SUBJECT: MEASURING ELEVATOR SYSTEM INERTIA

The DSD412 dc drive has an internal digital velocity regulator specifically designed for repeatable position tracking of elevators during acceleration, running, and deceleration. It is simple to tune because it does not use the interacting P-I-D type adjustments often found with traditional regulators. But it does require knowledge of the system inertia, operating speeds, gear ratio, acceleration rates, and torque capability of the motor. These values are neither familiar nor necessarily available to the adjuster who is responsible for tuning up elevator performance, and at first may seem to be intimidating. However, a combined ratio of these parameters is what is needed, not the individual values. This ratio is the Per Unit Inertia of the system, and can be easily estimated and measured using the techniques listed below. The beauty of this method, and a digital regulator, is that once tuning of a particular hoistway is accomplished, a second identical hoistway can often be successfully tuned by merely entering in the same parameter values.

PER UNIT INERTIA

Per Unit Inertia is defined as the ratio of the strength required to accelerate the mass of all moving parts of the elevator system to rated speed versus the strength of the motor used to do it. When expressed in terms of rotation as geared to the motor shaft, the mathematical relationship is:

$$Jpu = \frac{(EquivRotatingInertia) \times (ratedSpeed)}{(RatedTorque)}$$

The correct physics term for Equivalent Rotating Inertia is known as the Moment of Inertia. And Moment of Inertia X Angular Velocity = Angular Momentum. The units in any choice of notation system are…

$$Jpu = \frac{(Force * Length * Time * Time) \times (\mathrm{Re}v)}{(Force * Length) \times (Time)} = Time$$

A convenient unit of time is Seconds. A simple explanation in words is that this is the time it would take to accelerate the inertia of the elevator to rated speed, using rated motor torque. Note that this is a pure inertia effect, not influenced by friction or gravity. The system inertia we have defined is that reflected to the rotating motor shaft and automatically takes into account all effects of gearing, sheave diameter or double roping; the mass of the car, counterweight, payload and ropes; and the rotating mass of motor armature, sheave and brake drum. The Per Unit Inertia is a key ingredient for the regulator to define how much torque is required, in percent of rated torque of the motor, in order to produce the acceleration required to follow a specific change in velocity reference. And when we further define rated torque to be that produced at nameplate rated amperes with the motor field being at full strength, the drive current regulator and its size calibration factors will then produce the correct motor current to provide the necessary acceleration torque.

MEASURING PER UNIT INERTIA

We should be able to calculate Per Unit Inertia by measuring the ampere-seconds it takes to accelerate the car, then divide by the rated motor amperes. However, it is recognized that there is more to an elevator than simple inertia. The effects of gravity and friction cannot be ignored. But elevators generally follow a repeated acceleration/velocity time profile during floor to floor operation. By taking a combination of simple measurements, one can easily observe and calculate the Per Unit Inertia.

Figures 1 and 2 show the typical velocity and acceleration profiles of two elevator floor to floor runs, first UP then DOWN with S-Curve type jerk control (fixed rate of change of acceleration). Note that if the car were to be perfectly balanced so that there were no effects from gravity, the required armature current profile would essentially be the same as that shown in Figure 2. [For the moment ignore starting or rolling friction.] Note that the acceleration and deceleration profiles are usually identical. So the accel and decel rates and jerk in and jerk out portions of the S-Curve are the same, regardless of the direction of travel. As a result, the time from T0 to T1 to T2 to T3 is the same as that from T4 to T7. The sought after Per Unit Inertia number is the ampere-seconds area under the armature current acceleration or deceleration time profile curve, divided by rated amperes. Since the jerk in and jerk out transitions both form the same triangular shaped ends, one can easily compute the area under the curve by reading armature current at the indicated points and assuming a rectangular area by using only the time from T0 to T2 (or T4 to T6), rather than the whole acceleration time. This time data is known and set within the velocity profile generator, whether it be internal or external to the DSD412 drive. An alternate method would be to set the S-Curve time portion to zero during the test. Then the whole accel/decel time (T0 to T3) would be valid to use for the calculation. Modifying the S-Curve profile at a later time does not change the Per Unit Inertia.

