

1. Introduction	1
2. Why Use Robots?	1
2.1. Quality improvements	1
2.2. Improvement of the Working Environment	2
2.3. Cost Effectiveness	3
2.4. Flexibility to Change	3
3. When Not to Use Robots	4
4. Complexity of Tasks for Robots	5
4.1. Level 1	5
4.2. Level 2	5
4.3. Level 3	5
4.4. Level 4	5
5. Communications	6
5.1. Binary signals	6
5.2. Analogue signals	6
5.3. Serial or Parallel Interfaces	6
5.4. Networks	6
5.5. Specialist Interfaces	6
6. Robot Structures and Their Characteristics	7
6.1. Jointed Arm	8
6.2. SCARA (Selective Compliance Assembly Robot Arms)	9
6.3. Tricept and Hexapod Robots	10
6.4. Cartesian Co-ordinate Robots	11
6.5. Cylindrical Co-ordinate Robots	12
6.6. Polar Co-ordinate Robots	13
7. Power Sources	13
7.1. Pneumatics	13
7.2. Hydraulics	14
7.3. Electric	14
8. Grippers / End Effectors	14
8.1. Gripper Types	14
8.2. Accessories	14
8.3. Gripper Drives	15
8.4. Gripper Design Considerations	15
9. Programming Methods	16
9.1. Teach Method	16
9.2. Lead Through	17
9.3. Off-line Programming	17
10. Maintenance Issues	17
11. Safety	18
12. The Future	18
References	19



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INTRODUCTION TO INDUSTRIAL ROBOTS ERROR! REFERENCE SOURCE NOT FOUND.

1. Introduction

There are many definitions for what a robot is and this often leads to discrepancies between statistics quoted about robots. The commonly accepted definition in the UK is that provided by the British Robot Association which is as follows:-

"An industrial robot is a re-programmable device designed to both manipulate and transport parts, tools, or specialised manufacturing implements through variable programmed motions for the performance of specific manufacturing tasks."

The definition of a robot used by the Japanese Industrial Robot Association widens this definition to include arms controlled directly by humans and also fixed sequence manipulators which are not re-programmable. This second group account for a large number of the devices in use in Japan. Having made this point it is important to stress that even using our definition of a robot, the number of robots in use in Japan is still well in excess of that in other countries.

2. Why Use Robots?

Yasuo Yamauchi [1] gives four major reasons why Nissan use automation and in particular industrial robots. These are:-

- Quality improvement.
- Improvement of working environment.
- Better cost effectiveness.
- Flexibility to change.

They currently employ around 2200 robots and are actively developing their own robots for specific applications. It is interesting to note that most of the companies that use robots well within their manufacturing areas also develop and build their own robots. This is probably due to them having personnel available with a deep understanding of how these complex machines operate as well as having a vested interest in the technology being successful. Many failures of this technology in the UK have been caused by the operators not buying into the project or not being sufficiently well trained to be capable of running the equipment.

2.1. Quality improvements

For certain tasks robots can be superior to humans in terms of the quality of the work that is produced. This has been found to be the case where one or more of the following are required :-

- High positioning precision.
- High repeatability.
- No deviation due to fatigue.
- Highly accurate inspection and measurement using sensors.

Examples showing the improvements that can be gained in spot welding and seam sealing from the application of robots are shown in Table 1 and Table 2 respectively.

	Manual Deviation	Robot Deviation
Position	20-30mm	0.5-1.0mm
Number of points	2%	0%
Attitude of weld gun	10-20 degrees	1 degree

Table 1: Quality Improvements Gained From Applying Robots To Spot Welding

	Manual Deviation	Robot Deviation
Position	5mm	1-2mm
Gun Speed	50%	10%
Sealing Bead Diameter	3-4mm	1mm

Table 2: Quality Improvements Gained From Applying Robots To Seam Sealing

These process improvements not only improve the visual appearance of the product and hence the perceived quality of the product but in terms of the spot welding give better welds due to the tighter control of the gun angle and higher strength joints due to the guaranteed spacing and number of the welds. For seam sealing the better accuracy in terms of positioning and the tighter control of the bead diameter allow less sealant to be applied while still assuring that the joint is sealed. This improves the appearance of the joint considerably and gives a major saving in material use and therefore cost. Similar improvements can be achieved for paint spraying, arc welding, assembly and many other operations.

An example of how robots can be linked with sensors to perform inspections is the Nissan painted surface inspection system. This uses laser lighting to detect any dust or dirt causing imperfections in the finished paint work of the car. This system was introduced in 1984 and increased the fault detection rate from 60% to 100%. In areas where high levels of concentration are required over long periods fatigue in humans can be a problem. The correct use of robots can eliminate this.

