Conveyor Speed Monitoring

Conveyor speed monitoring may be required as a basis for the following functions:-

- Drive pulley slip.
- Conveyor under speed.
- Feedback for acceleration control during start-up ramping.
- Feedback for reduced speed running. (rate reduction or empty belt inspection)
- Feedback for proportionally controlled braking via open disk or wet brakes.

Feedback for speed the control scenarios would not be required where variable frequency drives are in use, but are required for variable torque devices such as control filled fluid couplings, pressure controlled clutches or brakes.

Drive Pulley Slip

Drive pulley slip occurs when the pulley attached to the drive motor exceeds the speed of the belting. This slip creates heat which will damage both the lagging of the pulley and belt carcass. Both may require replacement. Unchecked, excessive slip will burn through a belt carcass or create a fire. Above ground belting burns with high heat once ignited. In underground situations, although the belting will not support fire, the fume and smoke produced in an enclosed environment can be dangerous.

Slip usually occurs when a mechanical or control component of a conveyor fails. Failures include:-

1. Insufficient tension applied by a weight tower or horizontal tensioning winch.
2. Insufficient drive torque from a secondary drive pulley to prevent the primary drive pulley from slipping.
3. Excessive torque applied to a drive head due an overload of material or control system failure.
4. Failed belt cleaners with excessive material between the belt carcass and the pulley lagging.
5. Excessive water between the belt carcass and the pulley lagging.
6. Worn pulley lagging.
7. Collapsed pulley bearing skewing the belt into support structure.
8. Jammed belting due belt wander.
9. Jammed belting due to blocked transfer chute.
10. Jammed belting due material carry back on the conveyor return strand jamming the tail or boot roller.
11. Dragging brake or tripper drive.
12. Broken belt.

Belt slip is measured by comparing the driven pulley speed to the speed of the belting. The speed of the belting is normally measured by monitoring a non-driven pulley whose angle of wrap and belt tension ensures that it will not slip against the belt carcass. Note that conveyor idlers do not meet these criteria. The speed of each driven pulley should be measured independently as each driven pulley may slip independently of the others. The normal amount of acceptable slip during start up is 10% of full speed for a period of between 10 and 30 seconds. After this, the conveyor should be shut down. Typically these values are based on regulations. Depending on the amount of slip, tension and lagging type, belting damage can be inflicted in less than this period. Smoke will be produced from a stationary belt under slip in as little as 10 seconds. With accurate speed measurement methods, shorter slip periods during conveyor starting may be used without nuisance tripping. This offers maximum protection for the belting.

Once the conveyor is at full speed, any slip of more than 10% for a short period is grounds for shutting down the conveyor.

In closed loop control systems, drive pulley slip will force more torque from the drive train as the control system calls for more torque to speed up the lagging belt speed. This exacerbates the slip problem. Instantaneous slip should be fed back into the control loop so it reduces or at least does not call for an increase in drive torque when slip occurs.

Conveyor Under-Speed

On shorter conveyors or where the likelihood of slip problems during starting are rare, designers may decide that conveyor under speed detection is adequate. This is usually associated with conveyors whose starting period is shorter than the 35 seconds. (Normal permissible starting slip.) Under-speed detection is engaged after the normal starting period. A failed to reach speed in time fault should also be engaged in case a slip event does occur during starting. Under speed is always monitored on a non-driven pulley. Typical under speeds are tripped at less than 90% of full speed.

The causes of under speed are the same as nominated in drive pulley slip with the addition of drive train problems. Drive trains may mechanically fail. Problems can occur if there is insufficient oil in fluid couplings or insufficient clutch pressure in clutch systems. These may cause a slowing of the conveyor under load. The designer may wish to trip the conveyor in these circumstances or create an alarm that requires attention. Conveyors may have both “drive pulley slip” and “under speed” faults.

Under-speed once the conveyor has reached full speed should initiate a trip as it means the drives are slipping.

The Regulations – Conveyor Safety Requirements - AS1755 – 2000

All designers of belt protection systems should purchase a copy of AS 1755 – 2000

These regulations state that belt slip protection is mandatory and the conveyor should stop when the belt slip exceeds 10%. The slip may be overridden during start up for a maximum of 35 seconds.

Individual statements in standards are open to interpretation, so designers should read the original standard for themselves and ensure they are familiar with the overall intention of the document.