EFFECTS OF CAR UNBALANCE

Figure 3 shows the motor armature current required for those same elevator runs under a typical condition where the counterweight weighs more than the car (i.e. – An empty car will fall UP). The required current profile is similar to that of Figure 2, but offset by the degree of gravity unbalance. Less current is required to accelerate UP and to decelerate while moving DOWN as the pull of gravity on the counterweight is helping. While running at constant speed in either direction, the drive must provide a constant downward torque to the car to balance the pull of gravity on the counterweight. Note that those same torque amperes are required to hold the car steady before and after the floor to floor run. When the drive is turned off at the floor, the elevator brake must provide this holding force. But the Per Unit Inertia data is only that required for acceleration of the car. The motor amperes offset due to an unbalanced load must be accounted for during the computation.

It is common for the counterweight to weigh more than the empty car by 40-50% of the rated payload of the car. Statistically, this is the weight of an average elevator load. A change in payload weight does change the system inertia. The two extreme cases will be at full load and empty car. But good performance with an empty car is relatively meaningless. Statistically, it makes sense to tune the elevator for best performance with an average load, or balanced car, by adding dummy payload weights. Then performance characteristics at other loads will deviate the least amount plus and minus about the optimum.

EFFECTS OF UNBALANCED ROPE COMPENSATION

In tall buildings the weight of support cables (ropes) is significant. These cables are routed from the top of the car up and over the machine sheave at the top of the hoistway and down the side of the elevator shaft to hang the counterweight. As the elevator car travels up, the length of cables on the elevator side of the sheave becomes shorter, and lighter, and that on the side of the counterweight becomes longer, and heavier. This causes a significant shift in the load balance and effort required from the elevator motor to maintain proper speed and car position. A common countermeasure is to hang compensating ropes from the bottom of the car, down the hoistway, around another pulley at the bottom, and up to the bottom of the counterweight. Now as the car travels up, the length (and weight) of ropes from the bottom of the car gets longer (and heavier), compensating for the change in weight of those attached to the top of the car. When done properly, car and counterweight balance will remain constant regardless of the position in the hoistway (Figures 2 and 3). When done poorly, car balance will change and cause a shift in motor running current dependant on hoistway position as shown in Figures 5 and 6. Note that since the actual moving mass of the system does not change, only the load balance of the elevator shifts, not the Per Unit Inertia of the system. MagneTek recommends that rope compensation be adjusted so that the variable load effects are less than +/-5% of rated motor current over the length of the hoistway. If the same count and size of ropes are used for rope compensation as that for hanging the car, compensation will be nearly perfect. Adding or removing compensating ropes does change system inertia. If rope compensation is changed, the Per Unit Inertia should be re-adjusted appropriately.

EFFECTS OF FRICTION

A closer look at a longer run UP is shown in Figures 4, 5, and 6. The desired velocity profile is of course similar, with a longer time spent at maximum contract speed to accommodate a longer floor to floor distance run. Sleeve type bearings on the machine supporting the weight of the elevator will typically settle during a long stop at a floor landing, causing some bearing lubrication to be squeezed out. As a result a significant amount of torque may be required at the beginning of the run in order to break away high bearing friction. This may cause a noticeable spike in current at the start of an elevator run. High starting torque may be also caused by a late-to-release mechanical brake if the drive must pull through the brake to follow the desired velocity profile. See Figures 5 and 6. It is important to note that the motor ampere data of interest (Reading #1 in Figure 5) is not necessarily the highest ampere reading when the car is started. Interference from a slow released brake does not change the Per Unit Inertia, but it can cause an unwanted time lag, vibration, or noise during starting, and at best will cause unnecessary brake wear. If the initial starting amps are greater than that required for constant acceleration, brake release timing probably needs to be re-adjusted.

