Why Are We Still Using Cams?

The Answer is

Simple!

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CAM MOTION CONTROL FOR PACKAGING AND ASSEMBLY MACHINERY

by Tim Seitzer, sales engineer

As engineers we are constantly asked for higher production rates and uptime from the equipment that we design and oversee. Higher speeds are not a matter of simply "turning up the speed pot". Vibration, noise, excessive power consumption, unacceptable down time and machine failure are the almost certain results of ignoring the laws of physics during the design phase of high-speed production and packaging machines. Since we cannot cheat the laws of physics we must learn to use them to our best advantage. The use of cams to move product or tooling allows us to, and in many cases forces us to, know and control the dynamics on our machines. This is an important cornerstone in the foundation to a successful machine design program.

Relative to cams, in this article we hope to:

1) Give the engineer a refresher in motion control as applied to production machinery
2) Offer some comparisons between various popular methods for controlling motion
3) Give some helpful motion control machine design parameters.
4) Discuss different methods and concepts for moving and presenting product in an automated production machine using commercially available cam devices.

Maximizing the speed, while maintaining reliability, of a machine requires first that the motion follow a controlled path that we prescribe. Control is the key word. Cams are capable of precisely controlling position, velocity and acceleration at all points of a motion. An acceleration curve with no discontinuity, or "jerk" (jerk or pulse is the derivative of acceleration and describes the rate of change in acceleration) is also an important aspect of controlled motion. Precise control of a motion can make a dramatic difference in speed capability, vibration, noise generation, energy consumption and (especially) life of the mechanism.

An automobile engine is a good example of mechanical motion control. Take the pistons that follow the cycloidal motion prescribed by the rotating crankshaft (see fig#1). The pistons are reciprocating masses, starting, stopping and reversing direction up to 10,000 times per minute (twice per rev at 5000RPM) while maintaining acceptable vibration, efficiency and wear levels. The crankshaft/piston combination is an example of controlling the motion of an individual component.

Now let's go beyond the individual components and examine how the valves and pistons work in concert. The intake and exhaust valves close (retract out of the piston's path) as the piston advances, missing a catastrophic crash by a fraction of an inch. This is an example of mechanical synchronization, which we will look at in more depth later on. Mechanical synchronization takes advantage of the controlled motion in that we know exactly where the valve and piston are going to be at any given time in a cycle.

Motion control of individual components and mechanical synchronization of these components are powerful tools in designing reliable, high-speed production equipment.

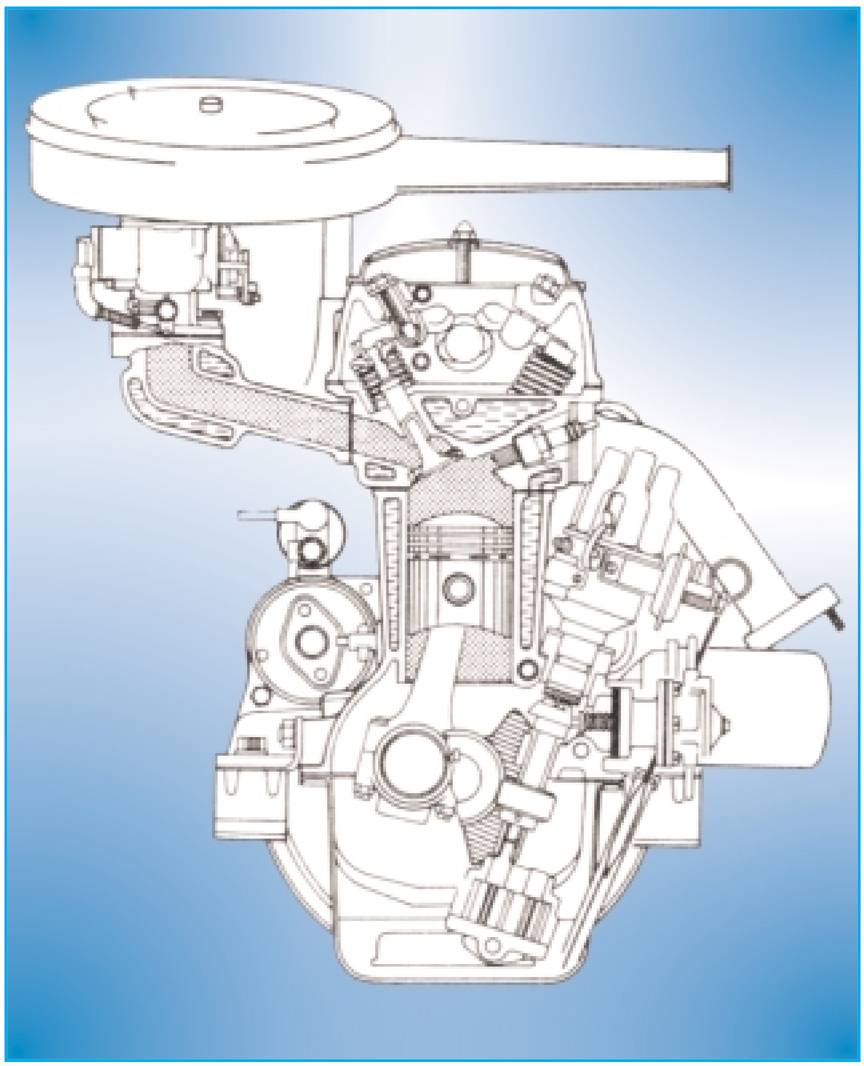


Fig #1

BASICS OF CAMS

A cam system basically functions as a mechanical read only memory. The motion profile information, permanently stored in the cam, is mechanically transferred to the follower system as the cam (for our purposes) rotates. For each movement, this profile information consist of:

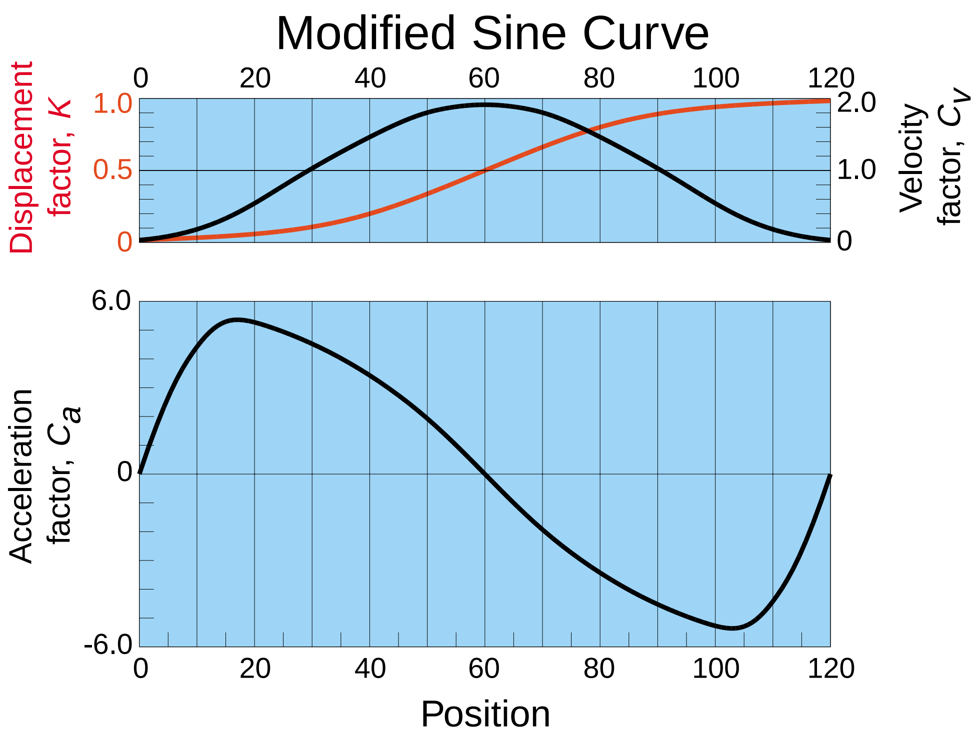
1) Distance of move
2) Motion period (number of degrees of camshaft rotation to accomplish a given move)
3) Dwell or rest period
4) Acceleration curve type(s)

The motion curves shown below are what is typically transferred, by the cam, to the output member. These popular curves are trigonometric functions with continuous acceleration curves and have been found to be the best overall for use in controlling motion for packaging and assembly machinery.

Note that the Modified Sine curve has become the most widely used curve due mainly to it's having the most cam time between peak acceleration and deceleration. This characteristic tends to have the most benefit in indexing heavy, pure inertia (minimal friction or work) loads. Other curves may make a better choice where high friction or workloads are involved.

The reader should note the minimal movement in the beginning and end of the displacement component of the following curves. This is the "slow stop/start" characteristic that you observe when watching a cam-actuated movement. This same characteristic enhances our ability to overlap motions in mechanically synchronized systems, as we will discuss later.

Please review the characteristics of the displacement, velocity and acceleration curves below:



We have established that a cam system exactly follows a prescribed motion. It follows that we can predict, or calculate, useful dynamic sizing information about our cam system.

In linear systems we usually need to know, and can calculate at any point in our motion, camshaft RPM (usually best if constant throughout the motion), linear position, linear velocity, linear acceleration and thrust force seen by our cam system. In rotary systems we need to know, and can calculate at any point, camshaft RPM (again most cam systems are designed to rely on constant camshaft RPM), rotary position, rotary velocity, rotary acceleration and torque. Note, complete sizing of a cam mechanism also requires calculation of camshaft torque, input horsepower, rotary and linear bearing life but this is beyond the scope of this article. The linear and rotary formulas are listed alongside each other so that the reader can see their similarities.

Motion-control Math

Cam systems follow a mathematically prescribed motion, so it is usually possible to calculate position, velocity, and acceleration as well as thrust forces and torques. Here's a look at some basic equations.

Linear acceleration A_l is described as

$A_l = M_c D/t^2$

where M_c = motion constant; D = distance, in.; and t = index time, sec.

For rotary acceleration,

$A_r = M_c D_r/t^2$

where D_r = distance, radians.

Thrust force F due to linear acceleration and rotary torque T due to rotary acceleration are found from

$F = mA$

and

$T = IA_r$

where m = mass, lb; and I = rotary inertia, lb-in.^{2}

Camshaft speed V_l for a linear system is

$V_l = ß/6t$

where $ß$ = index angle, degrees. For a rotary system, camshaft speed V_r is calculated using

$V_r = ß/6tn$

where n = number of indexes or dwells per camshaft revolution.

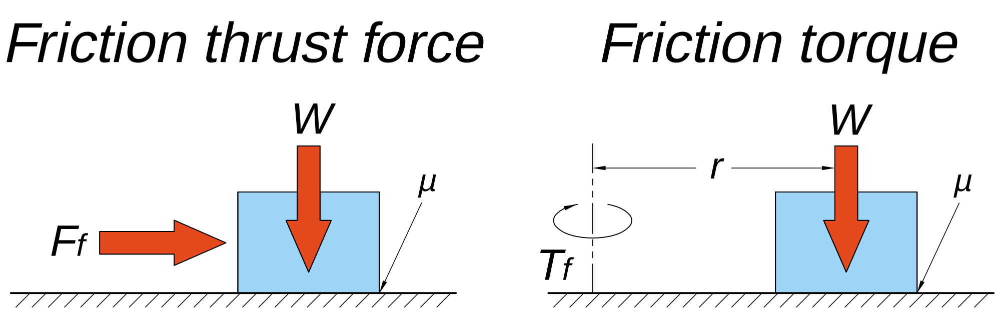
Determine friction thrust force F_f and friction torque T_f with

$F_f = W\mu$

and

$T_f = Wr\mu$

This details the force or torque needed to slide a moving weight on a horizontal surface. W = object weight, lb; r = radius, in., from the center axis to the center of action of the friction force; and μ = dynamic coefficient of friction between the object and surface.



PRE-LOADED CAM MECHANISMS

In a properly designed cam system the mechanical transferal of information (motion) from the cam to the output member is precise but it will depend on the following factors to faithfully reproduce the intended motion:

1) In almost all cases, constant speed or minimal camshaft speed fluctuation.

