BALDOR
MOTORS AND DRIVES

BALDOR ELECTRIC COMPANY

SERVO CONTROL FACTS

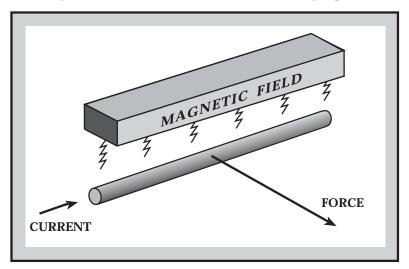## A HANDBOOK EXPLAINING THE BASICS OF MOTION

TABLE OF CONTENTS

TYPES OF MOTORS

The direct current (DC) motor is one of the first machines devised to convert electrical energy to mechanical power. Its origin can be traced to machines conceived and tested by Michael Faraday, the experimenter who formulated the fundamental concepts of electromagnetism. These concepts basically state that if a conductor, or wire, carrying current is placed in a magnetic field, a force will act upon it. The magnitude of this force is a function of strength of the magnetic field, the amount of current passing through the conductor and the orientation of the magnet and conductor. The direction in which this force will act is dependent on the direction of current and direction of the magnetic field.
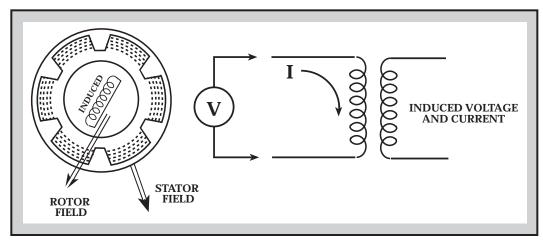

Fig. 1 - **CONCEPT OF ELECTROMAGNETISM**

Electric motor design is based on the placement of conductors (wires) in a magnetic field. A winding has many conductors, or turns of wire, and the contribution of each individual turn adds to the intensity of the interaction. The force developed from a winding is dependent on the current passing through the winding and the magnetic field strength. If more current is passed through the winding, then more force (torque) is obtained. In effect, two magnetic fields interacting cause movement: the magnetic field from the rotor and the magnetic field from the stators attract each other. This becomes the basis of both AC and DC motor design.

AC MOTORS

Most of the world's motor business is addressed by AC motors. AC motors are relatively constant speed devices. The speed of an AC motor is determined by the frequency of the voltage applied (and the number of magnetic poles). There are basically two types of AC motors: *induction* and *synchronous.*

INDUCTION MOTOR. If the induction motor is viewed as a type of transformer, it becomes

Fig. 2 - **INDUCTION MOTOR**

easy to understand. By applying a voltage onto the primary of the transformer winding, a current flow results and induces current in the secondary winding. The primary is the stator assembly and the secondary is the rotor assembly. One magnetic field is set up in the stator and a second magnetic field is induced in the rotor. The interaction of these two magnetic fields results in motion. The speed of the magnetic field going around the stator will determine the speed of the rotor. The rotor will try to follow the stator's magnetic field, but will "slip" when a load is attached. Therefore induction motors always rotate slower than the stator's rotating field.

Typical construction of an induction motor consists of 1) a stator with laminations and turns of copper wire and 2) a rotor, constructed of steel laminations with large slots on the periphery, stacked together to form a "squirrel cage" rotor. Rotor slots are filled with conductive material (copper or aluminum) and are short-circuited upon themselves by the conductive end pieces. This "one" piece casting usually includes integral fan blades to circulate air for cooling purposes.
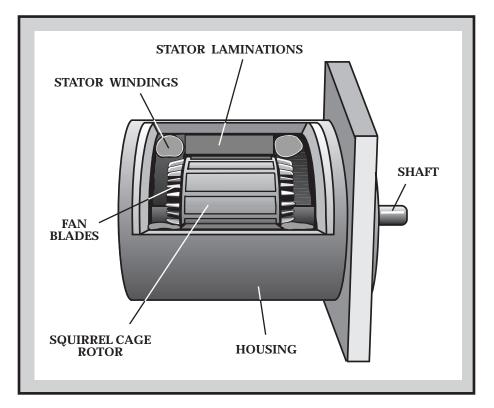

Fig. 3 - **CUTAWAY OF INDUCTION MOTOR**

The standard induction motor is operated at a "constant" speed from standard line frequencies. Recently, with the increasing demand for adjustable speed products, controls have been developed which adjust operating speed of induction motors. Microprocessor drive technology using methods such as vector or phase angle control (i.e. variable voltage, variable frequency) manipulates the magnitude of the magnetic flux of the fields and thus controls motor speed. By the addition of an appropriate feedback sensor, this becomes a viable consideration for some positioning applications.

Controlling the induction motor's speed/torque becomes complex since motor torque is no longer a simple function of motor current. Motor torque affects the slip frequency, and speed is a function of both stator field frequency and slip frequency.

Induction motor advantages include: Low initial cost due to simplicity in motor design and construction; availability of many standard sizes; reliability; and quiet, vibration-free operation. For very rapid start-stop positioning applications, a larger motor would be used to keep temperatures

within design limits. A low torque to inertia ratio limits this motor type to less demanding incrementing (start-stop) applications.

SYNCHRONOUS MOTOR. The synchronous motor is basically the same as the induction motor but with slightly different rotor construction. The rotor construction enables this type of motor to rotate at the same speed (in synchronization) as the stator field. There are basically two types of synchronous motors: *self excited* (as the induction motor) and *directly excited* (as with permanent magnets).

