Design and installation considerations for conveyor drive applications

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Conveyor Applications

- Constant torque applications:
  - continuous rated torque is required over 0-100% speed and often higher
  - momentary 150% torque is typical but torque levels and duration requirements vary with each application
  - Mine equipment environmental conditions are important considerations and will require appropriate control house / enclosure characteristics
    - altitude
    - dust
Induction motor torque, speed and current

- Breakaway Torque
- Pull up Torque
- Motor Torque
- Constant Torque Load
- Variable Torque Load
- Breakdown Torque
- Locked Rotor Torque
- Motor Current

Graph showing p.u. Torque and % Current against Synchronous Speed.
Evaluating Torque Requirements

• Although load torques may be between constant torque and variable torque, worst case conditions must be satisfied
  – Torques required to break away loads
  – Acceleration, deceleration torques
  – Starting, stopping & speed changes require substantial additional torques when large inertia’s are involved

• Duty cycle for cyclic loading as defined by length of time at each torque level

• Momentary repetitive overloads, shock loading
  – Magnitude, repetition and average loading
Motor & Load Torque Evaluation
MV Drive control of conveyors

- Conveyor applications:
  - Mine conveyors are critical to their process, reliability is paramount
  - Different dynamics and control requirements are encountered depending on conveyor configuration
    - Uphill, downhill, level or combination of these
    - Different lengths, tension control systems
    - Single or multimotor
    - Drive pulley arrangement
  - Affected parameters
    - Starting torque
    - Regeneration
    - Loadsharing
    - Brake interface

![Diagram showing conveyor control system with VFDs, motors, reducers, and feedback signals.]
MV Drive control of conveyors

• Benefits of MV Drive control of a conveyor:
  – reduces voltage drop and system disturbance during start by reducing current draw
  – reduces mechanical stress on equipment (improves life expectancy)
    • mechanical equipment is not subject to motor breakdown torque during starting
    • torque is controlled and limited by the drive
  – slower speed operation reduces wear and maintenance
  – Often less power is required when changing to drives due to easier handling of starting torques (drive, motor and gearbox)
  – Automatic compensation for different motor slips and lagging or pulley wear, keeping torques equal
  – Detection of belt slip and recovery through torque reduction
Conveyor control methods

Conveyor Motor Control Design Considerations

In any application there are many choices available when considering control. For conveyors some of the criteria by which to evaluate these choices are maintainability, reliability, electrical and mechanical starting characteristics, load sharing capability between multiple motors and efficiency. Among the choices often considered for conveyors are wound rotors, fluid couplings, full voltage starting, reduced voltage starting and variable frequency drives, both CSI and VSI types. A brief list of advantages and disadvantages of each are as follows:

Wound Rotor Motors:
This solution was common due to higher torque capability and some speed variation between motors to compensate for load sharing but wound rotor motors have a disadvantage in maintainability due to brushes, rotor resistance and control switchgear. Limited speed variation and efficiency are also problems with this control. Wound rotor motors have a relatively high brush and subject the equipment to higher peak torques during starts.

Variable Frequency Drives:
This solution provides many benefits including reduced voltage drop (starting currents are at nominal levels), reduced mechanical stress (starting torques are controlled at nominal levels), variable speed, good load sharing capabilities between multiple motors and relatively good efficiency. Reliability and maintainability has improved tremendously for this solution in recent years. Some of these characteristics differ between the type of drives being considered.

Fluid Couplings:
For high torque starting capability this solution is also a good choice but maintenance and reliability are issues with more complicated mechanical solutions such as this. Efficiency is poor and during constant use can become an economical issue. Some load sharing capability also exists with this solution by adjusting the slip between motors. The voltage drop associated with a full voltage start still exists with this method although shorter in duration since the total conveyer inertia does not affect or lengthen the motor acceleration period. Mechanical shock loading is smoothed out with torque limit control.

Across Line Or Full Voltage Start:
This solution is economical but has many other issues. Voltage drop, low torque, mechanical shock and poor load sharing are all limitations with this method.

Reduced Voltage Starting:
Although beneficial for reducing voltage drop and limiting mechanical shock as the motor passes through its breakdown torque, this method is often plagued by poor torque performance due mainly to the low torque characteristics of medium voltage induction motors.

VSI Volts/Hz Control:
Drives must have high torque starting capability when used with conveyors which is more difficult to generate without direct field oriented control. Although volts/hz control is usually capable of multiple motor per drive control this becomes a problem when load sharing is required since the motors will run at slightly different speeds. The volts/hz controller in this case does not afford any more load sharing capability than what exists in across the line operation. VSI drives are also inherently more difficult to use on existing motors without derating since they subject the motor to harmonics and voltage waveforms with relatively higher dv/dt content.