2.2. Improvement of the Working Environment

In order to get the best long term performance from the work force it is important to make the working environment as conducive as possible to high quality, high output work. The human body if used incorrectly is susceptible to short term fatigue or long term injury or disability. Where possible automation should be used to reduce fatigue and to minimise the risk of injury. With the current trend of increased health and safety legislation it is predicted that companies that do not see the sense in introducing automation in these areas voluntarily will in the long term be forced to by legislation. The four areas where automation should be considered are as follows:-

- Heavy lifting.
- Repetitive work.
- Contaminated environments.(solvents, noise, heat, dust)
- Jobs requiring continuously high levels of concentration.

Guide lines quoted by Yamauchi show that where the total weight lifted per shift exceeds 20 tons or the number of repetitions of a single action per shift exceed 4000 then Nissan would consider that those tasks should be automated. An example of where this has been applied is in mounting wheels onto car bodies where wheels weighing 20-30Kg are handled 1000 times per shift. A robot has been developed using both vision and tactile sensors to pick up the wheels and mount them correctly onto the hub. Examples of repetitive tasks are palletising of pressed or injection moulded parts.

Many jobs within the manufacturing industry take place in an environment that is hostile to the human body. Many organic solvents from paint spraying are known to be carcinogenic, press shops are noisy and can cause hearing damage and foundries and welding shops are generally hot and dusty with danger of injury from sparks and hot components. Robots can easily handle these environments with no danger to themselves in fact one of the largest research areas in robotics at this moment in time is for decommissioning nuclear power stations and performing repairs within existing reactors. Obviously the environment here precludes the use of humans and much of the work requires very intelligent robots with a large range of sensors.

As well as physical work being tiring jobs requiring high levels of concentration can also lead to mental fatigue and stress. The surface inspection task described earlier is a prime example of this.

2.3. Cost Effectiveness

Cost effectiveness of robots is not always an easy calculation to perform. Most of the cost is up front in terms of the robot and tooling costs. Often due to the lack of intelligence in robots the tooling costs are the most significant. In comparison to this performing the operations using humans the largest cost is in wages and for hazardous environments such as a paint shop, environmental control (i.e. providing a clean air source for the operator to breathe) can also be expensive. Where possible robots should be installed such that they can operate continuously for 24 hours per day in order to get the best productivity from them. This is however not possible where they are operating on lines utilising humans who require breaks. Often it is the humans in the process who limit the output of robot cells.

2.4. Flexibility to Change

In the correct circumstances robots can not only be more flexible to change than fixed automation but can also be faster than what is often regarded as the most flexible solution humans. With the globalisation of markets the life time of a product on the market is steadily decreasing. This requires that new products can be brought to market quicker and also that production lines are flexible and can handle more than one product. The solution to this is to use re-programmable automation and wherever possible to remove hard tooling. Rolls-Royce have succeeded in eliminating hard tooling and reducing lead time by some 75% because of this in their chemical machining cell. The old process involved coating the components in maskant and then manually scribing the maskant using a scalpel and a template before peeling off the relevant areas of maskant and etching away the correct amount of metal. The scribing process is now performed using a robot programmed off-line using CAD data. This eliminates the need for the templates to be made. A number of other benefits have been gained by the use of a robot for this application the main one being that the quality of the resulting components has increased.

Nissan are looking to take the concept of flexible manufacturing to the limit. They are currently working on an Intelligent Body Assembly System [2]+[3] which is effectively a fully programmable car body framing line. The aim of it is to be able to produce any one of their car models on the same assembly line. The way that they are planning to achieve this is by using simple robots to replace fixturing. In order to produce such a complex robotic cell they are using computer based simulation techniques and off-line programming.

3. When Not to Use Robots

Although in many applications robots can offer benefits over humans with the current level of technology available and at today's prices there are still a large number of areas where using a robot is either impossible or impractical. Humans have the following advantages over robots:-

- They have an impressive array of sensors (touch, vision, hearing, pattern recognition)
- They have the ability to learn and make decisions where all of the required data does not exist.
- They can be very flexible and easy to program.
- Mobility.
- Low capital investment.

The places that humans are therefore preferred are jobs requiring one or more of these skills. Final assembly of cars is one area where robots have made little impact. Handling wire harnesses and carpets that are flexible and unpredictable requires sensory capabilities that robots do not currently possess and where the quality of incoming components is not tightly controlled a human operator can scrap bad parts where a robot would attempt to fit it. Where components are supplied to a robot it is essential that the orientation and location of the part is controlled. This adds expense to the process and often for humans parts are simply supplied in bins and can be in any orientation. In order to handle this complex pattern recognition is required.