2) In all cases, minimal input and output system backlash. It should be noted that many of the problems experienced with cam systems can usually be traced to backlash.

Output backlash of the cam mechanism itself is completely eliminated in pre-loaded cam systems. In these systems, either a spring, or a second, opposing cam follower functions to eliminate all play in the system. Since there is no backlash or play, these systems tend to be extremely accurate both in terms of positioning and faithfully following the intended profile. This explains the use of pre-loaded cam systems in cam index drives, as the cam must both move and locate the load. Since the motion profile is precisely followed, and there is no backlash in the cam mechanism, unwanted motion components, such as jerk, are not introduced. This allows for extremely high-speed capabilities from the pre-loaded cam mechanism (provided input and output connections don't introduce backlash and the camshaft speed is constant).

As for spring pre-loaded systems, the spring force must slightly exceed the forces (usually dynamic) attempting to lift the follower from the face of the cam. These forces usually result primarily from the dynamic load and can be calculated. These same spring forces must be overcome by the input drive during normal operation of the mechanism. This can increase input power requirements.

Cam mechanisms that derive their pre-load from opposing cam followers will have only a slightly elevated input power requirement due to overcoming the rolling interference fit of the followers to the cam rib. Maintaining the pre-load of opposing follower type through external mechanisms (such as in a cam pick & place) can add to complexity and cost, whereas a spring pre-load can eliminate backlash in all intermediate mechanisms and still be quite simple.

DISADVANTAGES OF CAM MECHANISMS

The following are typically cited as disadvantages of cam mechanisms:

1) Lack of flexibility. Most cam mechanisms do not allow stroke changes. It is next to impossible to change the motion profile itself (i.e. timing and dwell times). The exceptions occur on cycle on demand applications (dwell times have infinite variation and cycle speeds are variable over a wide range) and certain mechanisms that allow mechanical stroke variation.
2) More upfront engineering is usually required to design cam operated machines. Because of less/no flexibility, the machine functions and timing must be mapped out during the design phase of the machine. Conversely, there is usually less time spent during the machine debug and programming phases.
3) There are fewer engineers versed in cam design and cam mechanism application. Electronics (especially) and pneumatics have gained in popularity.
4) Overload protection must be provided and is not a "given" as it is with pneumatic systems. With the exception of the spring pre-loaded mechanisms discussed above, most cam mechanisms are positive mechanical devices with the ability to damage tooling and even themselves.
5) Cam systems usually have higher upfront costs as compared to pneumatics. Depending on the application, this upfront cost can sometimes be partially or fully recouped in less programming, plumbing, wiring and debug costs.

ADVANTAGES OF CAM MECHANISMS

The following are typically cited as advantages in the use of cam mechanisms:

1) Cams offer extreme high-speed capability. Some servo operated systems now approach the speed capabilities of cams with the added benefit (if needed) of flexibility. The flexibility benefit comes, however, with higher system cost and complexity. It is reasonable to expect that a more highly trained, electronics oriented, maintenance staff is required for servo based systems.
2) Most cam systems in commercially available motion control components utilize all rolling contact elements constructed of hardened and finish ground tool steel. These design parameters minimize friction and heat build-up and, along with precise control of the motion, extend the service life.
3) Cam mechanisms are usually quite simple. Inexperienced maintenance personnel can quickly size up or eliminate a cam mechanism as a source of trouble. Repairs can usually be performed by those with basic mechanical skills. Contrast the simplicity of a cam pick & place mechanism with that of a pneumatically operated unit. Each move in a pneumatic pick & place must be sensed, fed to a PLC, a valve must be energized, the infinitely adjustable flow controls must be properly set for each direction of each move. The above scenario occurs six times for a typical single pick & place cycle. Personnel must be capable of diagnosing pneumatic and control system (logic) problems.
4) A cam system's dynamics are highly predictable. Since the dynamics are controlled, the loads can be calculated and the mechanism sized accordingly.
5) Reliability of the cam mechanism is a natural by-product of predictable/controlled, motions, simple construction and all rolling elements.
6) Superior energy efficiency as compared to fluid power systems. Losses in compressing, conveying and exhausting still compressed air are high. In addition, the following table re-printed from the Compressed Air & Gas Handbook shows losses due to leaks.