The self excited motor (may be called reluctance synchronous) includes a rotor with notches, or teeth, on the periphery. The number of notches corresponds to the number of poles in the stator. Oftentimes the notches or teeth are termed salient poles. These salient poles create an easy path for the magnetic flux field, thus allowing the rotor to "lock in" and run at the same speed as the rotating field.

A directly excited motor (may be called hysteresis synchronous, or AC permanent magnet synchronous) includes a rotor with a cylinder of a permanent magnet alloy. The permanent magnet north and south poles, in effect, are the salient teeth of this design, and therefore prevent slip.

In both the self excited and directly excited types there is a "coupling" angle, i.e. the rotor lags a
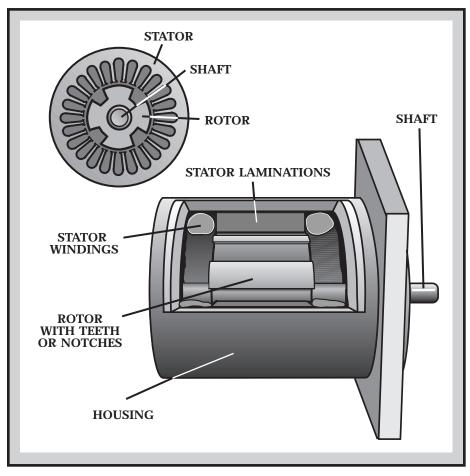

Fig. 4 - **CUTAWAY OF AC SYNCHRONOUS MOTOR**

small distance behind the stator field. This angle will increase with load, and if the load is increased beyond the motor's capability, the rotor will pull out of synchronism.

The synchronous motor is generally operated in an "open loop" configuration and within the limi-
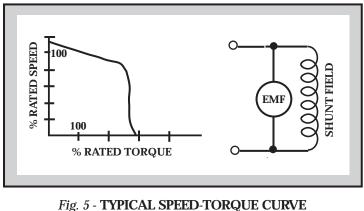
tations of the coupling angle (or "pull-out" torque) it will provide absolute constant speed for a given load. Also, note that this category of motor is not self starting and employs start windings (split-phase, capacitor start), or controls which slowly ramp up frequency/voltage in order to start rotation.

A synchronous motor can be used in a speed control system even though a feedback device must be added. Vector control approaches will work quite adequately with this motor design. However, in general, the rotor is larger than that of an equivalent servomotor and, therefore, may not provide adequate response for incrementing applications. Other disadvantages are: While the synchronous motor may start a high inertial load, it may not be able to accelerate the load enough to pull it into synchronism. If this occurs, the synchronous motor operates at low frequency and at very irregular speeds, resulting in audible noise. Also for a given horsepower, synchronous motors are larger and more expensive than non-synchronous motors.

DC MOTORS

Most of the world's adjustable speed business is addressed by DC motors. DC motor speeds can easily be varied, therefore they are utilized in applications where speed control, servo control, and/or positioning needs exist. The stator field is produced by either a field winding, or by permanent magnets. This is a stationary field (as opposed to the AC stator field which is rotating). The second field, the rotor field, is set up by passing current through a commutator and into the rotor assembly. The rotor field rotates in an effort to align itself with the stator field, but at the appropriate time (due to the commutator) the rotor field is switched. In this method then, the rotor field never catches up to the stator field. Rotational speed (i.e. how fast the rotor turns) is dependent on the strength of the rotor field. In other words, the more voltage on the motor, the faster the rotor will turn.

The following will briefly explore the various wound field motors and the permanent magnet (PMDC) motors.
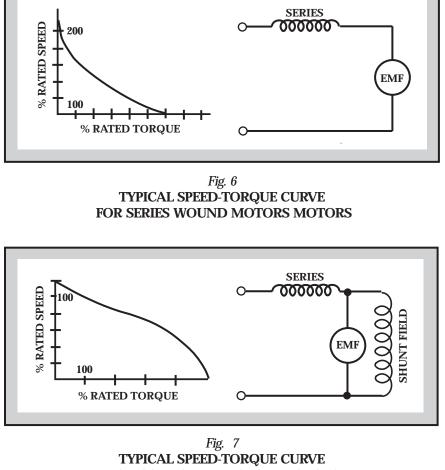

Fig. 5 - **TYPICAL SPEED-TORQUE CURVE FOR SHUNT WOUND MOTORS**

SHUNT WOUND MOTORS. With the shunt wound, the rotor and stator (or field windings) are connected in parallel. The field windings can be connected to the same power supply as the rotor, or excited separately. Separate excitation is used to change motor speed (i.e. rotor voltage is varied while stator or field winding is held constant).

The parallel connection provides a relative flat speed-torque curve and good speed regulation over wide load ranges. However, because of demagnetization effects, these motors provide starting torques comparatively lower than other DC winding types.

SERIES WOUND MOTORS. In the series wound motor, the two motor fields are connected in series. The result is two strong fields which will produce very high starting torque. The field winding carries the full rotor current. These motors are usually employed where large starting torques are required such as cranes and hoists. Series motors should be avoided in applications

where they are likely to lose load because of the tendency to "run away" under no-load conditions.

Fig. 6
**TYPICAL SPEED-TORQUE CURVE
FOR SERIES WOUND MOTORS MOTORS**

Fig. 7
**TYPICAL SPEED-TORQUE CURVE
FOR COMPOUND WOUND MOTORS**

COMPOUND WOUND MOTOR. Compound motors use both a series and a shunt stator field. Many speed torque curves can be created by varying the ratio of series and shunt fields.