While on spot welding lines robot cells are normally designed with some redundancy such that if one robot has a fault the others can pick up its work load it is impossible to quickly move a robot onto another job at the other end of a production line. With humans this level of mobility is possible and where tasks are not complex generally they can be taught the task quickly by simply demonstrating it to them and then watching them for a few cycles. Reprogramming a robot is not yet quite that simple.

Often companies that are not in a sound financial decision are put off automation by the capital investment requirement. If cash is in short supply then even though in the long term automation would pay back the investment cannot be made. In this case manual labour is the sensible option.

4. Complexity of Tasks for Robots

Robotic applications can be broken down into four different levels of complexity depending on the amount of sensing and decision making required. The applications that fall into the first category are the easiest to automate and those in the fourth category the most difficult and in many cases not possible with current technology.

4.1. Level 1

Applications that can be achieved using a simple robot using jigs and fixtures to position components and tooling to achieve the required accuracy. Example applications include spot welding, adhesive or sealant application, painting etc. In order for these to work the variation of the components along with the repeatability of the robot used must be within the tolerance required by the process.

4.2. Level 2

Applications requiring sensory feedback in order for small modifications to be made to the program to account for variation in the components. Examples for this include arc welding, automotive window glazing and spare wheel mounting. For arc welding the accuracy with which thick section metal sheet can be cut and formed lies outside of the tolerance in torch position for quality arc welding. To overcome this sensors are often used to locate the position of joints and seam tracking devices which can use either vision systems or through arc sensing are used to track the seam once it has been located. Seam tracking is essential for most applications of arc welding as the localised heating caused by the process tends to cause the component to warp.

4.3. Level 3

These applications require more complex sensory capabilities such as pattern recognition. They also tend to require complex decision making based on this feed back. Examples where this level of application has been automated are few and tend to be in the assembly area. A number of systems now exist for mounting wheels onto car bodies. This requires the robot to find out where the wheel hub is and in what orientation it is such that the holes in the wheel can be matched to the studs. It then needs to work out the orientation of the wheel in the rack and calculate how to pick it up so that it can place it accurately onto the hub. It then runs the wheel nuts onto the studs to the correct torque level.

4.4. Level 4

The most difficult applications are those involving unpredictable behaviour of either the components or other equipment within the cell. Operations such as handling of flexible components i.e. carpets or water hoses for example are examples of this. In the future robots may also link more intelligently with humans so that they can judge for themselves when it is safe to operate without having comprehensive guarding and safety interlocks everywhere. Some robots are already being developed for the nuclear industry that have tactile sensors covering the arm such that collisions can be detected before any damage is caused.

5. Communications

The key to performing the more complex tasks with a robot is linking it intelligently to other machines for sequence control and sensors so that it can react sensibly to variations in either the components or the environment. In order to achieve this robot controllers have a range of different communication ports which are either provided as standard or are options. In designing a robot cell the types and number of communication channels required to perform the sequence control and ensure that parts, materials etc. are available will need to be calculated. The number required for even a simple task can quickly rise above the number of channels provided as standard with most controllers. Some system builders prefer to use a PLC to handle the communications and limit the number of channels used by the robot to a minimum this also reduces the complexity of the robot program but obviously adds cost to the system and requires a program for the PLC. All types of communication ports are available for robot controllers and are used for varying applications.

5.1. Binary signals

These are simple on/off signals represented by two different voltage levels. They can be used as inputs for simple micro switches to indicate that a component is loaded correctly or as outputs to fire relays to switch ancillary equipment on and off. They can also be used in a group to pass numbers in binary format between machines.

5.2. Analogue signals

For applications such as temperature measurement using a thermocouple or distance measurement using a proximity sensor where a variable voltage is provided by the sensor an analogue input is required. The robot controller can then convert the voltage which must lie within an allowable range into a number which can be used to modify the robots actions. Analogue outputs are also available and convert a number within the robot controller into a voltage within a specified range. This voltage can then be fed to an amplifier or used directly to drive electric motors, arc welding power supplies etc.

5.3. Serial or Parallel Interfaces

Just as personal computers can link to peripheral equipment such as disk drives, printers etc. using standard parallel or serial ports so too can robots. These are used for program development and storage mainly but can also be used from within a robot program for producing reports on the work performed or interfacing to complex sensors such as vision systems for pattern recognition.

5.4. Networks

Networks are becoming more popular for linking together computer systems and these are available for robots. One of the first networks available for robots was MAP but apart from within a few companies, this has not been widely used due to its cost. Some robots are now also available with ethernet connections and although not widely used at the moment for robots this is used very widely throughout industry for CAD etc.