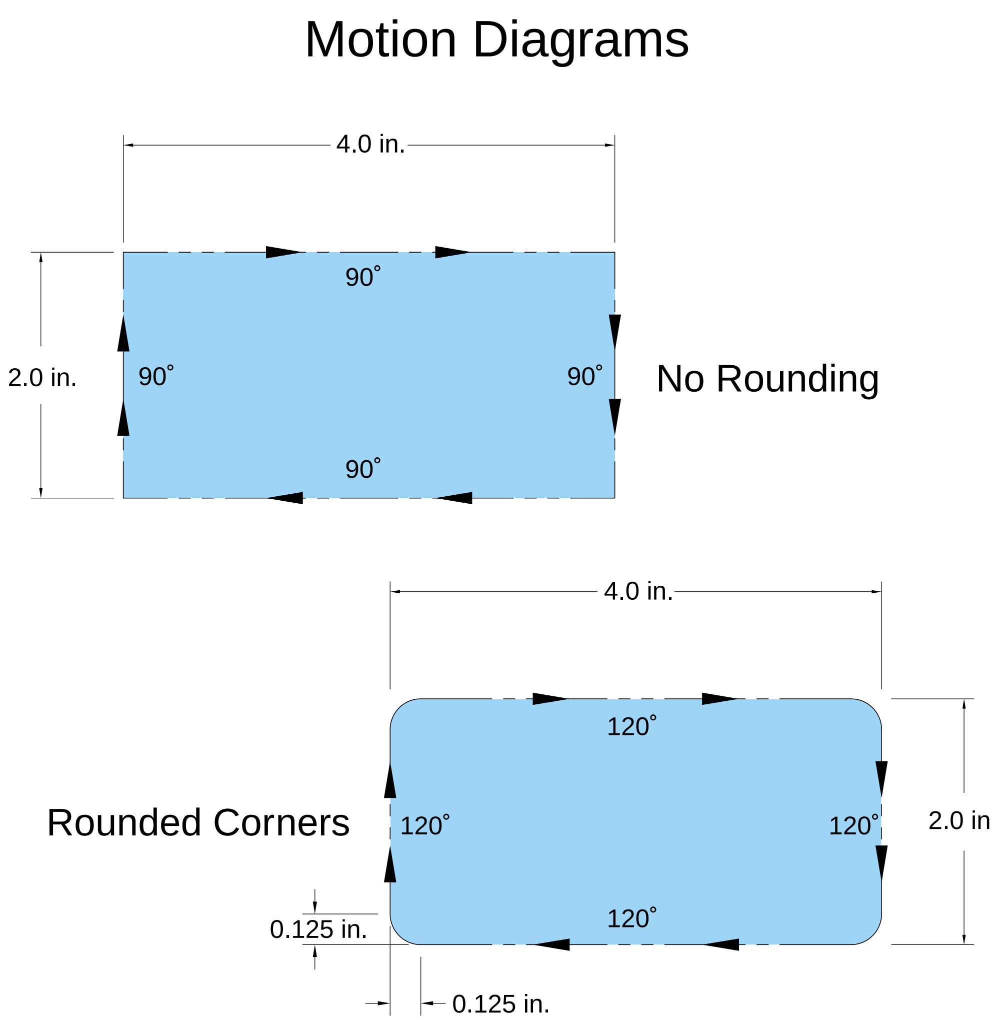
Annual cost of a compressed air leak

Plant air pressure					
90 psi	Hole size - in.	1/8	1/4	3/8	1/2
	Air lost - cfm	23.70	94.80	213.00	379.00
	Horsepower lost	5.93	23.70	53.25	94.75
	Annual Cost	$1,993	$7,927	$17,912	$31,873
100 psi	Hole size - in.	1/8	1/4	3/8	1/2
	Air lost - cfm	26.00	104.00	234.00	415.00
	Horsepower lost	6.50	26.00	58.50	103.75
	Annual Cost	$2,187	$8,746	$19,678	$34,900

7) Energy efficiency, quiet operation along with eliminating the exhausting of oiled air into the plant environment help cams to be environmentally friendly. Cam mechanism are often chosen for clean room applications and mounted underneath the machine tabletop.
8) Lower upfront costs per force/torque output as compared to electronic systems. Can be higher than fluid systems but the motion is not precisely controlled.
9) The output of the cam system predictably follows its prescribed displacement program and is not affected by line pressure variations, flow control adjustments or voltage fluctuations. This means that we know it will be where it is intended to be, when it is intended to be there. This allows us to use two related and very powerful tools; motion overlap and synchronization.

MOTION OVERLAP

As shown in the equations above, the dynamic loads on a mechanism increases/decreases with the square of the move time. Cutting the move time in half increases the dynamic load by a factor of four! Conversely, increasing the move time by say 25% results in the dynamic load decreasing by almost one half. In two axis cam systems (such as pick & place and walking beams drives), very significant dynamic benefit can be gained by slightly rounding the corners of the motion. We do this by extending the cam time of each segment so that it encroaches, or overlaps, into the adjoining segment. The example below showing a "square cornered" motion contrasted with a "rounded corner" motion illustrates the difference in loading seen by the mechanism.

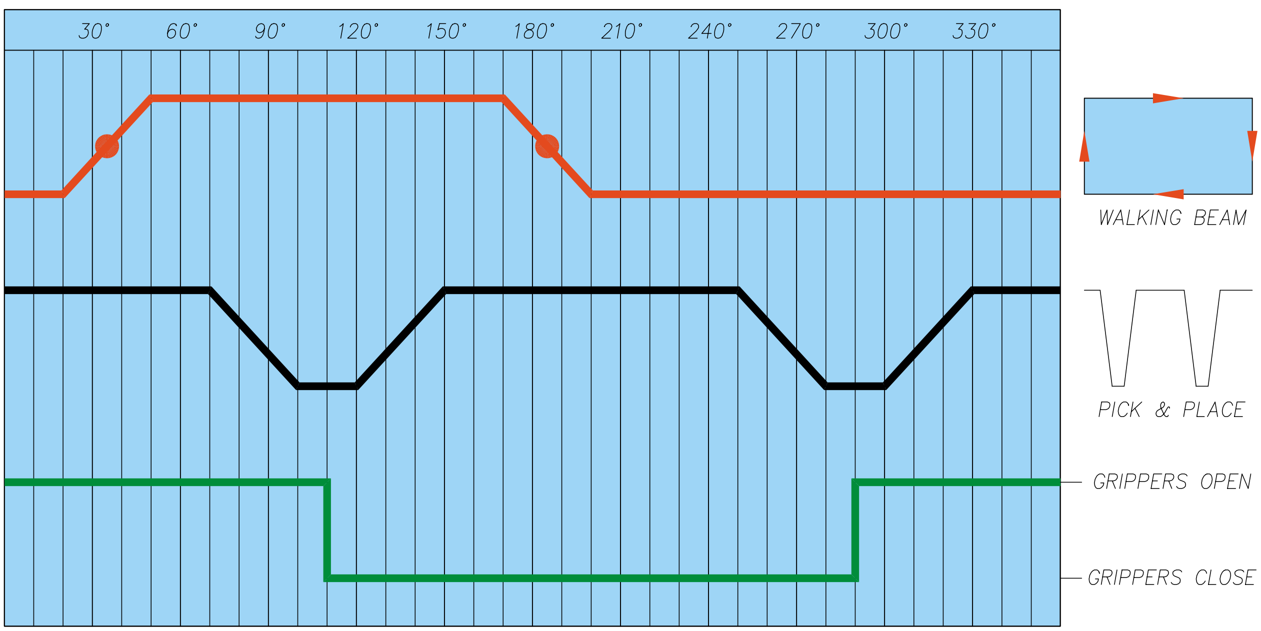


Cams allow us to easily overlap motions to gain the benefits shown above. As the reader might expect, air actuated systems do not have this ability to overlap motions. In addition to overlap, the pneumatic systems lack of control of the individual segments of the movement means even higher accelerations, loading, vibration and wear on the mechanism. Precise control of the motion essentially has a two tiered advantage over systems with less control.

