3.4 Motor Actuator Output Capability

Minimum Torque Switch Setting. Most motor-operated valves use the torque switch to shut off the motor at the end of the closing stroke. Some valves use limit switches for this purpose, and use a torque switch as a safety device to prevent structural overloads, particularly in the event of a limit switch malfunction or incorrect setting. In a few valves in specific applications, the torque switch is bypassed, and the actuator relies entirely on the limit switch to disconnect the motor. However, the discussion here focuses on actuators with torque switches.

Figure 3-33 shows how the torque switch operates. The worm is free to slide on the splined shaft, but is held in place by the spring pack. The spring pack is typically a Bellville spring pack like the one shown here. When the disc is wedged in the seats and the stem nut becomes difficult to turn at the end of the closing stroke, the worm gear (which directly drives the stem nut) slows and stops. However, the worm continues to turn, sliding on the splined shaft as it climbs the teeth of the now stationary worm gear, and compressing the spring until the lateral displacement of the worm trips the torque switch. The torque switch, in turn, trips a relay that disconnects power to the motor. The stiffer or tighter the torque spring, or the greater the spring displacement, the greater the actuator torque applied to the worm gear by the worm. Changing the torque switch setting changes the amount of spring displacement needed to trip the switch. The torque applied to the worm gear by the actuator at torque switch trip is the available actuator torque (assuming that the torque switch has not been bypassed, and that the motor does not stall before the torque switch trips).

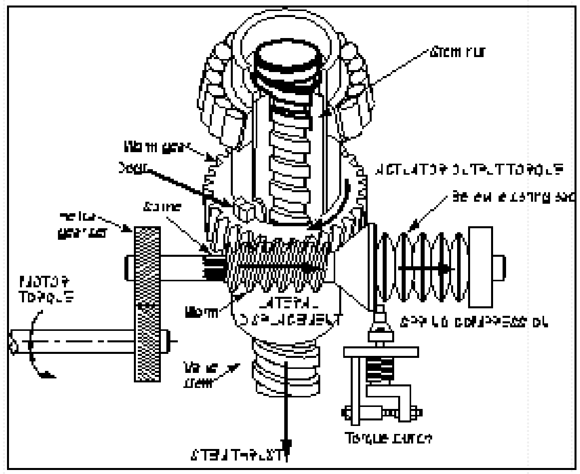

Figure 3-33 Actuator Gear Box Components

In Limitorque actuators, the torque switch setting is represented as a numerical scale marked on a dial on the torque switch mechanism. Because the dial is small, and because the scale is not marked in small increments, precise settings are difficult. The numerical scale on the torque switch dial references to a chart for that particular torque switch, and the chart indicates the corresponding actuator torque. Figure 3-34 shows the torque switch setting chart for the 0501-184 spring pack. These torque values are only modestly reliable for new actuators, and are less reliable for older ones; research has shown that the spring pack can lose its strength as it ages with time and use, so that a torque switch with an aged spring might be more likely than a new one to trip at a lower torque than indicated by the chart.

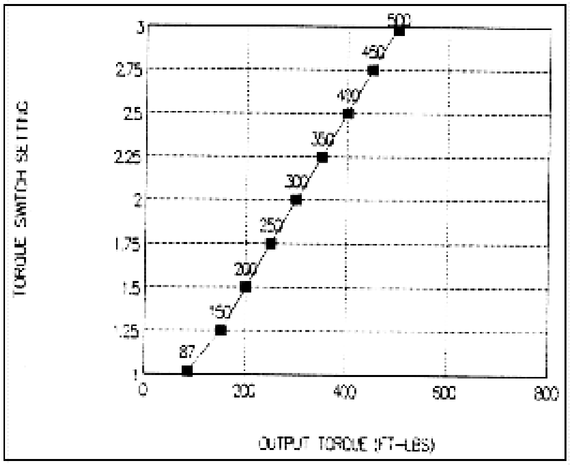

Figure 3-34 Limitorque Torque Switch Chart for 0501-184 Spring Pack

The torque switch assembly is usually equipped with a limiter plate whose function is to prevent the torque switch from being set too high (above the overload limits of the valve and actuator). It is easy to modify or remove the limiter plate, and such modification or removal is rather common in U.S. plants.