In general, small compound motors have a strong shunt field and a weak series field to help start the motor. High starting torques are exhibited along with relatively flat speed torque characteristics. In reversing applications, the polarity of both windings must be switched, thusrequiring large, complex circuits.

STEPPER MOTOR. Step motors are electromechanical actuators which convert digital inputs to analog motion. This is possible through the motor's controller electronics. There are various types of step motors such as solenoid activated, variable reluctance, permanent magnet and synchronous inductor.

Independent of stepper type, all are devices which index in fixed angular increments when energized in a programmed manner. Step motors' normal operation consists of discrete angular motions of uniform magnitude rather than continuous motion.
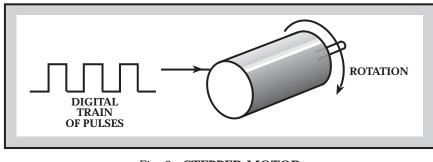

Fig. 8 - **STEPPER MOTOR**

A step motor is particularly well suited to applications where the controller signals appear as pulse trains. One pulse causes the motor to increment one angle of motion. This is repeated for one pulse.

Most step motors are used in an open loop system configuration, which can result in oscillations. To overcome this, either complex circuits or feedback is employed – thus resulting in a closed loop system.

Stepper motors are, however, limited to about one horsepower and 2000 rpm, therefore limiting them in many applications.

PMDC MOTOR. The predominant motor configuration utilized in demanding incrementing (start-stop) applications is the permanent magnet DC (PMDC) motor. This type with appropriate feedback is quite an effective device in closed loop servo system applications.
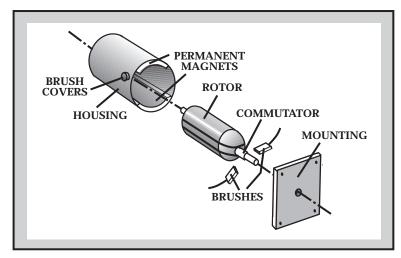

Fig. 9 - **TYPICAL DC MOTOR CONSTRUCTION**

Since the stator field is generated by permanent magnets, no power is used for field generation. The magnets provide constant field flux at all speeds. Therefore, linear speed torque curves result.

This motor type provides relatively high starting, or acceleration torque, is linear and predictable, and has a smaller frame and lighter weight compared to other motor types and provides rapid positioning.

OPEN LOOP/CLOSED LOOP

In a system. the controller is the device which activates motion by providing a command to do something, i.e. start or change speed/position. This command is amplified and applied onto the motor. Thus motion commences . . . but how is this known?

There are several assumptions which have been made. The first assumption is that power is applied onto the motor and the second is that the motor shaft is free to rotate. If there is nothing wrong with the system, the assumptions are fine – and indeed motion commences and the motor rotates.
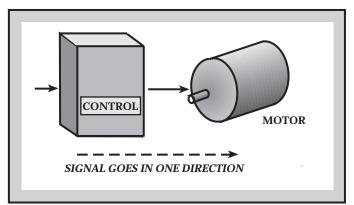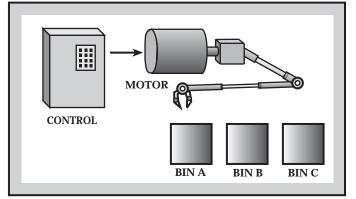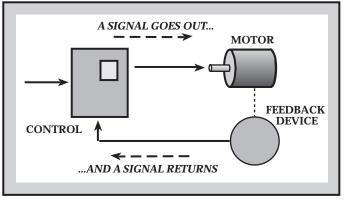

SIGNAL GOES IN ONE DIRECTION

Fig. 10 - **OPEN LOOP DRIVE**

If for some reason, either the signal or power does not get to the motor, or the motor is somehow prevented from rotating, the assumptions are poor and there would be no motion.

Systems that assume motion has taken place (or is in the process of taking place) are termed "open loop". An open loop drive is one in which the signal goes "in one direction only". . . from the control to the motor. There is no signal returning from the motor/load to inform the control that action/motion has occurred.

Fig. 11
**EXAMPLE OF AN APPLICATION
USING OPEN LOOP DRIVE**

A stepper drive is a perfect example of an open loop system. One pulse from the control to the motor will move the motor one increment. If for some reason the stepper does not move, for example due to jamming, the control is unaware of the problem and cannot make any corrections. As an example, suppose an application calls for automatically placing parts into bins A, B and C. The control can trigger one pulse, resulting in shaft rotation and placement of a part in bin A. Two pulses cause shaft rotation and part placement in bin B and three pulses for part placement in bin C. If for some reason the shaft cannot rotate to bins B and C, the control is unaware of the problem and all parts are placed in bin A – a big problem if not discovered immediately by an operator.

If a signal is returned to provide information that motion has occurred, then the system is described as having a signal which goes in "two directions": The command signal goes out (to move the motor), and a signal is returned (the feedback) to the control to inform the control of what has occurred. The information flows back, or *returns*. This is an example of a "closed loop" drive.

Fig. 12 - **CLOSED LOOP DRIVE**

The return signal (feedback signal) provides the means to monitor the process for correctness. From the automatic pick and place application example previously cited, if the shaft cannot rotate to bins B and C, the feedback will inform the control of an error and the control can activate a light or a horn to alert the operator of the problem.