SYNCHRONOUS CAM MOTIONS

Synchronous cam operated machines usually involve more than one cam mechanism mechanically linked to (or driven by) a common shaft, usually the main drive shaft. The main shaft becomes the clock of the machine and all machine functions are driven by and timed to it. Usually an encoder is coupled to the main shaft to feed the machine control positional data for actuating machine functions that are not mechanically actuated by the shaft. For instance, grippers are opened and closed and air cylinders are actuated relative to the position of the main shaft as read by the encoder and commanded by the PLC. The sketch below illustrates an example of machine timing to the main shaft in a synchronous machine.

Timing chart for synchronous walking beam application



This illustration shows the timing sequence for a walking beam with a pick and place unit and a pair of grippers. The walking beam will pick-up and index the product along a pair of rails. The index time will consume 150° of the cycle leaving 210° of dwell to perform the desired operation with the pick and place device. In this case the pick and place will pick-up from a dead nest, during the index of the walking beam, and place into the product at the mid-point of the walking beam return stroke. The grippers will be actuated precisely at the mid-point of the pick-up and de-actuated at the mid-point of the placement or insertion into the product. Thus, synchronous timing is easily achieved between the cam operated devices and the PLC by means of an encoder which is attached to the main drive shaft.

Again, since we control all aspects of the cam motions, we know exactly where the output members of the cam mechanisms will be at any given time in their respective cycles. This allows us to time events for the maximum dynamic advantage. For instance, we could have a pick & place mechanism be engaged with a fixture on an indexing dial, then, begin to move and clear the fixture by only a fraction of a inch as the dial begins to index. We could do this reliably at high speeds thanks to mechanically synchronized cam motions. If, as with cycle on demand or other non-synchronous methods, we had to allow half the total lift stroke to occur before we index, we would loose a considerable amount of potentially productive cycle time. Forces that cause mechanism wear, vibration and energy consumption, again, go up with the square of this lost time.

Synchronous motion also allows us to do various types of work "on the fly" to a moving product. This is often called velocity tracking and is used in continuous motion machines where starting and stopping the product is not practical.

A good example would be liquid filling into a moving container. Often two axis of synchronized cam motion are employed. In liquid filling the "X", or horizontal, axis would accelerate, then match speed with the container. The "Y", or lift axis, would plunge the fill head to the bottom of the container and lift to stay just ahead of the liquid fill level. When the container is filled to the desired level, the "X" axis would then rapidly return in order to fill the next container. There is an almost limitless variety of single and dual axis velocities matching applications that are possible.

CYCLE ON DEMAND CAM MECHANISM OPERATION

Cycling a cam mechanism on demand involves starting and stopping the camshaft (input drive) one or more times per machine cycle. Cycling is approached differently for the main drive of a machine (a walking beam drive, dial or conveyor indexer) versus ancillary equipment (a cam pick & place for example). There are usually three reasons for choosing cycle on demand operation:

1) Machine cycle speeds are slow enough that running the camshaft continuously actually can be detrimental to our cycle time. How can this happen? Say for example that we have a machine that runs at 20 cycles per minute and we want to select a dial indexer. Due to cam geometry considerations the shortest movement (or index) period that the cam can accommodate is 90 degrees. From our equations above, we see that our index time is .75 seconds. When we calculate dynamic loading on the cam mechanism, however, we see that it can safely handle a .25 second index. We don't want to waste the half second so we simply drive the cam mechanism with it's own faster drive and cycle this drive on and off. This is a common arrangement on many dial and conveyor indexing machines.
2) A drive shaft is not accessible to power the cam mechanism.
3) Machine control considerations (i.e. familiarity or special requirements) dictate cycling on demand.

Cycle on demand is, as a very general rule of thumb, beneficial from a cycle time point of view at speeds of less than 30 cycles per minute. Cam indexers intended for cycling usually revert to a 270-degree index period driven by the appropriate reducer ratio to accomplish the desired index time. This is done to keep the pressure angle of the cam minimized, to reduce camshaft torque requirements and so that the input drive has adequate dwell to stop the camshaft but not excessive dwell to turn through to get to the next index. Each cam mechanism must be equipped with a reducer, a cycling motor, cycling motor controller, or a clutch brake package that would not be needed in a synchronous or continuous running system. The machine logic is also more complex.

Let's look at a different aspect of cycling by adding a cam pick & place mechanism to the above machine. We would find that, unlike the indexer example above, the pick & place are not pacing, but following the machine. This is because the pick & place usually only slows the cycle when it is:

1) Interfering or engaged with dial, conveyor, or walking beam during placing of a part.
2) Or, the pick & place simply is not completing its full cycle in a machine cycle.

In order to keep up with the machine we would need to compensate for motor start-up times and other delays associated with cycling. The camshaft of the cam pick & place mechanism would need to turn, as a rule of thumb, 10-15 RPM faster than the machine cycle speed. In our example above, the cam mechanism being cycled would need to run at 30 to 35 RPM in order to keep up with the machine running at 20 cycles/min. For the record, please note that this results in acceleration forces acting on the mechanism that are 2.25 to 3.0 times higher than running the mechanism continuous at 20 RPM.

Even in light of the increased accelerations due to cycling we are still considerably better off dynamically than with an air-operated mechanism. We would have the same, or more, delays in making sensors, making PLC decisions, actuating air valves, filling air lines and cylinders. We do not precisely control the motion (we build up velocity until we hit our end cushions) and we cannot predictably round corners (overlap motions). This allows cam mechanisms, even when cycling on demand, to operate more reliably, and at higher speeds that most fluid power systems. Cam pick & place units offer the additional benefits of simplicity, high load capability, lower shock and vibration as well as increased energy efficiency.