PERFORMING THE MEASUREMENTS

Refer to Figures 7 and 8. This method averages four accel/decel cycles, first UP then DOWN, and includes extra measurements to compensate for car and rope unbalance. There will always be cases where one cannot balance the car. In those cases the inertia of a typical partial payload weight will not be measured, creating non-optimum data.

1. Determine and set motor Full Field conditions prior to making the test. (Changing motor field amperes will affect the strength of the motor and the effective Per Unit Inertia.)

2. If possible, add load weights so that the car is balanced at mid-hoistway. This will provide the best compromise for variable loads and rope compensation.

3. Adjust top speed to be just under the point at which any field weakening takes place. This will ensure that the motor field remains at Full Field during the test.

4. Use the normal S-Curve acceleration profile but determine the T0 to T2 time for the calculation (See Figure 2). **OR** temporarily set the S-Curve portion time to zero to use the whole accel/decel time.

5. Determine the necessary number of floors to travel to achieve full speed during the run.

6. Set the car to a lower floor, leaving room to travel the required number of floors to reach full speed.

7. Call for a run UP, to a floor near the top.

8. Observe motor amperes on the display unit of the drive, Function #611, and…
   a. Record acceleration amperes midway during the constant acceleration portion, **(Reading #1)**
   b. Record deceleration amperes midway during the constant deceleration portion. **(Reading #2)**
   c. Record the Hold-At-Floor amperes when the car reaches the destination floor, just before the brake sets. **(Reading #5)** Be sure to record the polarity sign of the readings.

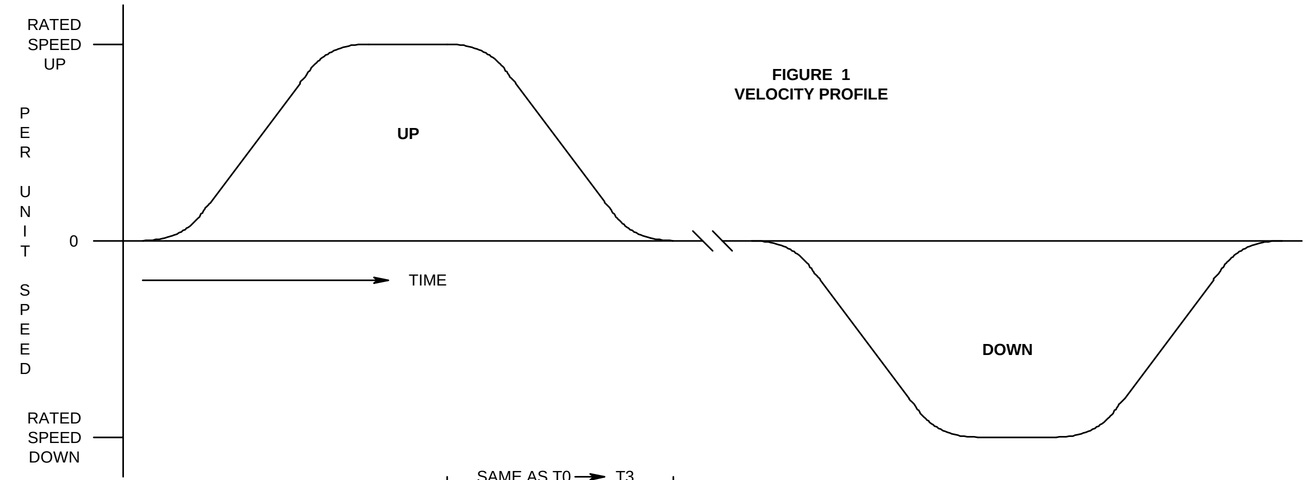
9. Call for a floor to floor run DOWN, back to the starting floor.