Feedback Speed for Control Systems

Where closed loop control is providing accelerating, decelerating or constant speed control, speed feedback is required for the process variable in the loop. For reliable control, the update period of the speed feedback, should be shorter than the cycle time of the closed loop control. This places a requirement on the resolution of the speed signal at low conveyor speeds. It also places a requirement on the uniformness of speed signal. An oscillating signal will place an oscillation in the control variable. It is optimistic to expect good speed control if the speed feedback is pulsing or oscillating due to poor sensing design. Although filters can be applied to the signal, this will provide a time lag in the change and therefore slow the available response of the control. (see determining number of targets)

Speed Measurement Methods

Some designers will prefer non-contact methods, others will prefer hard connected methods. Each has advantages and disadvantages.

In the past, DC generating tachometers were popular. They provided an output voltage proportional to shaft rotational speed. Although generally reliable, they required maintenance due to the brush gear and commutators used in their construction.

Electronics has led to the use of digital pulses as a reliable method of determining speed. Uniformly spaced targets provide a frequency. Pulses are counted for an accurate fixed period in high frequency applications. The period between pulses is measured accurately in lower frequency applications.

Resolvers and associated electronics offer a robust method to measure conveyor speed, however their cost normally excludes them.

Pulses may be generated by:-

- A wheel in contact with the linear motion of the conveyor. (Useful for slow moving conveyors)
- A wheel in contact with a rotating shaft. (Useful for slow rotating gearbox output shafts)
- An enclosed encoder connected to the end of a rotating shaft. These may use optical sensing or magnetic sensing internally. The units can be connected to the end of a rotating pulley shaft supported by plummet block bearings or intermediary shaft in a gearbox. (if accessible)
- A proximity detector sensing a toothed target mounted on the high speed side of the input shaft of a gearbox. A larger disk mounted on a pulley that will not slip against the motion of the conveyor. For this, idlers are not suitable and a pulley should have sufficient wrap or sufficient tension against it so that it always matches the belt speed. (Even under poor environmental conditions)
- A proximity detector sensing uniformly spaced bolt heads on a coupling or pulley.
- A proximity detector sensing uniformly machined studs or holes in a rotating component of the drive train.
- A hall effect sensor detecting magnets mounted in a non-magnetic collar attached to a rotating shaft.

Converting Pulses to an Analogue Value Representing Speed

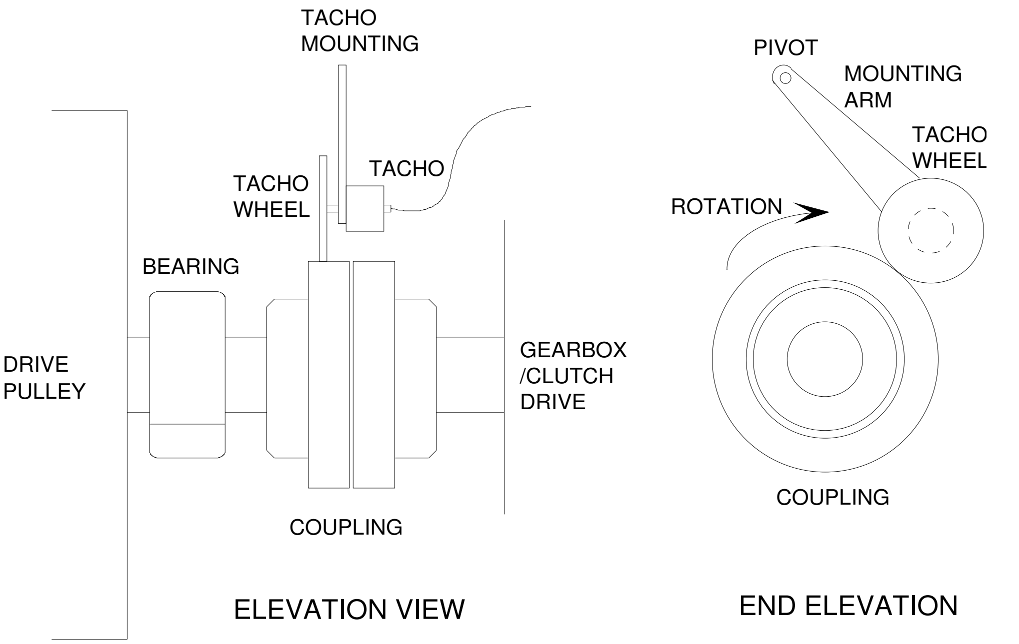
Two methods are usually employed in relation to conveyors controlled by a PLC.