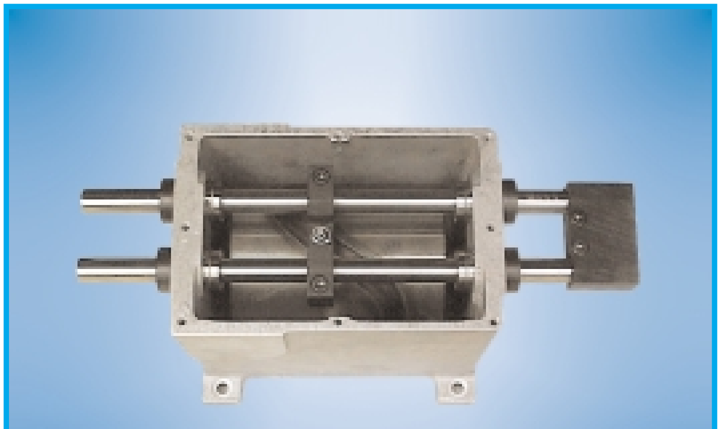
CAM MECHANISM EXAMPLES

Rather than having to master cam mechanism designs, the machine designer has a wide variety of proven pre-packaged cam components available from reputable manufacturers, such as Stelron Components, to choose from. Due to relatively high volume manufacturing and engineering amortized over many units, using these pre-packaged mechanisms can often be an economical choice. Most products have been well tried and refined in the production environment. Manufacturers typically warrant suitability for a given application and will have sales engineers to assist the machine designer in sizing and applying the appropriate product. Examples of cam mechanisms and typical applications follows:

SINGLE AXIS LINEAR CAM MECHANISMS

Mechanism Types:

1) **Barrel Cam** - Single-track non pre-loaded or rib type pre-loaded cam designs available. Long strokes available. Available with cycling drive packages.
Applications: Synchronous shot pin, high speed escapement, cross shuttle, pusher, lifter, velocity tracking, linear oscillators, insertion, in lieu of air cylinders where high speeds or precise timing are required, conveyor indexer and other single axis applications.



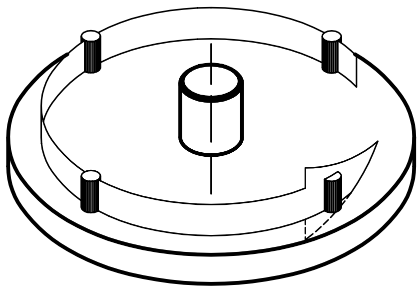
Stelron “Reciprocator”

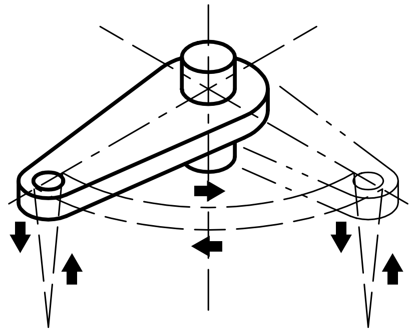
2) **Conjugate Cam** - Pre-loaded design with two opposing followers contacting dual plate cams. Generally shorter strokes.
Applications: Same as Barrel Cam but short strokes and shafts at right angle to motion.

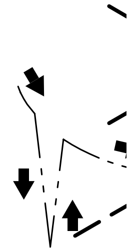
Stelron “Cam Slide”

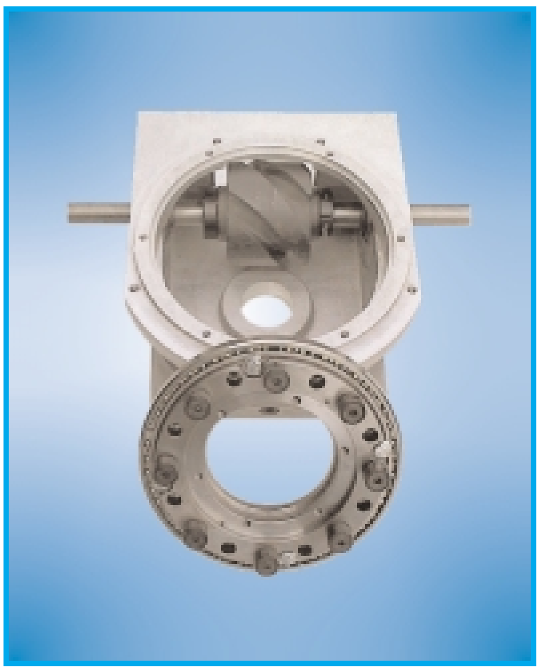
3) **Rotary Oscillator with External Linkage** - Often a pre-loaded device based on an indexer but with a (special) oscillating cam. Customer usually provides the linkage and the linear slide.
Applications: Same as both of above. Strokes depend on cam unit rotary stroke and crank arm length.

SINGLE AXIS ROTARY MECHANISMS







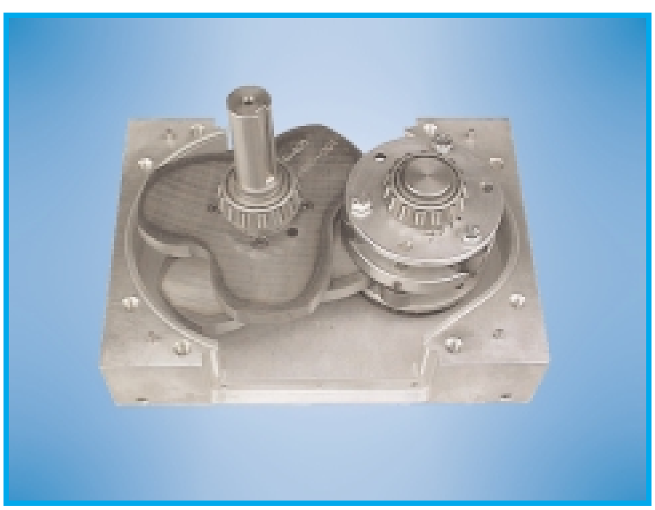


Mechanism Types:

1) **Dial Output Type Indexers or Oscillators** - Normally utilize pre-loaded Barrel or Globoidal type cams. Large flange outputs for stable dial plate mounting. Available with cycling drive packages.