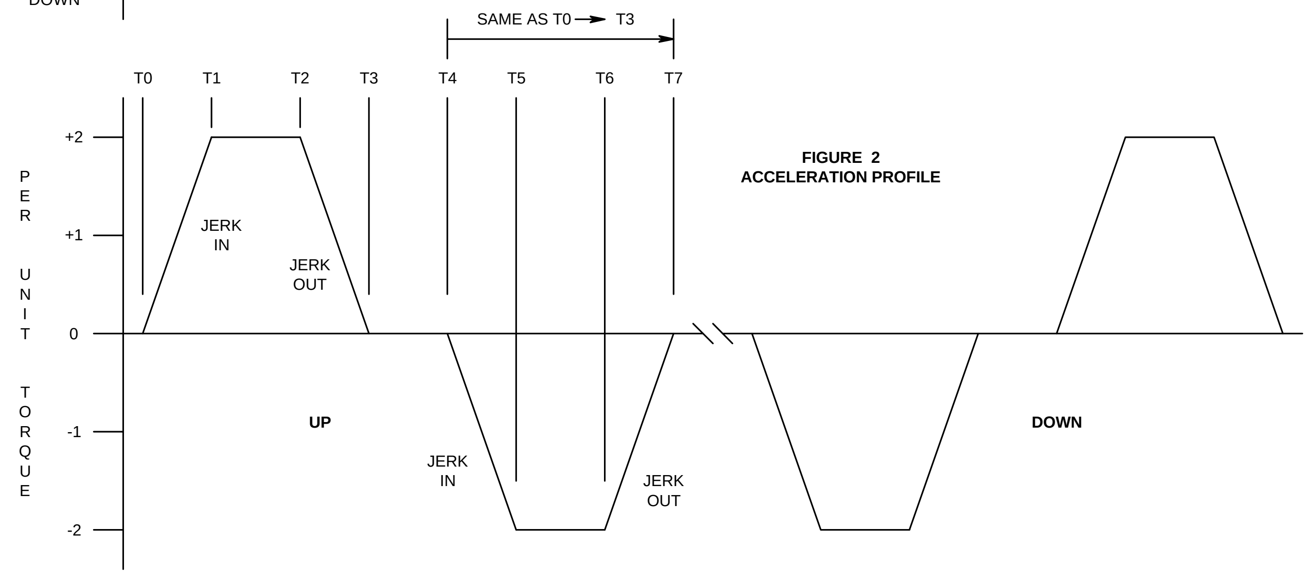
10. Again observe motor amperes during the run, and…
    a. Record acceleration amperes midway during the constant acceleration portion. **(Reading #3)**
    b. Record deceleration amperes midway during the constant deceleration portion. **(Reading #4)**
    c. Record the Hold-At-Floor amperes when the car reaches the destination floor, just before the brake sets. **(Reading #6)** Be sure to record the polarity sign of the readings.

11. Calculate the Per Unit Inertia using the following formula:

$$Jpu = \frac{AccelTime(T0toT2only)}{RatedAmperes(Param\#3)} \times \frac{(Rd\#1 - Rd\#2 - Rd\#3 + Rd\#4 + 2Rd\#5 - 2Rd\#6)}{4}$$

Remember, the readings are signed numbers, they may be positive or negative depending on car balance.
The expected result should be between 1.2 and 3.5 seconds. This is the measured Per Unit Inertia to enter as drive Parameter #41. If the car was not balanced the calculated inertia may not represent a truly realistic or typical elevator load. There may be a need to adjust the number slightly upwards for optimum performance if the measurement was made with an empty car.