CSI-PWM Direct Vector Control:
Along with good motor waveforms that do not require motor derating, this topology provides high starting torque capability and allows improved load sharing among motors. Under torque control on separate drives, the motors are not bound to operate at precisely the same frequency. This method automatically compensates for mechanical differences between pulleys, lagging or gearboxes and keep the torques generated equal between motors.
Multiple Rectifier Options (CSI)

- 6-pulse rectifier
- 18-pulse rectifier
- PWM rectifier (Active Front End) also available with Common Mode Choke
Motor Friendly output waveforms (CSI)

- **Near sinusoidal current and voltage @ all speeds and loads**
  - no additional motor heating or voltage stress to insulation compared to sine wave operation

- **Compatible with standard motors**
  - Induction, synchronous or wound rotor motors
  - no de-rating
  - inverter duty motor not required
  - new or retrofit applications

- **Virtually unlimited motor cable distance**
  - stable operation up to 15 Km
  - no capacitive coupling or dv/dt issues

Typical motor waveforms @ full load, full speed

- 4160V, 933 kW, 60 Hz
- Top - Motor Current
- Bottom - Motor Voltage
CSI drive control of conveyors

- Transformerless drive configuration achieved with CMC which eliminates neutral offset, reduces size, weight and losses
- inherent regenerative capabilities of CSI drive for deceleration or downhill configurations (no additional equipment required)
- unlimited cable lengths without extra filtering, very low dv/dt
- sinusoidal output waveform causes very little temperature rise due to drive operation
  - can be used on existing motors without derating

The Active Front End uses switching and Selective Harmonic Elimination to reduce harmonics.
CSI Drive Regenerative operation

DRIVE PERFORMANCE DURING CONTROLLED STOP
TR02-Deceleration at 9000 TPH

- Speed f/b
- I Stator
- Torque
- Flux f/b

Frequency Hz vs. Time seconds graph showing the performance of a CSI drive during a controlled stop.
CSI drive control of conveyors

• flexible speed and torque control loops
  – access to speed and torque control loops
  – load sharing achieved with various possible master/follower drive control arrangements
• various communication network possibilities simplifying integration into existing control systems
• torque capability is up to 80% of motor BDT
• encoder feedback needed for starting torques greater than 90%
  – options include non-drive and drive end mounting of optical or magneto-resistive type encoders
  – Magneto Resistive reduces risk of dirt contamination
Drive control of conveyors

PLC

Conveyor Speed Ref.

Control Logic

PLC I/O

VFD

Speed fdbk

M

Pulley

Drive

S - Speed Mode - Master Drive
T - Torque Mode - Follower Drive

Speed Setpoint

Spd ref

Torq ref1

Torq ref

Torq ref2

Torq

Speed Setpoint

Spd ref

Torq ref1

Torq ref

Torq ref2

Torq
Conveyor torque loadsharing
• Mechanical vibrations:
  
  – equipment vibrations result from natural frequencies, are excited by a ‘forcing function’ resulting in a resonant condition
    • natural frequencies exist in support structure, rotating equipment
    • mechanical asymmetries cause excitation of natural frequencies

  – for torsional vibrations there is little mechanical damping unless added by a coupling

  – when resonances occur the drive software parameters can be used to reduce some vibrations and interactions with the dynamics of the mechanical system
Vibrations
Mode shapes of torsional vibration

NATURAL FREQUENCY MODE SHAPES

Mode shape for Motor interacting with Load

Mode shape for Coupling interacting with Motor and Load
Torsional vibrations for 1st mode

Master and Follower Drive Speed Error signal oscillations 180 degrees out of phase.
Torsional Analysis

- Predicts vibrations from torsional model
- Solutions to vibration problems:
  - altering inertia’s or stiffness’s of the mechanical equipment to change resonant frequencies or increase system damping to reduce vibration amplitudes
    - $F_r \sim \frac{\text{Stiffness}}{\text{Inertia}}$
    - changing the coupling to a more flexible or highly damped unit
    - increasing shaft size, adding a flywheel
    - high slip motors (add damping)
    - stiffer support structure
    - high quality alignment
    - tighter specifications on allowable vibration of separate equipment
MV Drive control of conveyors

• Filtering feedback signals:
  – speed feedback signals can be filtered by a second order low pass filter
  • filtering the feedback signals reduces control signal fluctuation and possible amplification

• MV Drive adjustments to minimize torsional vibration
  – change slip or motor operating point on T-S curve
  • the motor torque curve has a lower slope resulting in reduced reactions to changes in load torque and speed
  • as load torque increases, flux is ramped up proportionally by the drive
MV Drive control of conveyors

Induction Motor T-S Curves

- rated pu motor torque
- 80% Flux Level
- 60% Flux Level
- 40% Flux Level

PU Torque vs Synchronous Speed

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• With high breakaway and accelerating torque requirements, motor torque needs to be applied smoothly
  – any abrupt change in torque will excite belt natural frequencies
  – belt natural frequencies can interact with the drive control to cause speed fluctuations and eventual instability and trips
  – torque control around zero speed or during speed reversals is difficult