1. Convert pulses to a 4 to 20mA signal with a frequency to current converter and use a PLC analog input. (Current loops have higher noise immunity than voltage driven inputs.)
2. Use a high speed input on a PLC to measure “counts for a fixed period” or measure the “period between pulses”.

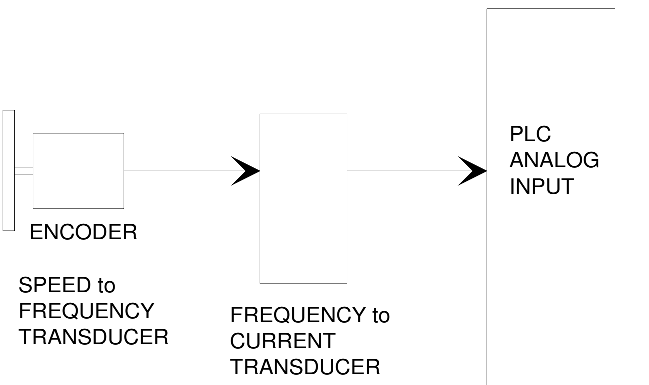
Sensing Examples

Ringway Pty Ltd manufacture a conveyor speed sensing device that is robust and has an attached wheel suitable for mounting on slow speed conveyors (< 3m/s) or on the rotating coupling of the output shaft of a gearbox. It produces a 4 to 20mA output signal proportional to conveyor speed. Internally it uses optics and a sliced brass disk with a frequency to voltage converter driving a current loop. Scale is adjusted by a trim pot in the back of the unit. Direct mounting of the wheel on fast moving belt is not recommended as the wheel tends to bounce on splices and clips. The pivot arm should be kept as short as possible to keep alignment true to the rotating direction and minimise stress on bearings.

The unit may have its wheel removed and be end mounted on a slow rotational shaft.