When would an application use an open loop approach? First of all, just think of how simple it would be to hook up – a few wires and no adjustments. Stepper motors are traditionally employed in open loop systems . . . they are easy to wire, they interface easily with the user's digital computer and they provide good position repeatability. Stepper motors, however, are limited to approximately one horsepower. Their upper speed limit is about 2000 rpm.

The weaknesses of the open loop approach include: It is not good for applications with varying loads, it is possible for a stepper motor to lose steps, its energy efficiency level is low and it has resonance areas which must be avoided.

What applications use the closed loop technique? Those that require control over a variety of complex motion profiles. These may involve the following: control of either velocity and/or position; high resolution and accuracy; velocity may be either very slow, or very high; and the application may demand high torques in a small package size.

Because of additional components such as the feedback device, complexity is considered by some to be a weakness of the closed loop approach. These additional components do add to initial cost (an increase in productivity is typically not considered when investigating cost). Lack of understanding does give the impression to the user of difficulty.

In many applications, whether the open loop or closed loop techniques employed often comes down to the basic decision of the user . . . and the approach with which he/she is most knowledgeable/comfortable with.

WHAT IS A SERVO?

What is a servo? This is not easily defined nor self-explanatory since a servomechanism, or servo drive, does not apply to any particular device. It is a term which applies to a function or a task.

The function, or task, of a servo can be described as follows. A command signal which is issued from the user's interface panel comes into the servo's "positioning controller". The positioning controller is the device which stores information about various jobs or tasks. It has been programmed to activate the motor/load, i.e. change speed/position.
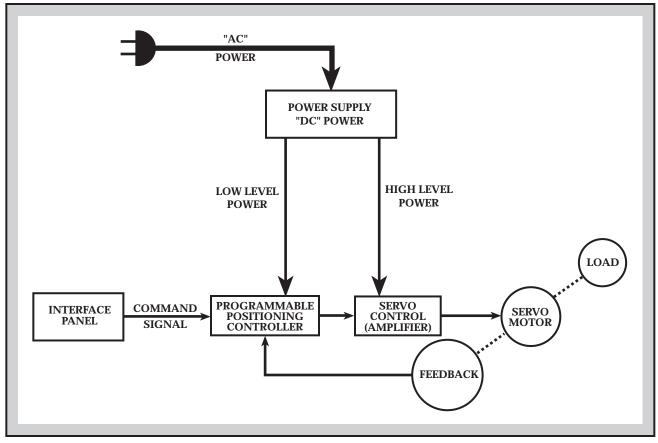

Fig. 13 - **THE CONCEPT OF A SERVO SYSTEM**

The signal then passes into the servo control or "amplifier" section. The servo control takes this low power level signal and increases, or amplifies, the power up to appropriate levels to actually result in movement of the servo motor/load.

These low power level signals must be amplified: Higher voltage levels are needed to rotate the servo motor at appropriate higher speeds and higher current levels are required to provide torque to move heavier loads.

This power is supplied to the servo control (amplifier) from the "power supply" which simply converts AC power into the required DC level. It also supplies any low level voltage required for operation of integrated circuits.

As power is applied onto the servo motor, the load begins to move . . . speed and position changes. As the load moves, so does some other "device" move. This other "device" is either a tachometer, resolver or encoder (providing a signal which is "sent back" to the controller). This "feedback" sig-

nal is informing the positioning controller whether the motor is doing the proper job.

The positioning controller looks at this feedback signal and determines if the load is being moved properly by the servo motor; and, if not, then the controller makes appropriate corrections. For example, assume the command signal was to drive the load at 1000 rpm. For some reason it is actually rotating at 900 rpm. The feedback signal will inform the controller that the speed is 900 rpm. The controller then compares the command signal (desired speed) of 1000 rpm and the feedback signal (actual speed) of 900 rpm and notes an error. The controller then outputs a signal to apply more voltage onto the servo motor to increase speed until the feedback signal equals the command signal, i.e. there is no error.

Therefore, a servo involves several devices. It is a system of devices for controlling some item (load). The item (load) which is controlled (regulated) can be controlled in any manner, i.e. position, direction, speed. The speed or position is controlled in relation to a reference (command signal), as long as the proper feedback device (error detection device) is used. The feedback and command signals are compared, and the corrections made. Thus, the definition of a servo system is, that it consists of several devices which control or regulate speed/position of a load.

COMPENSATION

Why must servos be compensated? Simply stated, it is required so that the controller and motor/load i.e. machine will operate properly. The machine must produce accurate parts and have high productivity.

In order for the machine to produce good, accurate parts, it must operate in two distinct modes: *transient* and *steady state*.

The first mode of operation, the transient state (may also be termed dynamic response state), occurs when the input command changes. This causes the motor/load to accelerate/decelerate i.e. change speed. During this time period, there is an associated 1) time required for the motor/load to reach a final speed/position (rise time) , 2) time required for the motor/load to settle and 3) a certain amount of overshoot which is acceptable.
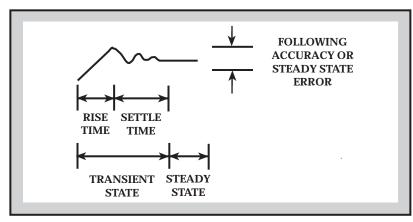

Fig. 14 - **SERVO RESPONSE**

The second mode of operation, steady state, occurs when the motor/load has reached final speed, i.e. continuous operation. During this time, there is an associated following accuracy (how accurate the machine is performing). This is typically called steady state error.