• Options for low speed torque control:
  – adjustable S curve - speed control
  – S curve with dwell - speed control
  – torque ramp control with change over to speed control
  – reducing flux during torque ramp before breakaway
    • motor acts like it has a higher slip, torque changes are less abrupt
  – accurate motor parameters crucial for motor model feedback and accurate flux and torque control, especially in open loop (without tach feedback)
Conveyor S curve acceleration

S curve acceleration

Time for Linear acceleration to full speed
= 45 seconds

S curve percentage = 25%

PU velocity

PU acceleration

pu velocity
linear ramp
pu acceleration

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Direct Vector Control, CSI Drive

Separate Control of Flux and Current
Direct Vector Control of CSI PWM Drive

- Drive synchronizes itself to the motor
- Speed control achieved through control of motor torque
- Motor speed is measured & torque is adjusted to control measured speed equal to speed reference
- Stator current is resolved into flux producing and torque producing components, which are controlled independently
  - results in similar performance to a DC machine
  - superior performance over volts / hertz drives
Multi-motor Synchronous Transfer Configuration

- Configuration where a single drive is used to start several motors
- Motor protection is covered by drive or by separate MPR under DOL operation
- Soft starting benefits, lower costs
Multi-motor configuration

- Reduced initial cost
- Simultaneous speed control
- Drive sized for total HP
- Motors can be mechanically coupled or separate
  - Mechanically coupled motors must have identical motor characteristics
- Individual motor protection required
- Can use output contactors to provide some redundancy
- Scalar control on separate motors, starting torques must be equal
Conveyor Application: Single Drive Two Motors

Motor current $I_{m1}$

Motor current $I_{m2}$

Line Reactor

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Conveyor Application: Single Drive Two Motors

Single drive with two motor operation (two drive, three motors)
Conveyor Application: Single Motor per Drive

Single drive with single motor operation (three drive, three motors)
Multiple motor conveyor application

- Three MV drives connected to a common bus:
  - Sinusoidal motor waveforms
  - Compact and efficient system
- Running multiple motors in parallel
  - Controller robust enough to handle various conditions
    - Dropping motors tested successfully
- Conveyor applications
  - Good performance with many advantages
  - Inherent regeneration
  - Particularly useful for down hill configurations
Liquid Cooled Drives

• Quiet operation
• Lower air conditioner loading
  – 90% of losses rejected outside control room via liquid/air or liquid to liquid heat exchanger
• Prevention of leaks and freezing
  – CPVC piping for pump panel, headers and manifolds
  – Non-silicon based heat resistant coolant hose
• Redundant cooling pumps
  – All auxiliary control incorporated into drive controller
Modernization:
- (3+1)*2 MW
- variable speed
- coordinated torque
- reduced power
- increased capacity

Length: 1-3 km,  Width: 2.5m,  Volume: 15 – 20,000 m³/h
Underground mining VSD packaging

Power Center complete with switchgear, transformers and drives

FOR UNDERGROUND MINING APPLICATIONS
Powder River Coal Overland Conveyor

- 2 pulleys, head and tail, 2 x 1500hp motors on each pulley
- 11,929 ft horizontal, -47ft. Vertical displacement
  - Loadsharing between all four drives
  - Single speed regulator at head and at tail pulley, 2nd drive is configured as a torque follower

Drive PLC Control System

Speed / Torque Reference communications
Powder River Coal Overland Conveyor

- Remote, Local and Stand Alone control for drives
  - Remote control through Ethernet to supervisory PLC
  - Local control from drive PLC through ControlNet to MV Drives
    - fiber optic link is used between head and tail locations
  - Stand alone control through operator interface local to drive allows individual drive testing for commissioning
  - Local serial communications to feeder protection relays
- Conveyor is allowed to run with fewer than 4 motors, when this happens the mastership can be transferred online to continue operation. This allows continued running at reduced capacity while a problem is repaired.
- A mechanical brake is used for braking and parking functions.
Powder River Coal Overland Conveyor

• Conveyor control:
  – Acceleration uses S curve profile with dwell time
  – 2:1 head to tail torque ratio during acceleration
  – Tail torque is not applied until speed exceeds 5%
  – Tail drives are controlled in speed mode with torque override
  – Tail speed reference is slightly higher than head speed
  – 10 second dwell time at 15% speed to stabilize belt
  – 1:1 head to tail torque ratio once up to speed
  – S curve deceleration profile, different profiles used for normal & emergency stop
  – All stopping torque is applied by the tail drive
Summary

• Higher power applications used in mining industry is suited to Medium Voltage CSI Drives

• Numerous MV Drive benefits include lower mechanical stresses, improved starting characteristics and improved process control

• The torque control provided by drives are a great benefit along with variable speed operation

• CSI PWM drive control flexibility suited to constant torque and conveyor applications in both motoring and regeneration applications

• Torque matching, drive configuration, control philosophy, vibration avoidance during planning and installation will lead to safe reliable operation