Applications: Dial indexers primarily. Also conveyor, turret and general indexing/oscillating applications where large flange output is advantageous.

Stelron “Rotary Indexer”

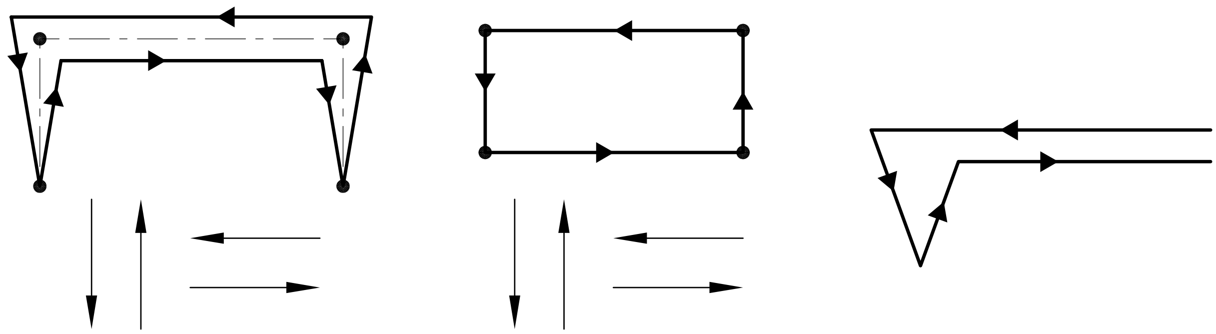


2) **Shaft/Flange Output Type Indexers or Oscillators** - Normally utilize pre-loaded Barrel, Globoidal or Conjugate cams. Conjugate cam units have input and output shafts parallel as opposed to shafts being at right angles for barrel and globoidal cams. Usually shaft/flange outputs. Available with cycling drive packages.

Applications: Wide variety of uses in high-speed synchronous packaging and assembly machines. Conveyor indexing, rotary oscillators, linear oscillators (with linkage), turret indexing and general indexing/oscillating applications where shaft/flange output is advantageous.

Stelron “Parallel Indexer”

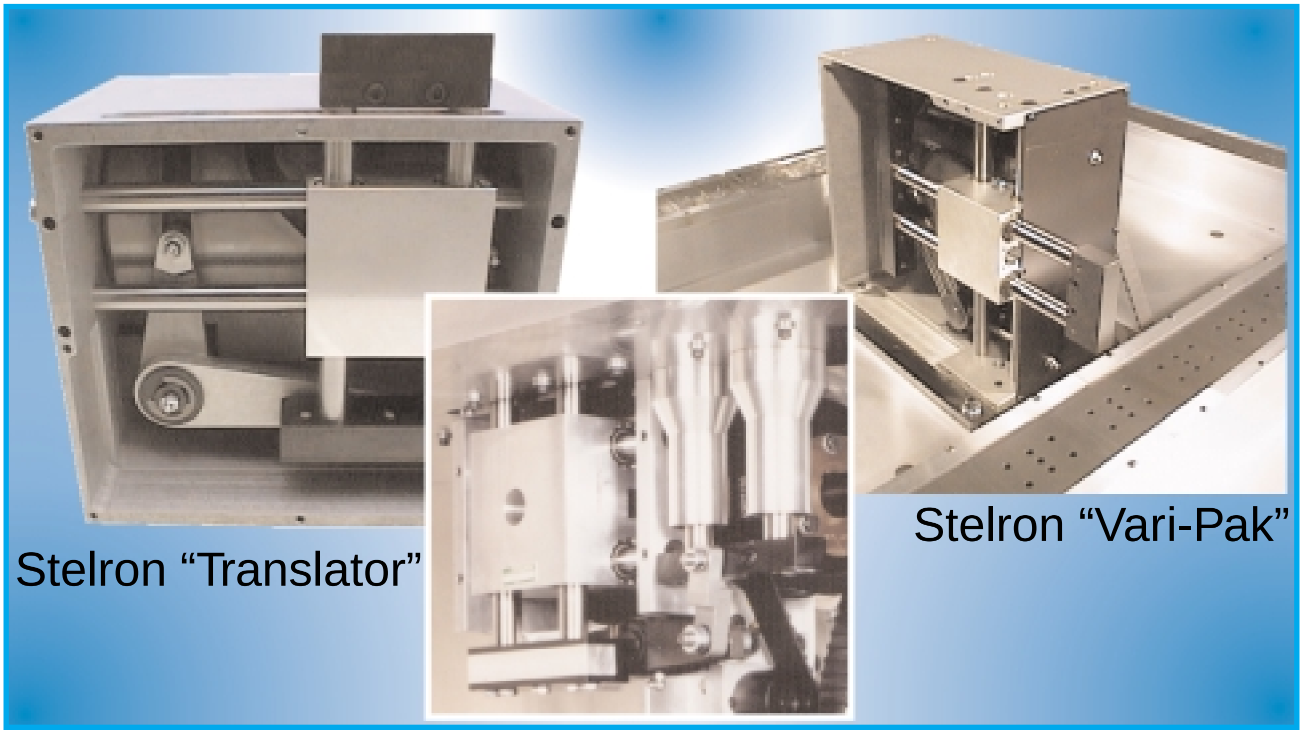
TWO AXIS LINEAR CAM MECHANISMS



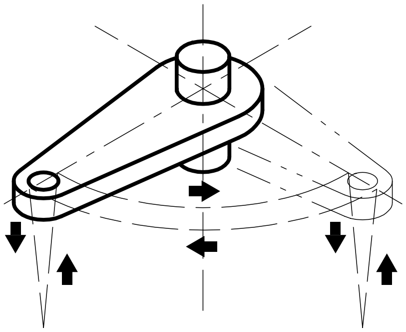
Mechanism Types:

