile environments and in vacuum.

Also, with minor changes, they can operate with a variety of internal fluids including hydraulic oil, steam, vacuum and water. Experimental units have run on tap water and pressure typical of city water systems.
Operation of five motion elements is shown in Figure 14 and represents the system schematic for the B•A•S•E® robot structure in Figure 12.

Each of the five components is plumbed through four way valves to shop air and hardwired to a programmable controller.

EXAMPLE OF DETERMINING SEQUENCE:

One or any combination of the sample motion patterns shown in Figure 12 can be programmed directly at the controller. Physical changes at the work station may require reprogramming adjustable and remotely controlled stops at the robot structure.

Motion pattern A is taken as an example and is shown in Figure 15 with numbers assigned to each motion.

As stated earlier, an object is picked from a parts feeder at station 2, processed at station 6, dropped to a conveyor at station 9 and then returns HOME.

HOME position is arbitrary, but usually represents a location for “parking” at the end of a sequence.

Motion pattern A defines the HOME position as having the following status for each of five components:

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>STATUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRIPPER</td>
<td>OPEN</td>
</tr>
<tr>
<td>&quot;X&quot; TRANSPORTER</td>
<td>RETRACTED</td>
</tr>
<tr>
<td>&quot;Y&quot; TRANSPORTER</td>
<td>UP</td>
</tr>
<tr>
<td>&quot;Z&quot; TRANSPORTER</td>
<td>RIGHT</td>
</tr>
<tr>
<td>INT. STOP CYL.</td>
<td>RETRACTED</td>
</tr>
</tbody>
</table>

Presetting the pneumatic system to a HOME position is easily accomplished by leaving power off to solenoids and turning air on to valves. Reverse air lines to any component which is not HOME.

Presetting HOME position with solenoids in the OFF mode is important and serves as a reference for setting ON/OFF commands. For example, the gripper is open in the HOME position with an OFF command, therefore, an ON command will close it.

Presetting to the HOME position with power off has another advantage. In case of power failure, the robot drops everything, returns to HOME position and stays there unless programmed otherwise. On resumption of power, it can be programmed to start from the beginning, returned to the interrupted motion or remain parked until reset by the attendant.

A table assigning ON/OFF commands to all five components can now be made using HOME position with valves OFF as a reference.

<table>
<thead>
<tr>
<th>ROBOT COMPONENTS</th>
<th>STATUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRIPPER (GR)</td>
<td>CLOSE</td>
</tr>
<tr>
<td>&quot;X&quot; TRANSPORTER</td>
<td>RETRACTED</td>
</tr>
<tr>
<td>&quot;Y&quot; TRANSPORTER</td>
<td>UP</td>
</tr>
<tr>
<td>&quot;Z&quot; TRANSPORTER</td>
<td>RIGHT</td>
</tr>
<tr>
<td>STOP CYLINDER (SC)</td>
<td>RETRACTED</td>
</tr>
</tbody>
</table>

Step number 1 of motion pattern A calls for movement from HOME to a point over the parts feeder. An ON command to TX is all that is required. All remaining components hold their respective positions with OFF commands.

Step number 2 calls for lowering an open gripper over the part. Maintaining an ON command to TX and introducing an ON command to TY lowers the gripper. The gripper is already open.

Step number 3 calls for closing the gripper onto a part with an ON command. All other components hold the commands given in Step 2 to maintain the position over the parts feeder.

There are thirteen steps in the motion pattern with the last step being HOME position.
MOTION SEQUENCE

<table>
<thead>
<tr>
<th>COMMAND STATUS</th>
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</thead>
<tbody>
<tr>
<td>STEP</td>
<td>MOTION</td>
</tr>
<tr>
<td>1</td>
<td>TX-OUT</td>
</tr>
<tr>
<td>2</td>
<td>TY-DOWN</td>
</tr>
<tr>
<td>3</td>
<td>GR-CLOSE</td>
</tr>
<tr>
<td>4</td>
<td>TY-UP</td>
</tr>
<tr>
<td>5</td>
<td>TZ-LEFT</td>
</tr>
<tr>
<td>6</td>
<td>TY-DOWN</td>
</tr>
<tr>
<td>7</td>
<td>TY-UP</td>
</tr>
<tr>
<td>8</td>
<td>TY-DOWN</td>
</tr>
<tr>
<td>9</td>
<td>GR-OPEN</td>
</tr>
<tr>
<td>10</td>
<td>TY-UP</td>
</tr>
<tr>
<td>11</td>
<td>TX-IN</td>
</tr>
<tr>
<td>12</td>
<td>TZ-RIGHT</td>
</tr>
</tbody>
</table>

PROGRAMMING NON-SERVO, PNEUMATIC ROBOTS:

Programming a non-servo, pneumatic robot consists of adding time increments to each step in the sequence.

Solid state programmable controllers are almost ideal for non-servo control where motion patterns are to be programmed and subsequently controlled by the same unit.

Controllers are easy to use, highly reliable, readily available at low cost and provide a broad range of programming capability.

Learning to use a solid state controller is only slightly more complicated than hand calculators. Controllers are shipped with simple tutorial handbooks and programming can be self-taught in a short time even without understanding internal details.

Programming non-servo, pneumatic robots with computers might appear overly sophisticated on first thought, however, there are many applications where control by computer is essential.

One application involves the integration of non-servo robots into an extensive automation setup where the entire system is computer controlled.

A complex network of sensor feedback might also require a computer.

Interactive programs where the operator is instructed on his next move are also best handled on a computer and permit programming non-servo robots by a person with little or no experience. See Picture 3.

Packaged systems are available for computer control of non-servo, pneumatic robots and may become popular in due time because of convenience.

EXAMPLE OF PROGRAMMING:

Operating systems for various controllers may differ but key elements for simple programming will be there, i.e. step no., duration of step and outputs for each step.
Decreasing cycle time involves reducing the duration for each step to cover the slowest component in motion at that time.

For example—in Step 3, closing a gripper is the only component in motion and reducing duration to 100 msec. is practical for fast acting grippers.

Cycle time for this “set up” is thirteen seconds. A practical running time might be six seconds or so depending on time required at the processing station (station 6).

Any of the motion patterns shown in Figure 12 may be reprogrammed by entering new sequences directly into the controller. Reprogramming stop locations within the robot structure is also required if there are changes in the physical locations of work stations.

**MONITORING, SENSING AND FEEDBACK:**

Pneumatic components are noted for reliability and the need for monitoring every step in a sequence is not necessary or desirable and tends to defeat the inherent simplicity of non-servo, pneumatic robots.

However, all automation applications involving safety and potential equipment damage should be monitored at key points and automatically shut down when a serious problem develops.

Monitoring, sensing and reaction control is a science unto itself and is outside the scope of this article.

**SUMMARY:**

Reprogrammable, non-servo, pneumatic robots fill a niche in simple automation applications. Advantages include low-cost, high reliability, good accuracy, easy to understand, easy to program and the only justifiable economic choice in many cases.
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