The machine must be capable of operating in these two distinct modes in order to handle the variety of operations required for machine performance. And in order that the machine will perform without excessive overshoot, settle within adequate time periods, and have minimum steady state error, the servo must be adjusted – or *compensated*.

Compensation involves adjustment or tuning the servo's gain and bandwidth. First of all, a look at the definition of these terms is in order and then how they affect performance.

Gain is a ratio of output versus input. As an example, examine a home stereo system. The ratio of the input signal (as received from the radio station) versus the output signal (what your ear hears) is gain. If the volume knob is low, the sound is soft – low gain; if the volume is turned up high, the sound is loud – high gain. Gain, therefore is a measure of the amplification of the input signal. In a servo controller, gain effects the accuracy (i.e. how close to the *desired* speed, or position is the motor's *actual* speed or position). High gain will allow small accurate movement and the machine will be capable of producing precise parts.

Bandwidth is expressed or measured in frequency. The home stereo system will again provide an example for the definition. If the frequency of the sound heard is low (base drum), there is no difficulty in hearing the sound. As the frequency is increased, the listener has more difficulty hearing the sound. At some point, the human ear cannot detect the sound. This is attributed to the range of frequencies which the human ear can detect, i.e. the bandwidth to which the human ear can hear or respond to. In a servo, bandwidth is a measure of how fast the controller/motor/machine can respond. The wider the bandwidth, the faster the machine can respond. Fast response will enable the machine to react rapidly, producing many parts.

Why then, are not all servos designed with high gain (high accuracy) and wide bandwidth (fast response)? This is attributed to 1) limitations of the components and 2) resonant conditions.

Limits of the components – they can handle only so much power. In addition, increasing gain adds components, cost, complexity.

Resonant conditions – To explain this, imagine a yard stick held in your hand. Slowly move it up and down. . . note that the far end of the rod will follow your hand movement. As movement is increased (increasing frequency of motion) the far end of the yard stick will bend in its attempt to keep up with your hand movements. At some frequency it is possible to break the stick . . . this is the resonant point.

Just as with this example, all systems have a resonant point, whether that system is a bridge, a tank or a servo. Machines must not be operated at the resonant point otherwise instability and severe damage will occur.

In conclusion, servos are compensated or "tuned" via adjustments of gain and response so that the machine will produce accurate parts at a high productivity rate.

TYPES OF CONTROLS

The control of a motor will employ some type of power semiconductor. These devices regulate the amount of power being applied onto the motor, and moving the load.

One type of semiconductor is the SCR (silicon controller rectifier) which will be connected to the AC line voltage. This type of device is usually employed where large amounts of power must be regulated, motor inductance is relatively high and accuracy in speed is not critical (such as constant speed devices for fans, blowers, conveyor belts). Power out of the SCR, which is available to run the motor, comes in discrete pulses. At low speeds a continuous stre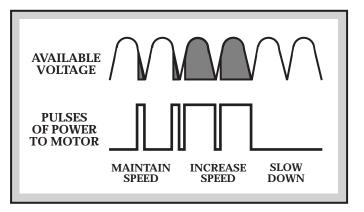am of narrow pulses is required to maintain speed. If an increase in speed is desired, the SCR must be turned on to apply large pulses of instant power, and when lower speeds are desired, power is removed and a gradual coasting down in speed occurs. A good example would be when one car is towing a second car. The driver in the first car is the SCR device and the second car, which is being towed is the motor/load. As long as the chain is taut, the driver in the first car is in control of the second car. But suppose the first car slows down. There would be slack in the chain and, at that poi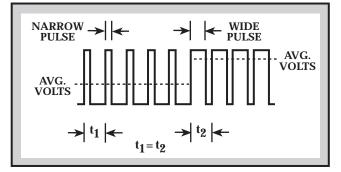nt, the first car is no longer in control (and won't be until he gets into a position where the chain is taut again). So, for the periods of time when the first car must slow down, the driver is not in control. This sequence occurs repeatedly, resulting in a jerky, cogging operation. This type of speed control is adequate for many applications

Fig. 15 - **AN SCR CONTROL**

If smoother speed is desired, an electronic network may be introduced. By inserting a "lag" network, the response of the control is slowed so that a large instant power pulse will not suddenly be applied. Filtering action of the lag network gives the motor a sluggish response to a sudden change in load or speed command changes. This sluggish response is not important in applications with steady loads or extremely large inertia. But for wide range, high performance systems, in which rapid response is important, it becomes extremely desirable to minimize sluggish reaction since a rapid changes to speed commands are desirable.
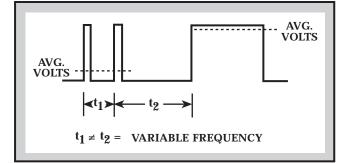
Transistors may also be employed to regulate the amount of power applied onto a motor. With this device, there are several "techniques", or design methodology, used to turn transistors "on" and "off". The "technique" or mode of operation may be "linear", "pulse width modulated" (PWM) or "pulse frequency modulated" (PFM).

The "linear" mode uses transistors which are activated, or turned on, all the time supplying the appropriate amount of power required. Transistors act like a water faucet, regulating the appropriate amount of power to drive the motor. If the transistor is turned on half way, then half of the power goes to the motor. If the transistor is turned fully on, then all of the power goes to the motor and it operates harder/faster. Thus for the linear type of control, power is delivered constantly, not in discrete pulses (like the SCR control). Thus better speed stability and control is obtained.

