Braking and Regenerative Energy with AC Drives

RELIANCE ELECTRIC

Application Solution

Introduction

What is Regenerative Energy?

When a motor turns faster than the commanded speed as set by its AC variable speed drive, the motor in effect acts as a generator. An example of this would be the control of an elevator car as it descends. With the help of gravity, the load will readily lower. In fact, the drive is actually regulating the motor so as to hold its load back to prevent a free fall. In the process, the motor would try to turn faster than the drive would command of it.

Discussion

Why overhauling?

Basic laws of physics require that the energy produced when a motor operates regeneratively must go someplace. In the case of an AC PWM drive, that someplace is back to the DC bus (The DC bus is that portion of the drive after the rectifier section where DC power is collected and stored for use by the inverter section). This net production causes the bus voltage to rise. However, the rectification of the AC power to the DC bus is a one-way street. Once this energy gets to the bus, there is no natural means to return it to the AC input line. The end result typically is a high bus fault. A tripped drive can do nothing to prevent uncontrolled motion, so in the case of the elevator car, it would fall freely in absence of a mechanical holding brake. (Emergency brake)

Where can these conditions be anticipated?

Regenerative operation of a drive/motor is not limited to applications such as the vertical descent of an elevator. There are many other scenarios where regenerative conditions occur.

- Ramped stopping (or even slowing to a reduced speed) of a high inertia load such as a flywheel or large mechanical arm.
- A sudden drop in load torque such as when an industrial saw completes a cut or a drilling operation completes work on a machined product.
- Indexing operations that repeatedly accelerate then decelerate to stop as part of the normal process, as occurs with material handling and packaging lines.
- A process where an unwinding operation is involved. The drive acts on the motor to hold tension against some downstream driven operation but allows the unwind to pay off its material.

What all these applications have in common is the need to make the driven load move slower than the load would in an otherwise uncontrolled state.

Additional considerations

Being in a regenerative situation does not automatically mean that external braking is required. In some cases, the degree of regenerative energy production is small, and readily absorbed at the DC bus without interrupted operation. This could be due to a combination of long deceleration cycle times, small changes in speed, or friction forces absorbing this energy. Typically, a drive that operates with 460 VAC input power has a normal or nominal DC bus voltage of 650 and is designed to tolerate up to 800 VDC before tripping on high bus faults. Sometimes the energy generated will not cause the bus to rise to that level.

How can the regenerative energy be predicted for an application?

Application predictions for regenerative energy can be determined from a few calculations as discussed in the steps below. The

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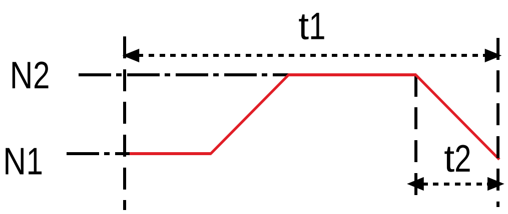
strategy is to calculate the regenerative energy in terms of horsepower and then compare it to the drive's horsepower rating. If (HPregen/HPdrive) <= 0.1 then external measures or equipment are not required to handle the regenerative energy.

If calculations show a need to apply either a braking or regenerative unit, then calculations for wattage and amps will be done to compare against the ratings of whichever unit is selected.

1. Determine the speed cycle profile of the application.

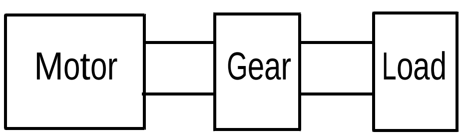
N1 = Minimum Speed
N2 = Maximum Speed
t1 = Total Cycle Time
t2 = Deceleration Time



2. Calculate or obtain the system inertia data.[1]
   System inertia =

$WK^2s = WK^2m + (WK^2L / GR^2)$

where WK^2s = Total system inertia
WK^2m = Motor rotor inertia
WK^2L = Driven load inertia
GR = Gear ratio as defined as Motor Revolutions/ Driven Load Revolution



3. Calculate the regeneration or braking torque required to decelerate the load with the information obtained by the following formula:

$$T_R = T_{decel} - T_f = \frac{WK^2s * (N2-N1) - T_f}{308 * t2}$$

where T_R = braking torque in ft-lbs.
T_f = friction torque

4. Calculate the HP required at top speed.

$$HP_{regen} = \frac{(T_R * N2)}{5250}$$

5. The value of HP_{regen} is compared to the drive's rating to determine whether external braking equipment is needed.

If $(HP_{regen} / HP_{drive})*100 > 10\%$, then external braking equipment is recommended.