5.5. Specialist Interfaces

Applications such as arc welding require a large number of analogue and digital signals in order to control the welding power supply and filler wire feed drives. These are often available as standard sets from the robot vendors with specialist instructions within the robot programming language to control them in an application specific manner.

6. Robot Structures and Their Characteristics

When selecting a robot for a particular task a number of decisions have to be made. The first of these is the structure of the robot required. There are a number of different structures commonly available and each has its own set of limitations and benefits.

6.1. Jointed Arm

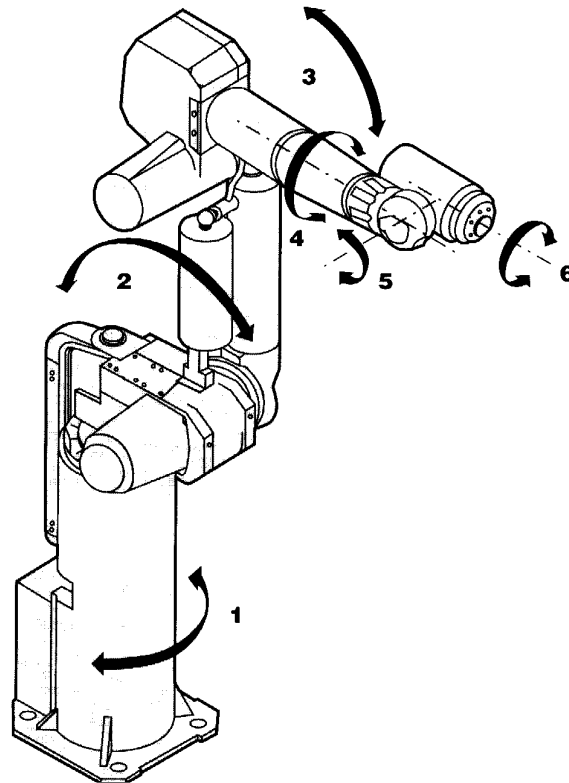


Figure 1 Jointed Arm Robot Structure

The jointed arm robot closely resembles the human arm. This structure is very flexible and has the ability to reach over obstructions. It can generally achieve any position and orientation within the working envelope in eight different ways. This can cause control problems. When driving these robots in their natural co-ordinate system (joint space) the motion of the robot from one point to another can be difficult to visualise as the robot will move each joint through the minimum angle required. This means that the motion of the tool will not be a straight line. This structure of robots is used for a wide range of applications including paint spraying, arc and spot welding, machine tending, fettling, etc.

6.2. SCARA (Selective Compliance Assembly Robot Arms)

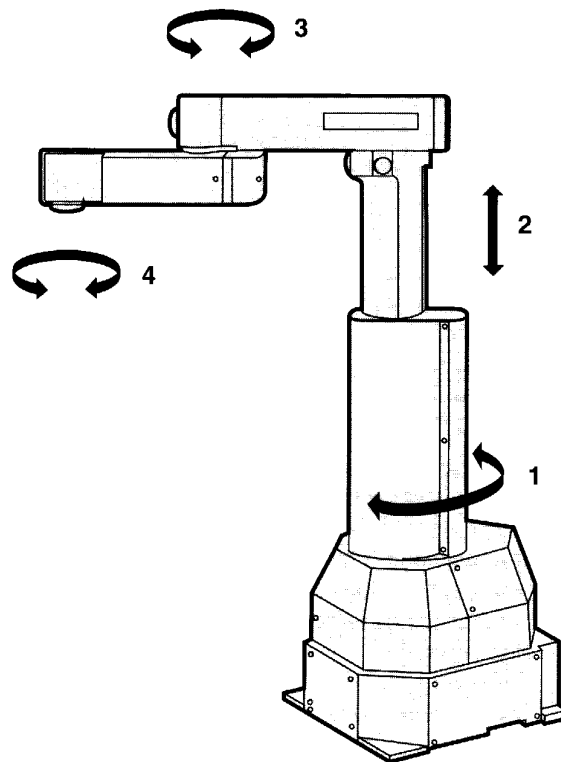


Fig 2 SCARA Robot Structure

SCARA robots are specifically designed for peg board type assembly and are heavily used in the electronics industry. They are very stiff in the vertical direction but have a degree of compliance in the horizontal plane that enables minor errors in placement of components to be accounted for. These robots tend to be fairly small and capable of operating very accurately and at high speed. They are used for assembly, palletisation and machine loading.