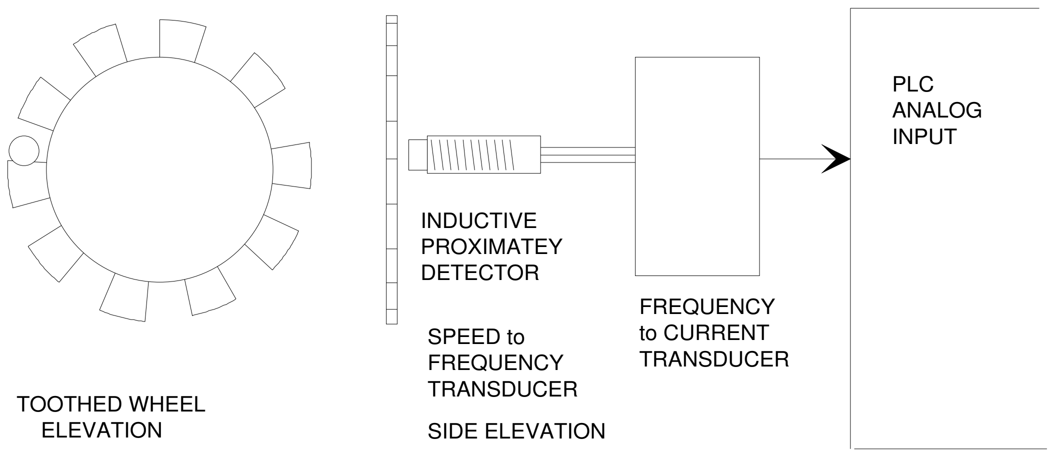


Generic Wheel Encoder with frequency to current loop signal converter

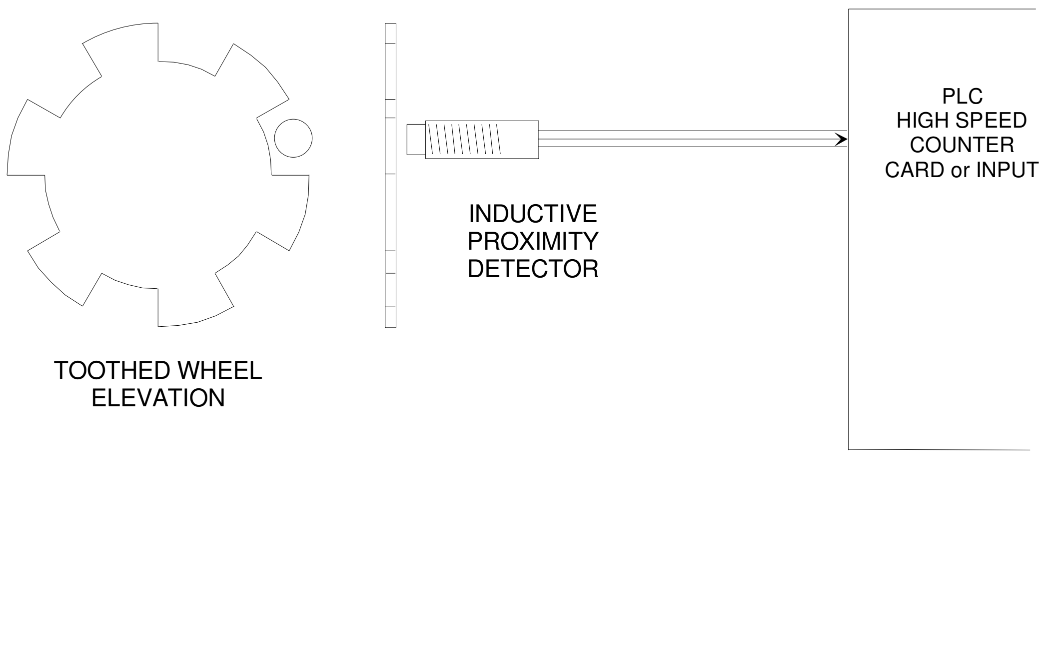


Generic toothed wheel with frequency to current loop transducer.

Note that for toothed wheel sensing to work, all teeth widths and gap widths must be identical and the distance from the proximity head consistent for a full rotation. Due to the nature of proximity detection, the distance between the proximity head and the toothed plate should not vary more than 1 mm per revolution. If this is not achieved then speed variations will be measured on each revolution of the wheel.

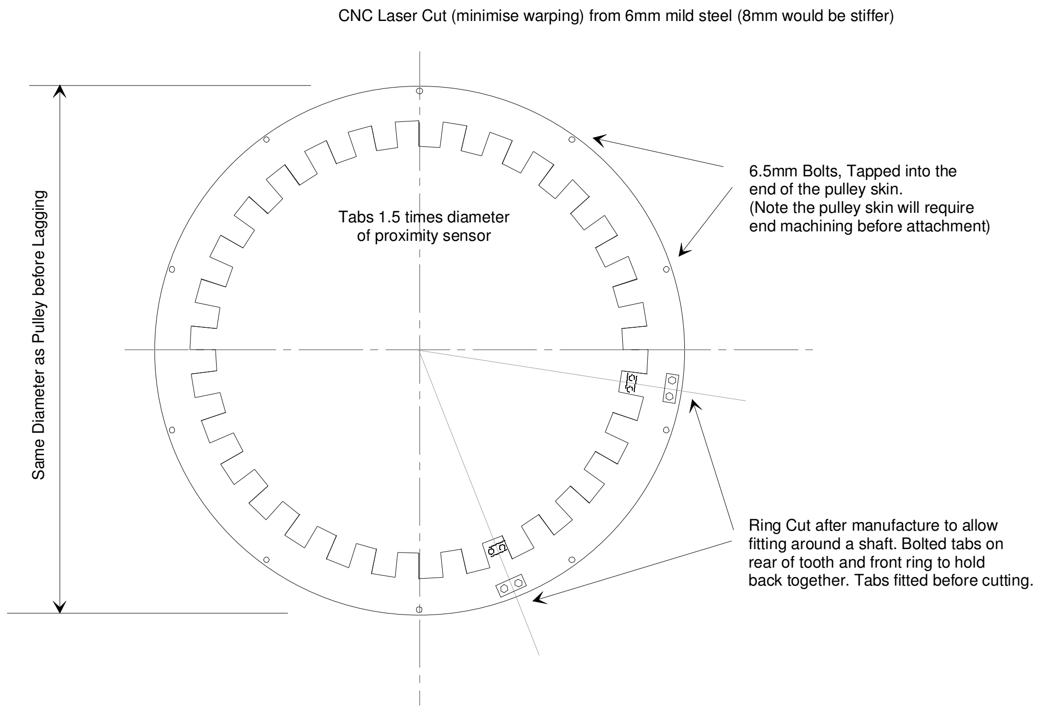


Generic toothed wheel with high speed input module.



Speed Measurement of a Non-driven Pulley.