RATED SPEED UP
PER UNIT SPEED
0
TIME
RATED SPEED DOWN
UP
DOWN
FIGURE 1
VELOCITY PROFILE


SAME AS T0 → T3
T0
T1
T2
T3
T4
T5
T6
T7
+2
+1
0
-1
-2
PER UNIT TORQUE
JERK IN
JERK OUT
UP
JERK IN
JERK OUT
DOWN
FIGURE 2
ACCELERATION PROFILE

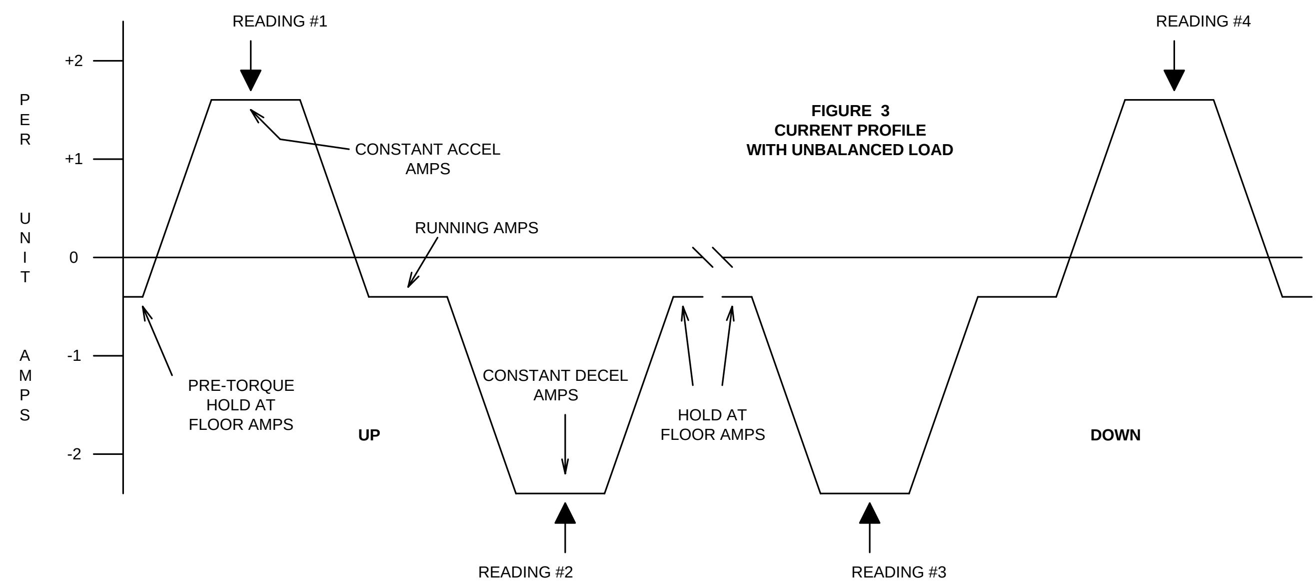
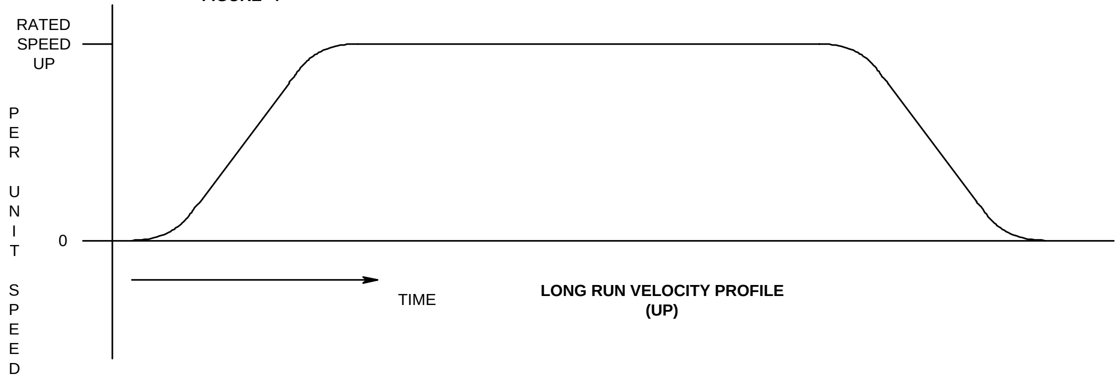