6.3. Tricept and Hexapod Robots



Fig 3: Tricept Robot

Tricept and hexapod robots use linear motors to control the position of the tool. The tricept uses three of these legs in conjunction with a central pillar to hold the head rigidly in position and then has a standard wrist mounted on it to achieve the orientation. A hexapod uses six legs and achieves both position and orientation using them. Both of these structures give very rigid robots but both have the disadvantage of small working envelopes and limited orientation ability. These structures tend to be used for machining operations where machine tool level tolerances are not required but greater flexibility is.

6.4. Cartesian Co-ordinate Robots

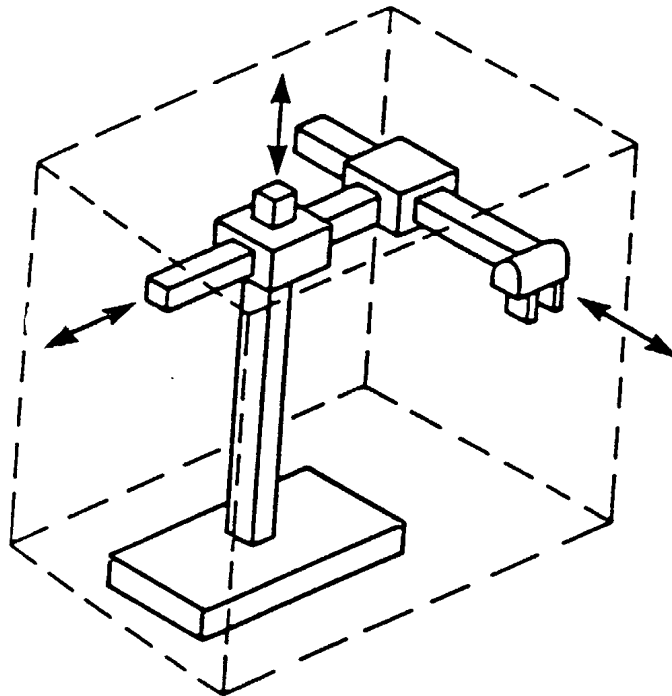


Fig 4: Cartesian Co-ordinate Robot Structure

This structure is most often seen in machine tools and co-ordinate measuring machines due to its high rigidity. It produces a robot that is very accurate and repeatable but which lacks flexibility as it cannot reach around objects. These robots are very easy to program and visualise but require a large volume to operate in. They are mainly used for pick and place operations and operations requiring great accuracy. Their linear joints are difficult to seal and this makes them unsuitable for working in damp and dusty environments.

6.5. Cylindrical Co-ordinate Robots

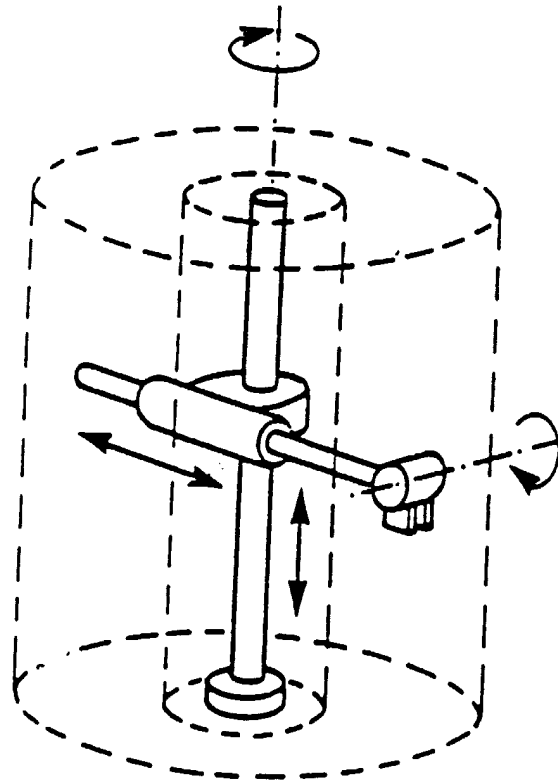


Fig 5: Cylindrical Co-ordinate Robot Structure

Very similar to the Cartesian co-ordinate robots these robots have good rigidity and are good for jobs requiring straight line moves. Programming them is simple as their motion is easy to visualise and they are good for reaching into cavities which makes them ideal for machine tending. The disadvantages of these robots is their inability to reach around objects and the amount of clearance required behind the robot. The linear joint makes them unsuitable for working in dusty or damp environments as it is difficult to seal.