Non driven pulleys often have a dead shaft. That is one where the centre shaft does not rotate and the bearings are mounted in the end plates of the pulley. Monitoring the speed of these pulleys poses considerable engineering challenges, particularly in the underground mining industry. In mining, installations are dismantled, moved and re-assembled on a regular basis. Toothed plates are often bent in the process. The following construction offers additional support for the toothed plate by attaching it to the skin of the pulley. Note that for plates to be exchangeable, they should be CNC laser cut.



Points to Consider When Designing your Conveyor Speed Sensing

1. Safety. Speed sensing will be monitoring moving parts. The sensing mechanism will be required to be inspected on a regular basis, as environmental conditions may cause damage. Barriers will be required to prevent personnel from coming into contact with moving parts. A good design will allow observation and perhaps adjustment of speed sensing, without the need to remove protection barriers. Mesh barriers may prove superior to solid barriers in these circumstances.
2. Protection from Damage. Material spillage from conveyors, needs to be taken into consideration as does build-up of excess lubrication grease, the water from de-dusting sprays and blocked transfer chute spillage. If possible, the speed sensing location should be well away from these conditions.
3. Access for Maintenance. Ease of maintenance access, will discourage personnel from removing protection guarding and taking safety risks. Removable guarding may require safety interlocking.
4. Ease of Calibration. The designer should be aware, that once installed, systems may be difficult to calibrate, particularly if the calibration is at the speed sensor, or mounted in a panel that should not be accessed due to safety issues. Considering both these points in the design will prevent personnel from taking unnecessary safety risks.
5. Uniform Spacing of Targets. This is critical to good results. Spacing of targets and gaps must be very exact. A mismatch as small as 1% will give a 1% cycling error in the speed reading.

Fitting individual targets on site by hand is not a viable option. Targets should be pre-cut with spacing via CAD/CAM systems and require no special alignment by hand.

6. Proximity Detector Fields. Be aware of the sensing field of the proximity detector. A good rule of thumb is a minimum tag width as wide as the diameter of the proximity detector and a minimum gap width of at least 1.5 times the diameter of the proximity detector. Sensing varies for proximity detectors with material type, material thickness, distance from head and temperature. If a hole is to be drilled in material to create a non-sensing pulse it should be at least twice the diameter of the sensing head.
7. Do not scrimp on the metal thickness of sensing teeth. Thick metal is stronger, less likely to be bent and it senses better.
8. Encoders offer higher resolution than toothed plates, but they may be more difficult to fit. Large drive heads vibrate and an encoder may need to be mechanically decoupled from vibration via rubber couplings or other methods.

Determining the Number of Targets You Need for Your Control Requirements. (ie what is the minimum resolution I need for conveyor speed measurement)

For drive pulley slip, the rule of thumb is 20 to 40 Hz at full speed. (120 to 240 pulses per minute) Higher resolution than this causes no problems, apart from being able to fit in enough targets.

Under speed calculations can be done on resolutions as low as 2 Hz at full speed as long as the input pulses are uniformly spaced. For these calculations to be accurate, some sort of processor interrupt or high speed counter card must be used so that accurate timing between pulses can be determined. Alternatively a frequency converter that measures time between pulses can be used to drive an analog input.

For control feedback, the designer will need to take into consideration several factors. If they are trying to start a long conveyor where pre-stretching the carry strand of the conveyor is necessary, then higher resolution may be required. In most circumstances, 5% speed sensing is suitable for the pre-charge/pre-stretch conditions. The speed update period during this control phase, should be at least faster, if not double the closed loop cycle period. For CSTs and BOSS clutches, cycle periods of 0.5 seconds are typically used. For variable scoop and fill/drain fluid couplings, typical cycle periods of 2 seconds are used.

If torque or motor current balancing is also part of the control loop, then the motor current feedback update period should also be at least, if not twice the speed of closed loop cycle.

A CST closed loop cycle using 0.5 seconds updates and travelling at 5% speed should be receiving an update pulse faster than 0.5 seconds and preferably every 0.25 seconds. This translates to a full speed pulse rate of 80 Hz. If accurate closed loop control is required at lower speeds, then the resolution must increase accordingly.

A fluid coupling closed loop cycle using 2 seconds and travelling at 5% speed should be receiving an update pulse faster than 2 seconds and preferably every 1 second. This translates to a full speed pulse rate of 20 Hz. If accurate closed loop control is required at lower speeds, then the resolution must increase accordingly.