READING #1
READING #4
+2
+1
0
-1
-2
PER UNIT AMPS
CONSTANT ACCEL AMPS
RUNNING AMPS
PRE-TORQUE HOLD AT FLOOR AMPS
UP
CONSTANT DECEL AMPS
HOLD AT FLOOR AMPS
DOWN
READING #2
READING #3
FIGURE 3
CURRENT PROFILE
WITH UNBALANCED LOAD

FIGURE 4



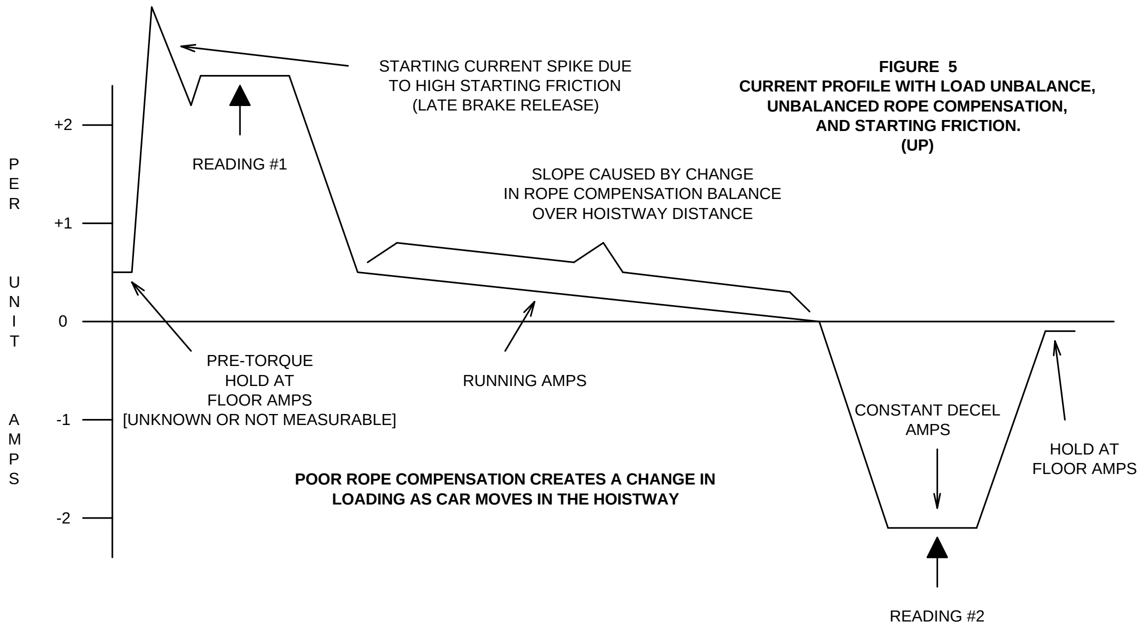


FIGURE 5
CURRENT PROFILE WITH LOAD UNBALANCE, UNBALANCED ROPE COMPENSATION, AND STARTING FRICTION. (UP)