Another technique is termed pulse width modulation (PWM). With PWM techniques, power is regulated by applying pulses of variable width, i.e. by changing or modulating the pulse widths of the power. In comparison with the SCR control (which applies large pulses of power), the PWM

Fig. 16
PULSE WIDTH DETERMINES AVERAGE VOLTAGE

Fig. 17
**PULSE FREQUENCY MODULATION
TO DETERMINE AVERAGE VOLTAGE**

technique applies narrow, discrete (when necessary) power pulses. Operation is as follows: With the pulse width small, the average voltage applied onto the motor is low, and the motor's speed is slow. If the width is wide, the average voltage is higher, and therefore motor speed is higher. This technique has the advantage in that the power loss in the transistor is small, i.e. the transistor is either fully "on" or fully "off" and, therefore, the transistor has reduced power dissipation.This approach allows for smaller package sizes.

The final technique used to turn transistors "on" and "off" is termed pulse frequency modulation (PFM). With PFM, the power is regulated by applying pulses of variable frequency, i.e. by changing or modulating the timing of the pulses. The system operates as follows: With very few pulses, the average voltage applied onto the motor is low, and motor speed is slow. With many pulses, the average voltage is increased, and motor speed is higher.
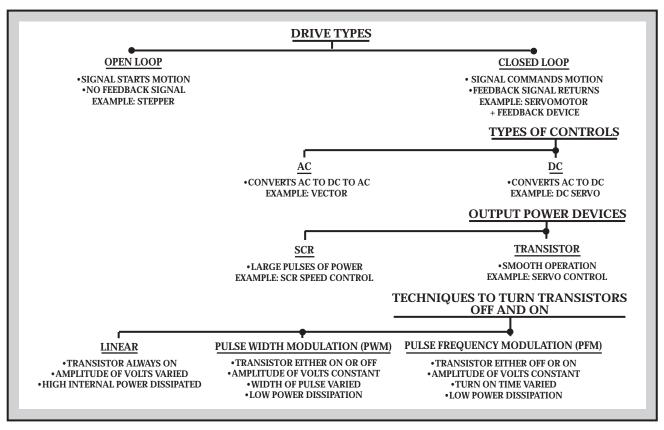

Fig. 18 - **SUMMARY OF DRIVE TYPES**

TYPES OF FEEDBACK DEVICES

Servos use feedback signals for stabilization, speed and position information. This information may come from a variety of devices such as the analog tachometer, the digital tachometer (optical encoder) or from a resolver. In the following, each of these devices will be defined and the basics explored.

ANALOG TACHOMETERS

Tachometers resemble miniature motors. However, the similarity ceases there. In a tachometer, the gauge of wire is quite fine, thus the current handling capability is small. But the tachometer is not used for a power delivering device. Instead, the shaft is turned by some mechanical means and a voltage is developed at the terminals (a motor in reverse!). The faster the shaft is turned, the larger the magnitude of voltage developed (i.e. the amplitude of the tach signal is directly proportional to speed). The output voltage shows a polarity (+ or -) which is dependent on direction of rotation.
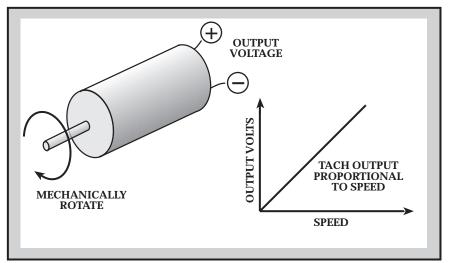

Fig. 19 - **TACHOMETER**

Analog, or DC tachometers, as they are often termed, play an important role in drives, because of their ability to provide directional and rotational information. They can be used to provide speed information to a meter (for visual speed readings) or provide velocity feedback (for stabilization purposes). The DC tach provides the simplest, most direct method of accomplishing this feat.

As an example of a drive utilizing an analog tach for velocity information, consider a lead screw assembly which must move a load at a constant speed. The motor is required to rotate the lead screw at 3600 rpm. If the tachometer's output voltage gradient is 2.5 volts/Krpm, the voltage read on the tachometer terminals should be:

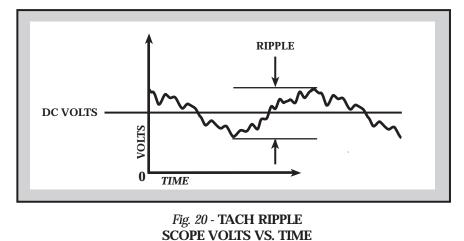$$3.600 \text{ Krpm x } 2.5 \text{ volts/Krpm} = 9 \text{ volts}$$

If the voltage read is indeed 9 volts, then the tachometer (and motor/load) is rotating at 3600 rpm. The servo drive will try to maintain this voltage to assure the desired speed. Although this example has been simplified, the basic concept of speed regulation via the tachometer is illustrated.

Some of the terminology associated with tachometers which explains the basic characteristics of this device are: *voltage constant, ripple and linearity*. The following will define each.

A tachometer's voltage constant may also be referred to as voltage gradient, or sensitivity. This represents the output voltage generated from a tachometer when operated at 1000 rpm, i.e. V/Krpm. Sometimes converted and expressed in volts per radian per second, i.e. V/rad/sec.

Ripple may be termed voltage ripple or tachometer ripple. Since tachs are not ideal devices, and design and manufacturing tolerances enter into the product, there are deviations from the norm. When the shaft is rotated, a DC signal is produced as well as a small amount of an AC signal

Fig. 20 - **TACH RIPPLE**
SCOPE VOLTS VS. TIME

which is superimposed upon the DC level.