When using braking control, the most critical part of the control is at high speed and therefore low speed pulsing is less of an issue. Closed loop cycles of 0.5 seconds are typically used, but 20 Hz at full speed is usually adequate. The primary function of braking to prevent too much material being transferred to the downstream or out-bye equipment and little of this occurs at low speed.

Measuring Belt Speed with High Speed Counter Cards and Control Logix.

A technique often used with measuring conveyor speed is a toothed wheel combined with a proximity detector feeding a high speed counter card.

Two methods may be employed to calculate a speed using the method.

1. Measure counts for a given time period.
2. Measure the period between two consecutive counts.

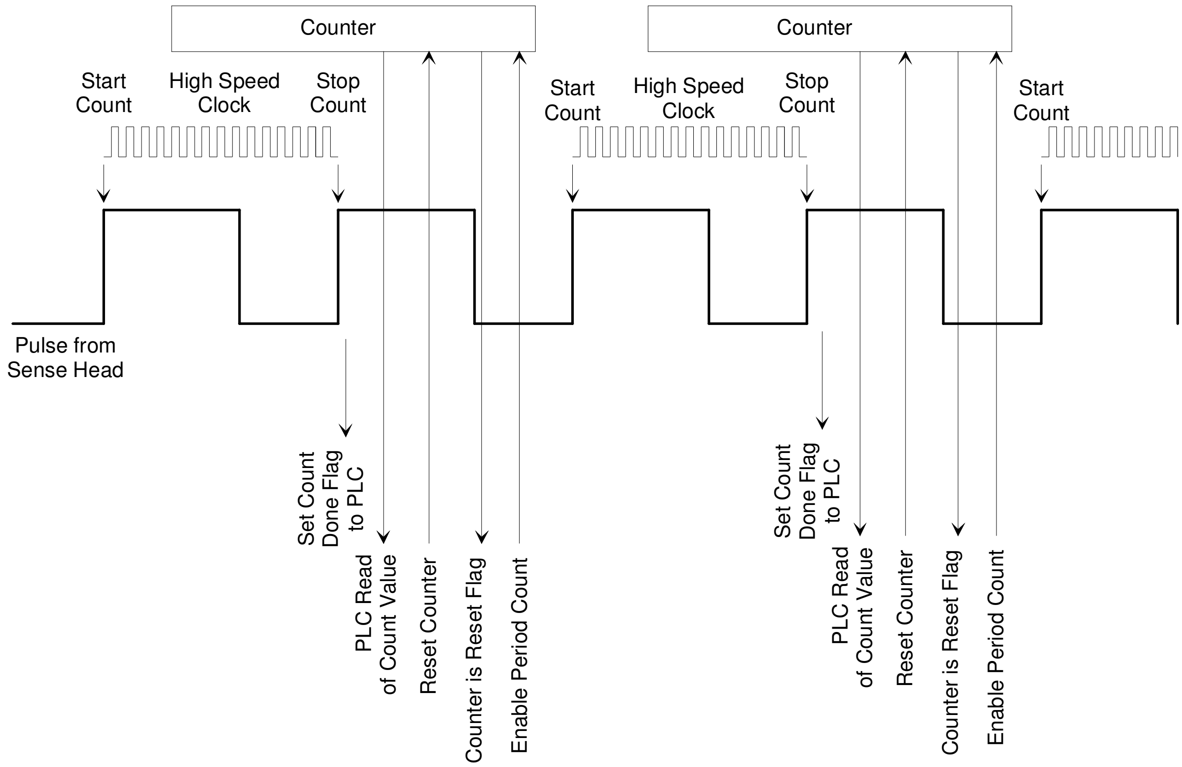
To use method # 1, the user must ensure that the time period to read accumulated counts is exact. To achieve this, the high speed counter card will need to be in the local rack with the processor so there are no remote rack communication delays. It will also require a method of interrupting the processor's normal program scan on an exact time basis. A short periodic task can be selected to run at 500 millisecond intervals. This task will then be required to get "immediate data" (note not I/O mapped data) from the high speed counter card. This data need not be processed in the same routine, but passed to the main program for conversion as part of the general scan. As periodic tasks are generally run as an interrupt with a service overhead of a few milliseconds, read timing errors are less than 0.5% for a 500 millisecond read. It is better to read multiple channels in a single periodic task than to run a periodic task for each channel. This will ensure more accurate timing.

Using this method, converting sampled counts to speed is a proportional multiplication. Run the conveyor to full speed and read the counts value per time sample. Multiply this value by a fixed ratio to convert from counts to 100% or meters per second, measured by a tacho or similar device.