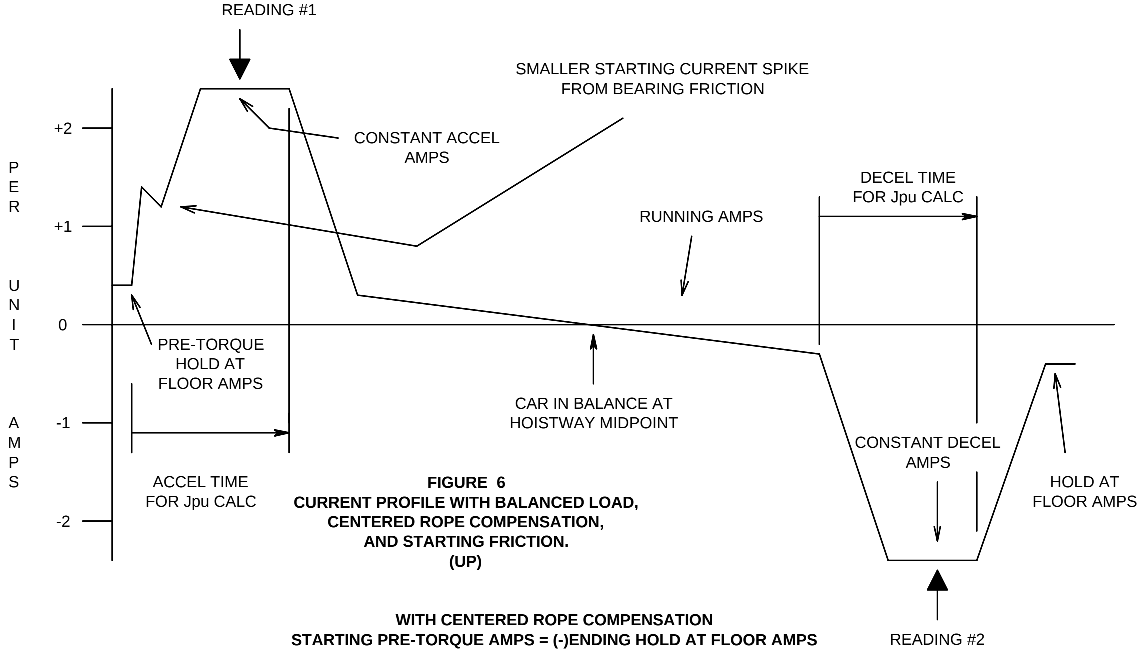


FIGURE 6
CURRENT PROFILE WITH BALANCED LOAD, CENTERED ROPE COMPENSATION, AND STARTING FRICTION. (UP)