6.6. Polar Co-ordinate Robots

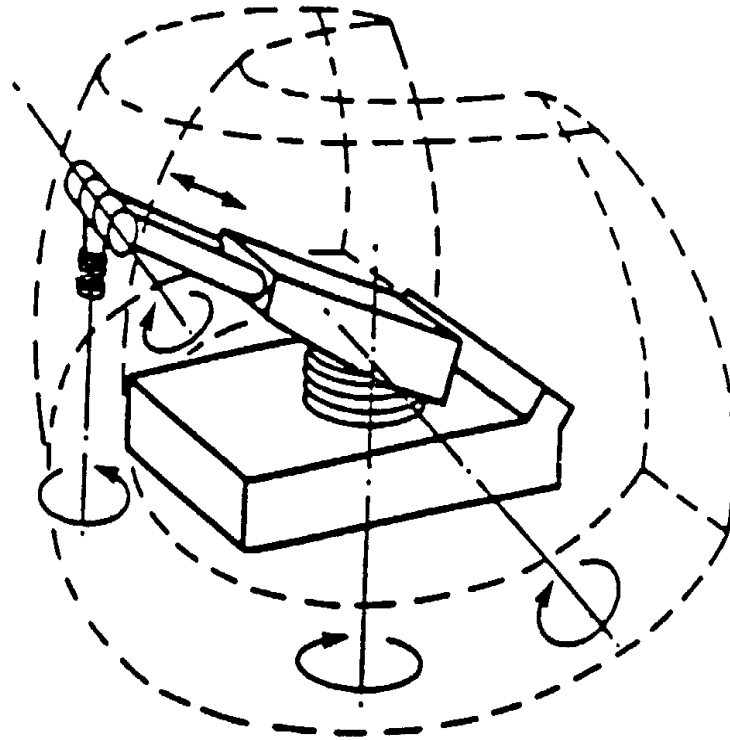


Fig 6 Polar Co-ordinate Robot Structure

The polar co-ordinate robot structure was the first one to be used in industry. The main reason for this was that it was ideal for hydraulic drives. Since the advent of all electric robots this structure has been all but replaced by the jointed arm robot but many of the old hydraulic robots are still working well in industry doing spot welding and many other tasks. A notable exception to this is the pendulum robot. This structure is effectively a polar robot hung from a gantry as a pendulum. It produces a very fast accurate robot as the centre of mass is at the centre of rotation of the major joints giving it a small moment of inertia. Pendulum robots are currently used for assembly, welding, gluing etc.

7. Power Sources

Almost all modern robots are driven by brushless AC servo motors but many of the robots existing in industry use other drives.

7.1. Pneumatics

Many of the simple pick and place arms are driven by pneumatics. This makes them cheap but has the disadvantage of being difficult to control. Pneumatics are still used with a number of modern robots to drive end effectors.

7.2. Hydraulics

Hydraulic drives were used on a large number of the early robots as it was more rigid and controllable than pneumatics and it could provide more power than the electric drives then available. The problems with hydraulics are that it tends to be fairly slow in operation and that due to the high pressures involved leaks can be very messy.

7.3. Electric

There are three major types of electric drive that have been used for robots.

Stepper Motors

These are used mainly for simple pick and place mechanisms where cheapness is more important than power or controllability.

DC Servos

For the early electric robots the DC servo drive was used extensively. It gave good power output with a high degree of control of both speed and position.

AC Servos

In recent years the AC servo has taken over from the DC servo as the standard drive. These modern motors give higher power output and are almost silent in operation. As they have no brushes they are very reliable and require almost no maintenance in operation.

8. Grippers / End Effectors

One of the most important areas in the design of robot systems is the design of end effectors[4]. Most of the problems that occur in production are caused by badly designed tooling and not by faults in the robots. There are many different types of gripper available along with the vast number of specialist tools for nut running, arc welding, paint spraying etc. These grippers are not used solely with robots however. They can be used for fixturing components anywhere in an automated or semi-automated line.

8.1. Gripper Types

The most commonly used grippers are finger grippers. These will generally have two opposing fingers or three fingers like a lathe chuck. The fingers are driven together such that once gripped any part is centred in the gripper. This gives some flexibility to the location of components at the pick-up point. Two finger grippers can be further split into parallel motion or angular motion fingers.

For some tasks however where flexible or fragile objects are being handled the use of either vacuum or magnetic grippers is preferable. With these the surface of the gripper is placed in contact with the object and either a magnetic field or a vacuum is applied to hold them in contact. Any errors in placement of the object at the pick-up point will be reflected in a similar error at the destination so these grippers are not usually used for high accuracy applications.

8.2. Accessories

Along with a wide range of standard grippers being available there are also a number of standard accessories for mounting them. If motion of the gripper is required which cannot easily be provided by the robot then this can be provided in the end effector. Linear and rotary units are available in many different configurations. The linear units tend to be used

where reaching into confined spaces is required while the rotary units are often used where more than one gripper is mounted to switch from one to the other.