In reviewing literature, care must be exercised to determine the definition of ripple since there are three methods of presenting the data: 1) Peak-to-peak – the ratio of peak-to-peak ripple expressed as a percent of the average DC level; 2) RMS – the ratio of the RMS of the AC component expressed as a percent of the average DC level and 3) Peak to Average – the ratio of maximum deviation from the average DC value expressed as a percent of the average DC level.

Linearity – The ideal tachometer would have a perfect straight line for voltage vs. speed. Again, design and manufacturing tolerances enter the picture and alter this straight line. Thus, linearity is a measure of how far away from perfect this product or design is. The maximum difference of the actual versus theoretical curves is linearity (expressed in percentage).
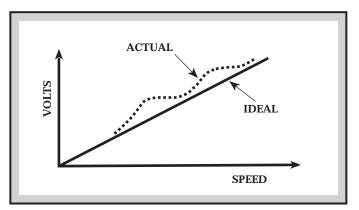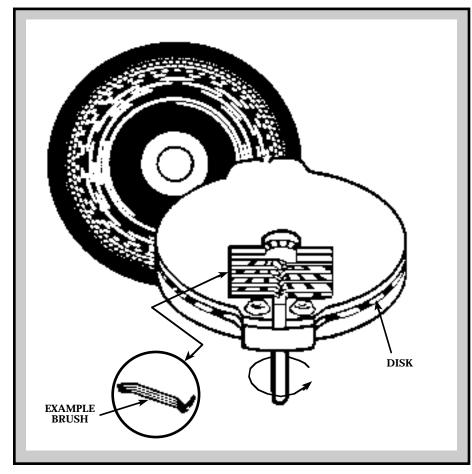

Fig. 21 - **TACH LINEARITY**

DIGITAL TACHOMETERS

A digital tachometer, often termed an optical encoder or simply *encoder*, is a mechanical-to-electrical conversion device. The encoder's shaft is rotated and an output signal results which is proportional to distance (i.e. angle) the shaft is rotated through. The output signal may be square waves, or sinusoidal waves, or provide an absolute position. Thus encoders are classified into two basic types: *absolute* and *incremental.*

ABSOLUTE ENCODER. The absolute encoder provides a specific address for each shaft position throughout 360 degrees. This type of encoder employs either contact (brush) or non-contact schemes of sensing position.

The contact scheme incorporates a brush assembly to make direct electrical contact with the electrically conductive paths of the coded disk to read address information. The non-contact scheme utilizes photoelectric detection to sense position of the coded disk.

The number of tracks on the coded disk may be increased until the desired resolution or accuracy is achieved. And since position information is directly on the coded disk assembly, the disk has a
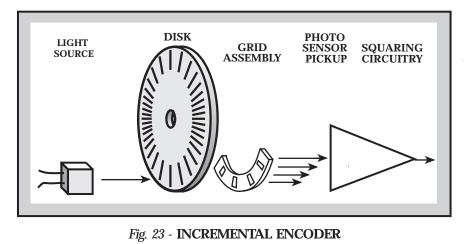
Fig. 22 - **ABSOLUTE ENCODER**

built-in "memory system" and a power failure will not cause this information to be lost. Therefore, it will not be required to return to a "home" or "start" position upon re-energizing power.

INCREMENTAL ENCODER. The incremental encoder provides either pulses or a sinusoidal output signal as it is rotated throughout 360 degrees. Thus distance data is obtained by counting this information.

The disk is manufactured with opaque lines. A light source passes a beam through the transparent segments onto a photosensor which outputs a sinusoidal waveform. Electronic processing can be used to transform this signal into a square pulse train.

Fig. 23 - **INCREMENTAL ENCODER**

In utilizing this device, the following parameters are important: 1) Line count: This is the number of pulses per revolution. The number of lines is determined by the positional accuracy required in the application. 2) Output signal: The output from the photosensor can be either a sine or square wave signal. 3) Number of channels: Either one or two channel outputs can be provided. The two channel version provides

a signal relationship to obtain motion direction (i.e. clockwise or counterclockwise rotation). In addition, a zero index pulse can be provided to assist in determining the "home" position.
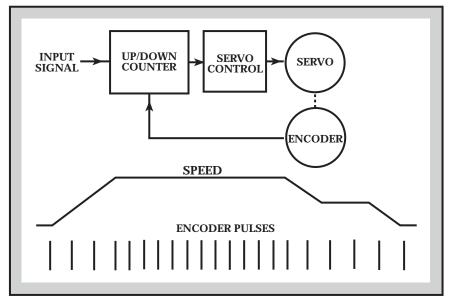

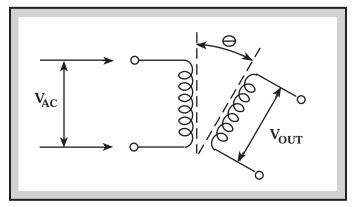Fig. 24 - **EXAMPLE USING ENCODER PULSES**

A typical application using an incremental encoder is as follows: An input signal loads a counter with positioning information. This represents the position the load must be moved to. As the motor accelerates, the pulses emitted from the incremental (digital) encoder come at an increasing rate until a constant run speed is attained. During the run period, the pulses come at a constant rate which can be directly related to motor speed. The counter, in the meanwhile, is counting the encoder pulses and, at a predetermined location, the motor is commanded to slow down. This is to prevent overshooting the desired position. When the counter is within 1 or 2 pulses of the desired position, the motor is commanded to stop. The load is now in position.