If the need for a regenerative braking device (Regen unit) has been established from step 5, then the unit must be properly sized. Three criteria help determine if the desired equipment will meet the application requirements: average power generation, peak power, and peak regeneration current.

1. Average power generation is determined by the following formula PROVIDED the deceleration is linear[2]. This gives a continuous rating for sizing braking units.

$$HP_{regen} = \frac{(T_R * (N2+N1)/2) * t1(\text{decel time})}{250 * t2 (\text{total cycle time})}$$

and $Watts_{regen} = HP_{regen} * 746$

2. Peak regeneration must be less than the peak rating of the regen unit. This is simply the result of step 4 above. Compare this value to the given rating as supplied by the brake manufacturer.
3. The regenerative current must be calculated to compare with the current rating of the regen unit. The regen current should not exceed the rated amp capacity of the desired braking unit. Simply taking the result from step 4 above, and applying either of these rule-of-thumb formulas can do this.

For 460 VAC Drives, $I_{regen} \cong 1.2 * Hp_{regen}$
For 230 VAC Drives, $I_{regen} \cong 2.4 * Hp_{regen}$
(For other voltages, the numeric constant can be determined via ratios.)

Reliance Electric offers a wide variety of braking units ranging from simple snubber resistors to regenerative synchronous rectifier units that can be coupled with multiple drives sharing a common DC bus. Contact your local Reliance Electric sales office for

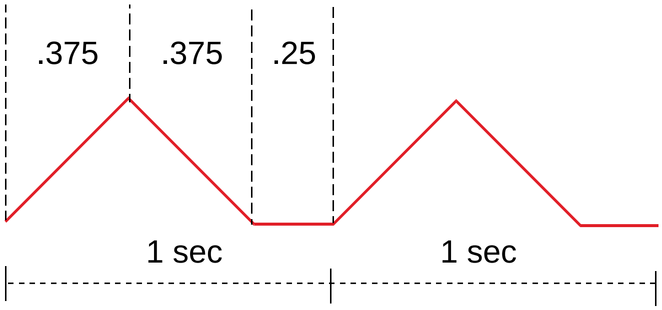
[1] While motor rotor inertias are readily available from the manufacturer, load inertia data can be extremely difficult to obtain. In absence of customer information, many computer programs exist that calculate inertias based on load configurations. This information is critical for any reasonable estimate of drive regenerative energy requirements.
[2] For non-linear deceleration, an integration of the speed curve over the deceleration time is required.

further information on this.

Example 1a

An indexing table rotates by 60° every second as parts are progressively machined. The motion profile is shown in the diagram below. The particular operating parameters are listed here. Dwell or pause time = 0.25 sec.

Table weight (load) = 500 lbs.
Friction torque = 40 in-lbs.
Motor gear ratio = 60:1
Table diameter = 36 inches



A sizing program has determined that a 1½HP drive/motor combination will satisfy the load demands. These parameters are as follows.

Motor top speed = 1600 RPM
Motor torque rating (Design B type) = 4.38 Ft-lb
Motor HP = 1½
Motor rotor inertia (from manufacturer) = 0.0938 lb-ft^2
Load inertia = 563 lb-ft^2
AC input volts = 230

Solution:

Applying the formulas and procedures as outlined above:

1. Per the profile:
   N2 = 1600RPM
   N1= 0RPM
   t2 = 0.375 sec.
   t1 = 1 sec.
2. Total system inertia: WK^{2}s = 0.0938 + 563/(60*60) =(0.0938 + 0.1563) = 0.250 lb-ft^2
3. The regen or braking torque is: T_{decel} = (0.250 lb-ft^2 * 1600 RPM)/ (308 * 0.375 sec) = 3.46 ft-lbs.
   Friction torque reflected to the motor = T_f = [40 in-lb/12(in/ft) / (60*.9 (gear ratio))] = 0.06 ft-lbs.
   TR = T_{decel} - T_f = 3.46 - .06 = 3.4 ft-lb
4. The regen or braking HP at top speed is: HP_{regen} = (3.40 ft-lbs. * 1600RPM)/ 5250 = 1.04 HP Since this is 70% of the drive/motor HP rating, external braking equipment is required here.

Completing the calculations to adequately size an external device:

Average power generation per cycle = [3.40 ft-lbs. * (1600 + 0)RPM /2]/ 5250* (.375sec)/1 sec = 0.197HP * 746 Watts /HP @ 150watts or 0.15 KW.

The regen at top speed is 1.04 HP (= 780 watts), so at 230 VAC input, the peak current during regeneration will be 2.4*1.04 HP = 2.50 amps.

In summary, any resistive unit with a rating of at least 2.52 amps, 780 watt inrush, and a continual rating of at least 150 watts will work.

Example 1b

Let's take the identical process above, but double the accel, decel, and dwell times. Applying the same procedure as above:

1. Per the new profile:
   N2 = 800RPM
   N1= 0RPM
   t2 = 0.75 sec.
   t1 = 2 sec.
2. Total system inertia: WK^{2}s = 0.0938 + 563/(60*60) = (0.0938 + 0.1563) = 0.250 lb-ft^2
3. The regen or braking torque is: TR = (0.250 lb-ft^2 * 800 RPM)/ (308 * 0.7 5 sec) - .06ft-lbs. (T_f from above) = 0.805 ft-lbs.
4. The regen or braking HP at top speed is: HP_{regen} = (0.805 ft-lbs. * 800RPM)/ 5250 = .122HP. Since this is approximately 8% of the drive/motor HP rating, external braking equipment is not necessary in this application. In this case, the drive should be capable of absorbing any regenerative energy produced.

The above illustrates the key role that the cycle time plays, and shows that its definition is critical for proper regenerative energy analysis.

Example 2

A palletizing process requires a stacking operation where pallets are successively piled on top of one another. Specifically, a driven platform device receives a pallet, lowers a fixed distance (12 inches in this case), and the next pallet slides in above the first. This process repeats until 10 pallets are stacked. The stack is removed via forklift, and the empty platform is raised back in place to receive the first pallet of the next stack. This sequence is then repeated. Each pallet weighs 200 lbs., and the empty platform is 500 lbs.

Other information:

1 second for each 12-inch move, with a 0.5 second accel,
0.5 second decel and a dwell or pause period of 1 second.

A pinion gear with a 2-inch radius drives the platform. Additionally, the pinion is geared in to a motor at a 14.4:1 ratio and a 90% efficiency. The load friction is 50 lbs.

The sizing program calculated that a 1½HP drive/motor combination will satisfy the load demands. These parameters are as follows.

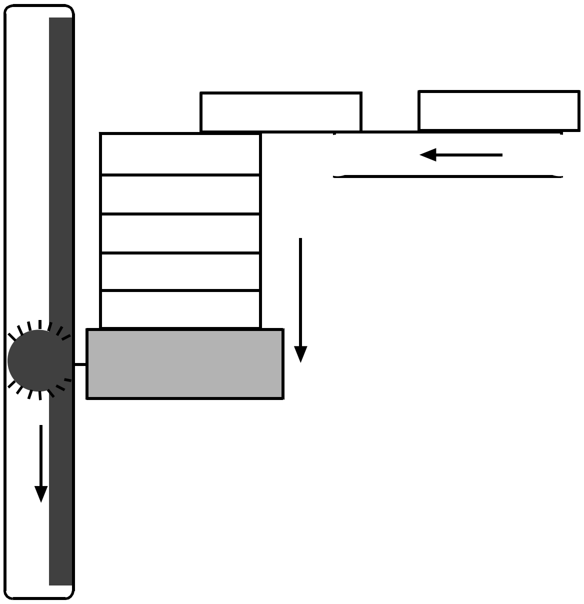
Motor top speed = 1650 RPM
Motor torque rating (Design B type) = 43 Ft-lb
Motor HP = 15
Motor rotor inertia (from manufacturer) = 1.374 lb-ft^2
Load inertia = 63.9 lb-ft^2
AC input volts = 460