Another mechanism that is frequently used is a collision detection system. A collision detection unit works in the same manner as a probe on a co-ordinate measuring machine. It is attached between the robot flange and the end effector. The device consists of two plates held together by a spring. The two plates contact each other at three electrical contacts arranged in a triangle. These contacts are wired in series such that any motion of one plate relative to the other will cause the circuit to break. This circuit can then be wired either to the emergency stop circuit of the robot or an interrupt in the program.

Where more than one job is being performed by a robot and all of the necessary tools cannot be assembled together, it may be necessary to use a tool changer. Devices exist such that all of the services to the tools (electricity, air, etc.) can be fed through the changer so that a tangle of different wires, pipes etc does not have to exist for each different tool. Where possible however it is preferable not to use tool changers as they add weight to the end-effectors and cause an increase in cycle time when changes are required.

8.3. Gripper Drives

The same options are available for grippers as for robots. The most popular one here is pneumatic however because of the ease with which it can be supplied to the end of a robot arm and controlled. The only disadvantages of pneumatics are that it has a slightly lower power to weight ratio than hydraulics and it is not as controllable or easy to feed as electricity. In most situations however these are not important.

8.4. Gripper Design Considerations

When selecting a gripper there are a number of factors that may need consideration.

8.4.1. Gripping force

When considering the gripping force required a number of factors must be considered. Not only must the mass of the object to be gripped be taken into account but also the accelerations imposed on it by the robot. Where accelerations are not known a figure of 2.5g is generally assumed. The coefficient of friction between the gripper and the object may also be an important factor. This can often be increased by using one of the special rubber based materials that have been developed. The use of these materials can create maintenance issues however as they have a finite life.

One other way of reducing the gripping force required is to use fingers designed for the form of the component. This reduces the flexibility of the gripper but dramatically increases the weight carrying capacity.

8.4.2. Weight

Industrial robots have fixed lifting capabilities and the combined weight of the gripper and gripped component may be important. Even where this weight is within the capability of the robot it may cause an unacceptable increase in the cycle time of the operation. The distance between the robot flange and the centre of mass may also be important and this should be kept to a minimum.

8.4.3. Supply of services

With robot end effectors loose cable or hoses are something to be avoided. They increase the size of the tool (making it harder to reach into confined spaces) and cause many failures due to rubbing or snagging on other parts of the mechanism. It is therefore preferable to route all services or signal connections through the robot arm and then internally through the tool.

8.4.4. Enviromental capabilities

End effectors are often required to work in hostile enviroments. High temperatures, dust or the presence of chemicals will require special materials or designs to be used.

8.4.5. Sensor capabilities

For certain applications some degree of sensory feedback from the gripper is necessary. This may be measurement of insertion or gripping forces or may simply be a proximity sensor to say if anything is between the jaws of the gripper. Some standard grippers are provided with feedback to show the seperation of the jaws but most grippers have no feedback.

8.4.6. Others

Other factors to be considered include the speed of the gripper jaws and the range of sizes of component they can grip. The amount of maintenance required is also important though most modern mechanisms require little or no maintenance. For some situations the behaviour of the gripper on power failure may be critical. Some but not all use either springs to apply the gripping force or non return valves to ensure that pressure is maintained.

9. Programming Methods

There are three basic methods for programming industrial robots but currently over 90% are programmed using the teach method.

9.1. Teach Method

The logic for the program can be generated either using a menu based system or simply using a text editor but the main characteristic of this method is the means by which the robot is taught the positional data. A teach pendant with controls to drive the robot in a number of different co-ordinate systems is used to manually drive the robot to the desired locations. These locations are then stored with names that can be used within the robot program. The co-ordinate systems available on a standard jointed arm robot are :-

Joint Co-ordinates

The robot joints are driven independently in either direction.

Global Co-ordinates

The tool centre point of the robot can be driven along the X, Y or Z axes of the robots global axis system. Rotations of the tool around these axes can also be performed

Tool Co-ordinates

Similar to the global co-ordinate system but the axes of this one are attached to the tool centre point of the robot and therefore move with it. This system is especially useful when the tool is near to the workpiece.

Workpiece Co-ordinates

With many robots it is possible to set up a co-ordinate system at any point within the working area. These can be especially useful where small adjustments to the program are required as it is easier to make them along a major axis of the co-ordinate system than along a general line. The effect of this is similar to moving the position and orientation of the global co-ordinate system.