Note! Problems are encountered with this method if normal PLC timers or remote I/O via serial communications are used. With these configurations, the user cannot control the accuracy of the measurement period. This typically gives a widely varying speed measurement that must be heavily filtered to be useful. Any form of filtering adds a time lag to the speed reading and makes speed or acceleration control more difficult.

Method # 2 provides a high accuracy measurement between consecutive targets, typically in micro seconds or 10ths of microseconds. The high speed counter card is configured for period measurement using an internal pulse of 1 micro second or 100 nano seconds. (1MHz or 10Mhz clock cycle) There is also an option of using either a 16 bit counter or a 32 bit counter to store the measurement. The module is first initiated by a PLC command. The HSC module then waits until it sees an input rising edge and begins counting the selected clock cycles. It continues counting the clock cycles until it sees the next rising edge of the input. The HSC stops and holds the counted clock cycle value. The value in the register now represents the time period in usecs or 0.1 of usecs between two consecutive pulses from the input. The high speed counter card now sets a flag to indicate that a measurement has occurred. The PLC program, then reads the stored count value, and resets the period counter to zero. Once the counter has reset to zero, the PLC may restart the process. The advantage of this method is that it provides an accurate reading of period regardless of the update time in the communications between the PLC and the high speed counter card. This makes it suitable for using high speed counter cards in remote racks linked via Ethernet, Control Net or DeviceNet. The speed of the I/O will determine how quick each speed update occurs, but it will not affect its accuracy. Even for very slow I/O update configurations, speed accuracy will never be lost and updates will still occur as fast as the I/O update period will allow. The PLC may read every second, or third target spacing, depending on how fast the targets are travelling and how slow the communication update is between the PLC and the high speed counter card.