WITH CENTERED ROPE COMPENSATION
STARTING PRE-TORQUE AMPS = (-)ENDING HOLD AT FLOOR AMPS

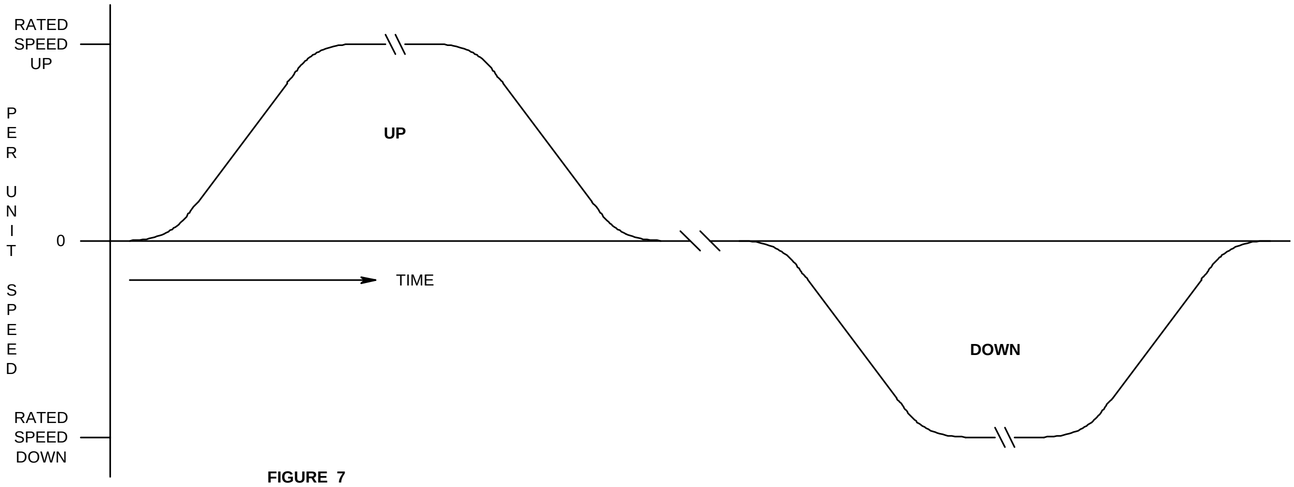


FIGURE 7
TEST VELOCITY PROFILE

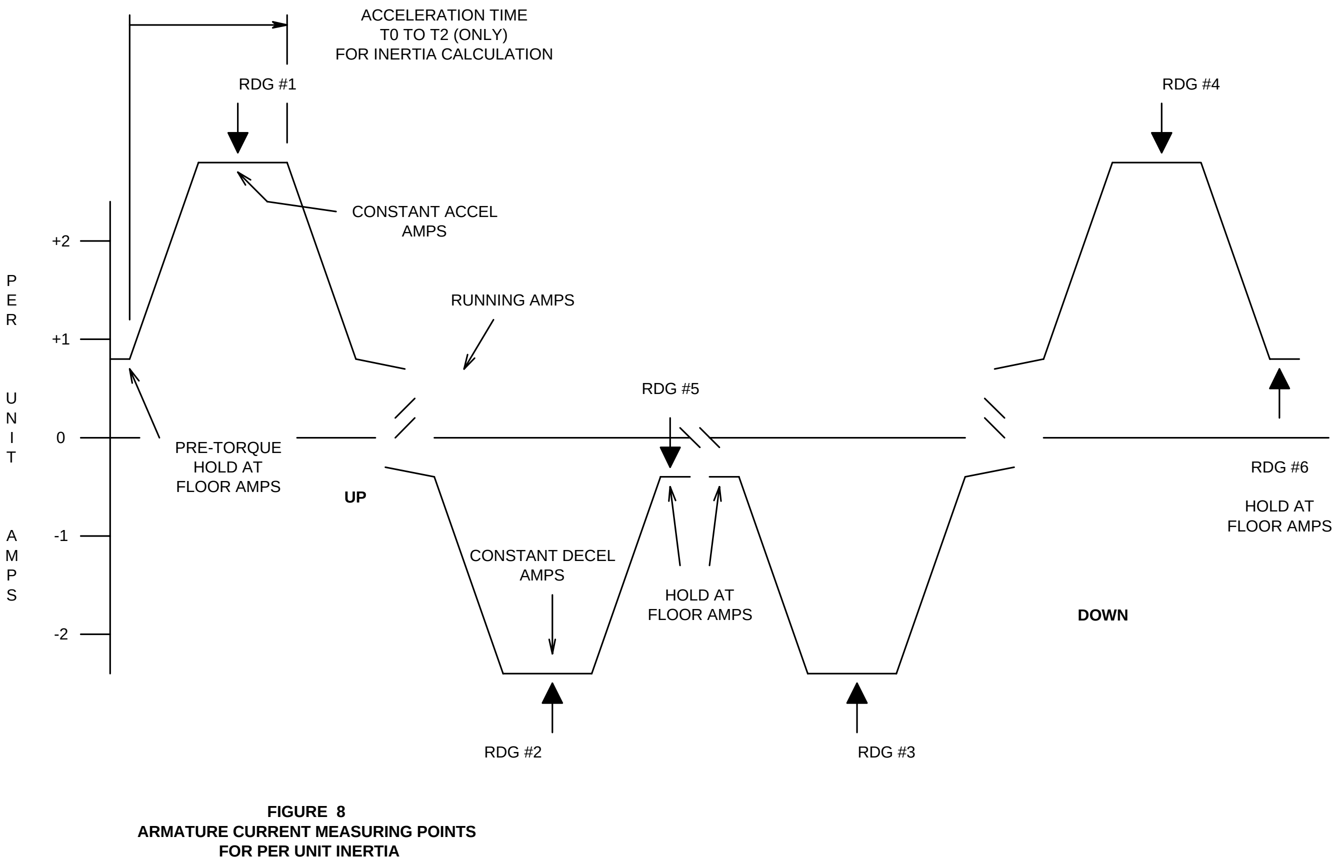


FIGURE 8
ARMATURE CURRENT MEASURING POINTS
FOR PER UNIT INERTIA
WITH AN UNBALANCED LOAD