RESOLVERS. Resolvers look similar to small motors – that is, one end has terminal wires, and the other end has a mounting flange and a shaft extension. Internally, a "signal" winding rotor revolves inside a fixed stator. This represents a type of transformer: When one winding is excited with a signal, through transformer action the second winding is excited. As the first winding is moved (the rotor), the output of the second winding changes (the stator). This change is directly proportional to the angle which the rotor has been moved through.

Fig. 25 - **RESOLVER: A ROTATING TRANSFORMER**

As a starting point, the simplest resolver unit contains a single winding on the rotor and two windings on the stator (located 90 degrees apart).
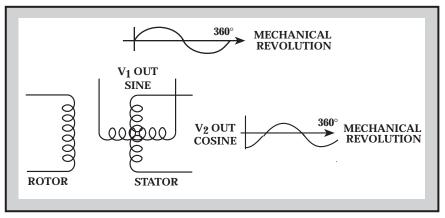

Fig. 26 - **TYPICAL RESOLVER OUTPUT**

A reference signal is applied onto the primary (the rotor), then via transformer action this is coupled to the secondary. The secondary's output signal would be a sine wave proportional to angle

(the other winding would be a cosine wave), with one electrical cycle of output voltage produced for each 360 degrees of mechanical rotation. These are fed into the controller.

Inside the controller, a resolver to digital (R to D) converter analyzes the signal, producing an output representing the angle which the rotor has moved through, and an output proportional to speed (how fast the rotor is moving).

There are various types of resolvers. The type described above would be termed a single speed resolver; that is, the output signal goes through only one sine wave as the rotor goes through 360 mechanical degrees. If the output signal went through four sine waves as the rotor goes through 360 mechanical degrees, it would be called a 4 -speed resolver.

Another version utilizes three windings on the stator – and would be called a synchro. The three windings are located 120 degrees apart.

The basic type of resolver discussed thus far may also be termed a "resolver transmitter" – one phase input and two phase outputs (i.e. a single winding of the rotor is excited and the stator's two windings provide position information). Resolver manufacturers may term this a "CX" unit, or "RCS" unit. Another type of resolver is termed "resolver control transformer" – two phase inputs and one phase output (i.e. the two stator windings are excited and the rotor single winding provides position information). Resolver manufacturers term this type "CT" or "RCT" or "RT". The third type of resolver is termed a "resolver transmitter" – two phase inputs and two phase outputs (i.e. two rotor windings are excited, and position information is derived from the two stator windings). This may be referred to as "differential" resolver, or "RD", or "RC" depending on the manufacturer.

TYPES OF ACTUATORS

The basic actuators for controlling motion (which involve control of either speed, torque or positional accuracy) would include:

- **Air Motors**
- **Hydraulic Motors**
- **Clutch/Brake**
- **Stepper Motors**
- **AC Induction Motors**
- **Servomotors**

The following presents a synopsis, of the strengths and weaknesses of each basic motion control technique.

Air Motors – use compressed air to create motion. Pressure and flow determine speed and torque positional accuracy is usually not a requirement.

Principle strengths:
1. Low cost
2. Available components
3. Easy to apply
4. Easy to maintain
5. Easy to understand
6. Centralized power source

Principle weaknesses:
1. Audible compressor noise
2. Difficult to regulate speed
3 Prone to contamination
4. Energy inefficient

Hydraulic motors – use pressurized oil to move a piston. Higher pressure results in higher torque (i.e. brute force).

Principle strengths:
1. Easy to apply
2. High torques available
3. Centralized power source
4. Easy to understand

Principle weaknesses:
1. Audible noise
2. Difficult to control speed
3. Slow positioning
4. Prone to leaks
5. Energy inefficient
6. Fire hazard
7. High maintenance required

Clutch/Brake – a device coupling a continuously rotating shaft and a load. Uncoupling the load results in stopping. Varying on/off time results in varying distances.

Principle strengths:
1. Easy to apply
2. Low comparative cost
3. Good for start/stop
   with light loads
4. Easy to provide speed matching

Principle weaknesses:
1. Uncontrolled acceleration
2. Inaccurate
3. Prone to wear
4. Non-repeatable performance

TYPES OF ACTUATORS *(cont.)*

Stepping Motors – electromechanical device which converts one digital pulse into a specific rotational movement or displacement. A "train of pulses" results in rotational speed.

Principle strengths:
1. Simple control
2. Moderate cost
3. Good for constant loads
4. Good positional accuracy

Principle weaknesses:
1. Prone to losing steps
2. Not good for varying loads
3. Energy inefficient
4. Large motor size
5. Resonance problems

AC Induction Motors – widely used for constant speed requirements. Electric "starters" provide connections/start-up/overload protection. Newer technology provides variable speed capability.

Principle strengths:
1. Simple motor
2. Low cost
3. Mature technology
4. Straightforward on/off control
5. Affordable coarse speed control
6. Simple wiring
7. Wide product variety
8. Many vendors available

Principle weaknesses:
1. Limited position control
2. Relatively larger size

Servomotors – A motor with a "feedback" device. Electronic packages control speed and position accuracy.

Principle strengths:
1. High performance
2. Small size
3. Wide variety of components
4. High speeds available
   with specialized controls

Principle weaknesses:
1. Slightly higher cost
2. High performance limited by controls
3. High speed torque limited by
   commutator or electronics

BALDOR ELECTRIC COMPANY
5711 South 7th Street
Fort Smith, Arkansas 72901
(501) 646-4711
Fax (501) 648-5792