Solution:

This application requires more detailed analysis than the previous example. In addition to the load inertia, gravity is also a major factor in this analysis. The most demanding case is when there are nine pallets on the platform and it is being lowered to receive the 10th. Total weight at that point is:

500lbs. (platform) + 9*200 lbs. (pallets) = 2300 lbs.

The additional force of gravity must be added to the normal accel and decel torques. (As an example, think of the difference between pushing a cart containing 200 lbs. as compared to lifting it off the ground. Or better yet, the difference between stopping that rolling cart as compared to preventing it from going into a free fall).



1) Calculate the net external torque at the pinion.

Net external torque = (Gravity force - friction force) * pinion radius = (2300-50)lbs * 2in = 4500 in-lbs = 375 ft-lbs.

Reflected torque at the motor shaft = 375 ft-lbs/14.4 (gear ratio)/0.9 (efficiency) = 28.9 ft-lbs.

2) Total system inertia = WK^{2}s = 1.374 + 63.9/(14.4*14.4) = (1.374 + .308) = 1.682 lb-ft^2

3) Recognizing that this force is in effect during both acceleration and deceleration, both motions must be evaluated and combined for regenerative requirements.

a) Acceleration torque = $T_A = \dfrac{WK^2s * (N2-N1)}{308^* \, T_{Accel}}$ - Net external torque

=[(1.682 lb-ft^2 * 1650 RPM)/(308 * 0.5 sec)] - 28.9 ft-lb = - 10.8 ft-lb

Since this value is negative, regeneration is occurring during acceleration.

b) Deceleration torque = $T_D = \dfrac{WK^2s * (N2-N1) + \text{Net external torque}^{(3)}}{308^* \, T_{Accel}}$

=[(1.682 lb-ft^2 * 1650 RPM)/(308 * 0.5 sec)] + 28.9 ft-lb = 46.9 ft-lb

[3] Note that the acceleration and decleration torques work in opposite directions, so the external torque adds to the deceleration torque and runs opposite of the acceleration torque.

4) $HP_{regen} = \dfrac{HP_{accel} * (T_{accel})}{T_{cycle}} + \dfrac{HP_{decel} * (T_{decel})}{T_{cycle}}$

$= \dfrac{(10.8 \text{ ft-lbs.} * 1650 \text{ RPM}) * (.5 \text{ sec})}{5250 * 2 * (2 \text{ sec.})} + \dfrac{(46.9 \text{ ft-lbs.} * 1650 \text{ RPM}) * (.5 \text{ sec})}{5250 * 2 * (2 \text{ sec.})} = (0.424 + 1.843) \text{ HP} = 2.26 \text{ HP}$

5) The regen or braking HP at top speed is: HP_{regen} = (46.9 ft-lbs. * 1650 RPM)/5250 = 14.74 HP. This is almost the same rating as the drive/motor HP rating.

6) To complete the specifications on a braking unit,

Peak regeneration rating = 14.47 HP * 746 Watt/HP = 10,800 watts

Current rating >= 14.47 * 1.2 = 17.5 amps

Continuous power rating = 2.26 HP * 746 Watt/HP = 1690 watts

Note that this extreme case happens every 9th cycle, after incrementally adding 200 lbs. of weight each time.

Reliance Standard Drives Marketing is prepared to evaluate your applications to recommend the proper regenerative braking solutions.

NOTE: This material is not intended to provide operational instructions. Appropriate Reliance Electric Drives instruction manuals precautions should be studied prior to installation, operation, or maintenance of equipment.

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Publication D-7743 – February 1999