The following diagram illustrates the handshaking and timing:-

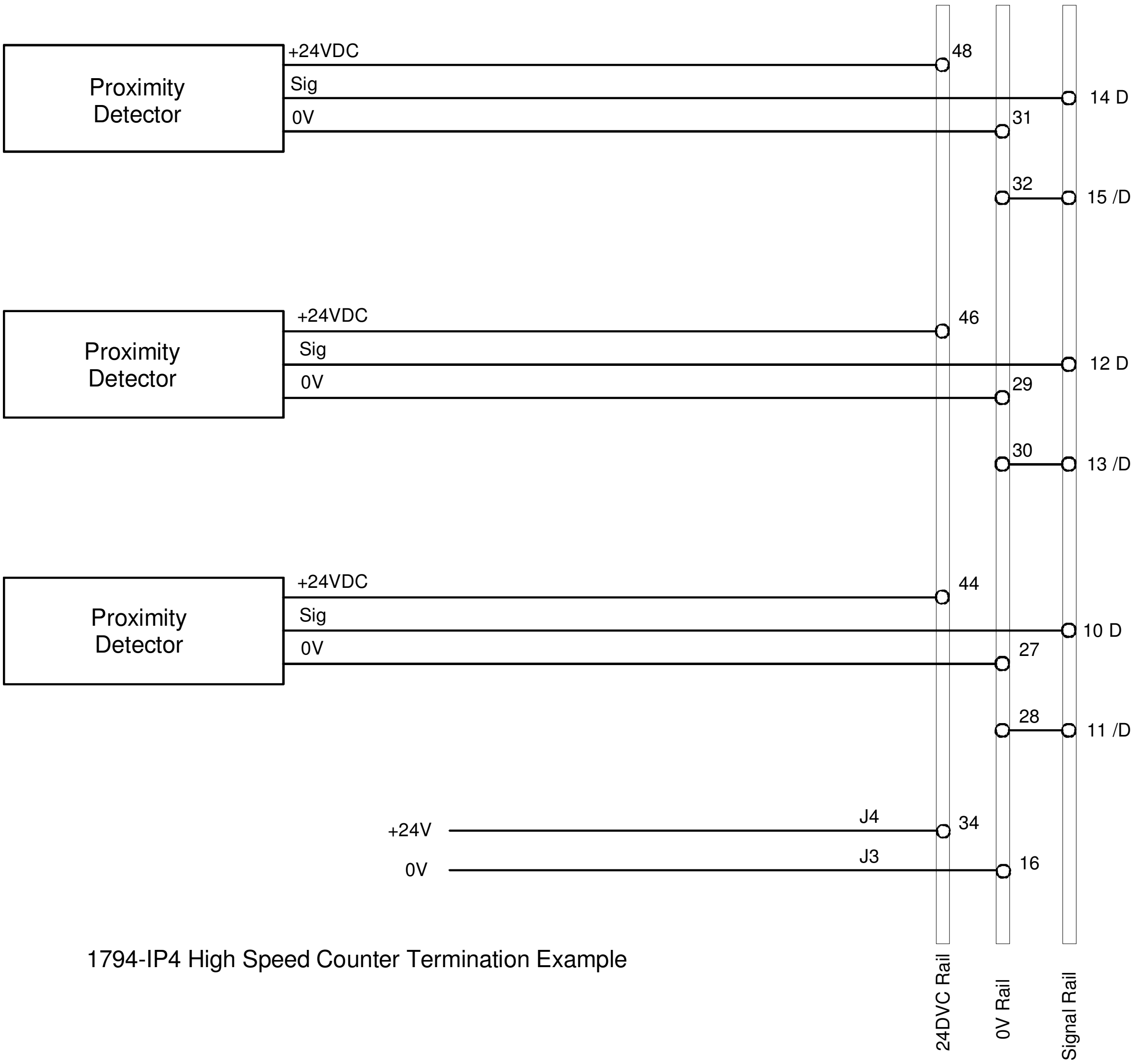


Using this method, the speed is inversely proportional to the counter value. The conversion to engineering units requires a fixed number to be divided by the counter value into the resultant engineering speed. To determine this value, run the conveyor to full speed and view the count value being returned from the high speed counter card. If you wish to monitor speed as a percentage, multiply the observed value by 100 and use this as the fixed value to be divided by the count value. If you wish to display m/s of say 4.5 at full speed, then multiply the observed value of 4.5 and use it as the fixed value.

Field Connections to High Speed Counter Cards

There are many models of high speed counter cards offered in the Control Logix and Compact Logix range. Allen Bradley has attempted to make each model as flexible as possible and so the designer must ensure that the field connections to the card are suitable. Some units have differential inputs which are primarily designed to connect to high speed encoders for both speed and position monitoring. Encoders typically provide a differential output driver of two lines of opposite polarity. While one line A is at 5V the other /A is at 0V. For inverted logic, A is at 0V and /A is at 5V. It is possible to use a single ended device such as a proximity detector. However, the negative differential input cannot be left floating. It must be tied to 0V for reliable operation. See example below.

Always ensure that the output specifications for the proximity detector are within the maximum and minimum input characteristics of the high speed counter card before connecting the two together.



1794-IP4 High Speed Counter Termination Example

Interrupting with Normal Input Cards with a Control Logix Processor

Proximity detectors may be connected to standard digital input card situated in the same rack as the Control Logix Processor. Speed sensing may be achieved by using the “interrupt on change flag” for a particular input to run a small routine that measures period between pulses. Control Logix and Compact Logix PLCs have a 1 millisecond time base. The timers are checked against a real time micro second clock which makes them as accurate as the point at which they were scanned. This allows an event driven, interrupt based routine to measure time reasonably accurately.

The change of state flags must be ticked for both on and off in the input card configuration for the inputs connected to the proximity detectors. As the input changes state it will generate an interrupt on the processor which calls an event driven subroutine.

An interrupt sub-routine is configured as an “event” type whose trigger is a “Module Input Data State Change”. The tag becomes the address of the input card that has the proximity sensor connected. This routine should be kept short as possible and only used to read the time between consecutive pulses. The main program can then be used to calculate the speed from the captured period between pulses.

Note that this method has the following limitations:-

- It can only be used on low frequency systems as it is continually interrupting the PLC processor scan. It interrupts on both raising and lower edges and so it is not suitable for pulse periods faster than about 300 milliseconds.
- The speed conversion code will not provide any accuracy below speeds of about 30% of full speed. This makes the method only suitable for under speed protection. It is not suitable for slip protection or speed control below 30% of full speed.
- If multiple inputs are being sensed by the one card, then there will be an asynchronous point during the interrupt routine, where another input changes and the change is missed. This is because only a single interrupt flag is used per card. (not per input) This will require filtering of the calculated speed, to eliminate the missed count and the accompanying calculation glitch. This condition will also generate a minor error in the PLC fault log.
- Great care must be taken when calculating the execution time of the interrupt routine, the number of interrupts to be received in a given period and the overall scan time of the PLC. It is possible for this style of measurement to impact poorly on the PLC scan period which may lead to watchdog timeouts in the program.