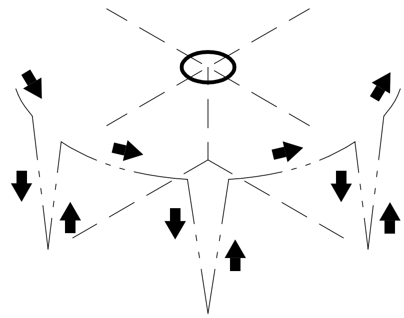
1) **Walking Beam and General Use** - Two axis of motion freedom allows for a high level of application versatility. Shape of output motion, strokes, dwell placement and timing are all variables selected by the designer. Walking beams with "soft touch" motions that slow down during contact and drop off of product are possible. Camshafts of multiple units can be linked for extended length beams. Normally utilize barrel cams with/without spring pre-load or pre-loaded globoidal cams. Some mechanisms (globoidal and some extended stroke barrel cam) use stroke amplification to achieve strokes. Some devices have output overload available in at least one axis of motion. Available with cycling drive packages.
Applications: Vertical (lift & carry) and horizontal walking beam, escapement, shuttle, heavy duty pick & place, pallet transfer, light pressing, velocity matching drives and other applications where a heavy duty, simple cam drive operating with one plane of motion freedom is useful.

2) **Pick & Place Mechanisms** - Two axis of motion freedom allows for a high level of application versatility. Shape of output motion (usually an inverted "U"), adjustable stroke (as on the Stelron “Vari-Pak” shown below), dwell placement and timing are all variables selected by the designer. Camshafts and outputs of two units can be linked for extended length "pick" beams. Normally utilize barrel cams, box cams, plate cams with spring pre-load or pre-loaded globoidal cams. Some mechanisms (globoidal and some extended stroke barrel cam) use stroke amplification (unequal length levers) to achieve strokes. Some devices have both output overloads available in both axes of motion and adjustable strokes. Available with cycling drive packages.



TWO AXIS ROTARY/LINEAR CAM MECHANISMS

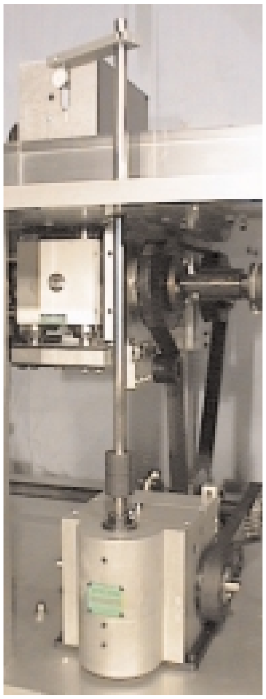




Mechanism Types -

1) **Oscillating Rotary Motion Pick & Place** - Two axis (one linear, one rotary) of motion freedom allows for a high level of application versatility. Shape of output motion, strokes, dwell placement and timing are all variables selected by the designer. Units may utilize pre-loaded barrel cams, box cams, plate cams with spring pre-load or pre-loaded globoidal cams. Some devices have output overload available in both axis of motion. Some units available with shaft output to facilitate under table mounting. Available with cycling drive packages.
Applications: Pick & Place, shuttle, turnover device, two axis velocity matching drive and other applications requiring one rotary and one linear axis of cam controlled movement.

2) **Indexing Rotary Motion** - Same as above except rotate cam indexes as opposed to oscillating.
Applications: Rotary lift & carry, Pick & Place, two axis velocity matching drive, shuttle, velocity matching drive and other applications requiring one rotary and one linear axis of cam controlled movement.



Stelron “Transpart”

INDEXER WITH SYNCHRONOUS SHOT PIN

Assume that accuracy of +/-.001" at a 12.00" (or greater) tooling radius with a high-speed index is required. Typical indexer accuracy is +/-.001" to .002" at a 6.00" radius and is dictated mainly by the ability to accurately locate the cam followers about the follower wheel. If, as on smaller dial type indexers, the followers are at a 3.00" radius, to give accuracy of +/-.001" at 6.00", the followers must be located to within +/-.0005".

This approaches limits of:

1) The machine tools that produce the follower wheels.
2) The run out specs of the followers themselves, particularly over time.
3) Other machining and component (i.e. bearings) tolerances.

Rather than machine indexer parts to extremely tight tolerances (with the associated high costs and "finicky" nature of this approach), this design utilizes an external, mechanically synchronized shot pin. The shot pin is actuated by a standard single axis cam device. The cam rib is ground slightly undersize in the dwell to eliminate "disagreement" between the indexer and shot pin mechanism.

Stelron “Dial Indexer”

BAND TYPE INDEXING CONVEYOR

A cam indexer at one end of the chassis drives individual spring steel band sections with a sprocket with protruding pins that engage holes in the bands. Fixtures are attached to the spring steel band sections. The most popular version is carousel which can be provided as a synchronous chassis or cycled on demand. Accuracy is high at drive end but decreases as stations are farther from drive end. Holes in bands may elongate over time.

LINK STYLE INDEXING CONVEYOR

A cam indexer at one end of the chassis drives a chain of cast and machined links using a special sprocket. Fixed distance between link paths based on a fixed sprocket diameter. Link pitches from 1.5-9.0". Some designs have a take up end that uses a special cam track that compensates for chordal effect (bringing a straight link around a radius changes effective overall chord length of the chain). Other designs use a spring-loaded take up end. Fixtures are attached to the links. Can be provided in carousel or over/under configurations. Can be cycled on demand or run synchronous. Accuracy is high at drive end but decreases as stations are farther from the drive end. Link chain may "stretch" over time as clearances change at link pivot points. Can index in multiples of link pitch. Indexing torques can be high due to relatively high mass being moved all at one time.

SYNCHRONOUS PALLET BASED ASSEMBLY CHASSIS

Transfers pallets around a rectangular table top using four synchronized **walking beams**. Locates pallets using four synchronized **locking beams**. Modular construction. Variable table widths, lengths, distance between pallet tracks and pallet sizes up to 12". Pallet either serves as fixture or fixture can be attached to pallet. Anvils back pallets up for pressing. Mostly synchronous applications. Accuracy is very high and independent of chassis length and location on the chassis (except corners). Locking beam maintains consistent positioning over time. Each of four "legs" of low mass pallets are indexed sequentially, therefore, low camshaft torques result. Pallets can be quickly removed from machine for product changeover or maintenance.