This method of programming is very simple to use where simple movements are required. It does have the disadvantage that the robot can be out of production for a long time during reprogramming. While this is not a problem where robots do the same task for their entire

life, this is becoming less common and some robotic welding systems are performing tasks only a few times before being reprogrammed.

9.2. Lead Through

This system of programming was initially popular but has now almost disappeared. It is still however used by many paint spraying robots. The robot is programmed by being physically moved through the task by an operator. This is exceedingly difficult where large robots are being used and sometimes a smaller version of the robot is used for this purpose. Any hesitations or inaccuracies that are introduced into the program cannot be edited out easily without reprogramming the whole task. The robot controller simply records the joint positions at a fixed time interval and then plays this back.

9.3. Off-line Programming

Similar to the way in which CAD systems are being used to generate NC programs for milling machines it is also possible to program robots from CAD data. The CAD models of the components are used along with models of the robots being used and the fixturing required. The program structure is built up in much the same way as for teach programming but intelligent tools are available which allow the CAD data to be used to generate sequences of location and process information. At present there are only a few companies using this technology as it is still in its infancy but its use is increasing each year. The benefits of this form of programming are:-

- Reduced down time for programming.
- Programming tools make programming easier.
- Enables concurrent engineering and reduces product lead time.
- Assists cell design and allows process optimisation.

10. Maintenance Issues

Within a company or plant there are a number of issues involved in selecting robots which are not always compatible with selecting the best robot to perform the task. Maintenance issues must be considered. Different robot manufacturers all produce their own control systems (some produce more than one) and many produce their own drive systems. This means that maintenance personnel require different specialist training in order to be able to deal with each different manufacturers robots. The areas where variations can give difficulties are electric connections(power supply, safety circuits and signalling), programming language and operating software. The electrical connections are not generally too much of a problem as company standards will set out how these are to be done but differences in the robot programming languages and operating software can cause problems where maintenance staff are not all familiar with them. To get around some of the possible problems a PLC is sometimes included in the cell to handle most of the signalling requirements rather than doing this within the robot controller. Provided the PLCs are standard throughout the factory any member of the maintenance staff should then be able to deal with problems in the machine communications. Most companies also restrict the choice of robot vendor to give some standardisation in robot controller.

Over the last ten years there have been a number of projects performed in academia looking at producing a standard robot programming language. These have never been widely adopted as people buying robots have not specified them and manufacturers of robots have continued with development of their own languages to try to get a technology lead over their competition. At some stage in the future when the development of robot programming languages slows down I believe that a standard will emerge. This may well be the Programming Language for Robots (PLR) which is currently under development by the International Standards Organisation.

Another maintenance issue is the requirement to reprogram robots after maintenance of the arm or replacement by another apparently identical arm. This is caused by the difficulty of setting up the datums or zero points on the robot axes which leads to every robot arm having a different arm signature. Tools and methods of setting the robot zero points have been developed but as yet these are complex, expensive systems which cannot always be used with the robot installed on the shop floor. Some makes of robot are better than others in this respect and in general the more recent the robot design the less likely you are to suffer from these problems.

11. Safety

In implementing a robot cell one of the major considerations must be the safety of operators and people working in the area. Modern robots are almost silent in operation and very fast. They can also be unpredictable to the inexperienced as they often have pauses built into their programs where they are waiting for something else to occur. This can appear to the uninitiated that the robot is deactivated where in fact it could continue at any time.

The only acceptable way to make robots safe is to exclude people from the robot working area. This is achieved by the use of safety fences, light curtains and doors with interlock switches. For the purpose of programming the robot the operator needs to be able to run the robot while being within the cell. This is allowed but only with the robot running at a reduced speed and with the operator holding the dead mans handle on the teach pendant.

The cost of making robot cells safe can be considerable and is generally between twenty and fifty percent of the overall cost of the cell. This can make a large difference to the cost justification for a project.

Apart from the safety of humans much can be done to ensure the safety of the equipment. Sensors can be used to ensure that components are present and loaded correctly or that tooling is operating properly. Collision sensors can be placed between the robot arm and the end-effector so that if excessive force is applied to the tool the robot arm will stop.

12. The Future

Robots are still developing very quickly. The abilities and ease of use of robots will be improved steadily for at least the next ten years. Major developments will come in the following areas.

- Faster control loops leading to more accurate and faster motion control.
- Simpler integration with sensors including force control and vision systems.
- Intelligent control of redundant robot structures.(Structures with more than six degrees of freedom.)
- Advanced off-line programming techniques.

In conclusion the range of possible applications for robots is rapidly expanding and it is imperative that a world class manufacturing company should keep an eye on developments and implement robots wherever benefits can be gained.

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