We are not yet done with our evaluation. We still need to ascertain that with a torque switch setting in this range, the motor won't stall before the torque switch trips, and we need to ascertain that this torque switch setting does not exceed the published allowable torque and thrust ratings of the gearbox and the valve. Those values define the maximum torque switch setting. As we approach the conclusion of our evaluation, we will select a torque switch setting somewhere between the minimum and the maximum. That torque switch setting will define the available actuator torque, and that, compared with the required actuator torque, will determine the operating margin.

3.4.1 Actuator Motor Performance

3.4.1.1 AC Motors

The next step is make sure the electric motor won't stall before the torque switch trips. The available torque determined by the torque switch setting, as described in the previous chapter, is applicable only if the electric motor is capable of supplying the actuator with sufficient torque to trip the torque switch. This chapter describes the process for estimating the electric motor's output torque with the motor operating at its design basis voltage and temperature conditions. The output torque of the electric motor is the input torque to the gearbox. The gearbox is discussed in the next chapter.

The formula for predicting the output torque of an ac electric motor is:

$$Tq_{motor} = Tq_{rated}\left(\frac{V_{act}}{V_{rat}}\right)^{n} F_{temp} F_{app}$$

Equation (3-22)

Where

Tq_{motor} = estimated output torque of the electric motor

Tq_{rated} = rated starting torque of the electric motor

V_{act} = actual voltage supplied to the motor

V_{rat} = the motor's rated voltage

n = usually 2 for ac motors and 1 for dc motors

F_{temp} = factor to account for losses due to motor heating

F_{app} = application factor

The formula begins with the motor's rated output torque at normal conditions, then multiplies that value by specified factors to account for torque losses due to voltage degradation and motor heating. The valve industry and the nuclear industry generally include an application factor to account for motor differences and minor fluctuations in the supply voltage. The application factor also serves to add conservatism to the estimate. The resulting value is the estimated output torque of the electric motor.

Performance Curves

Although the rated output torque (called the rated torque or the rated starting torque on the motor nameplate) serves as the parameter of interest in our evaluation, it is generally useful to know the actual output torque at normal conditions as well. The rated torque is the minimum expected output at normal conditions (temperature and voltage). The actual torque at normal conditions might be higher than the rated torque.

The motor manufacturers and actuator manufacturers publish motor data in the form of performance curves that show motor torque versus motor speed and motor torque versus current. These motor data are best thought of as theoretical performance curves, because they are produced from calculations of motor input (current), motor efficiencies, and other

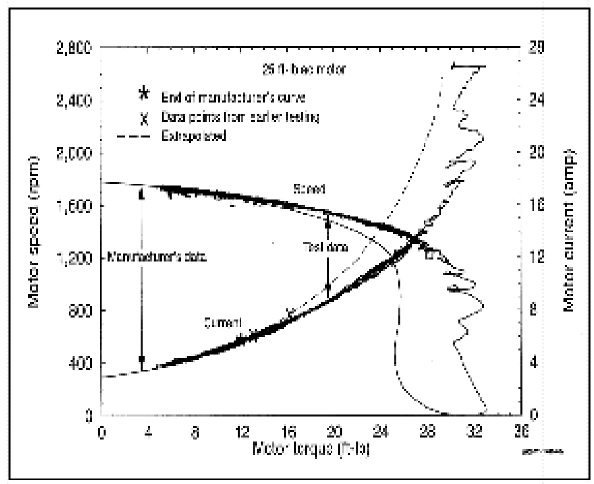

Figure 3-35 25 ft-lb AC Motor Torque Curve

parameters; they are usually not produced from dynamometer test data. The results of the 1996 NRC/INEEL motor and gearbox tests showed that for the four ac motors we tested, these performance curves are usually conservative; that is, the theoretical curve shows the motor producing less torque than the motor actually produces. Figure 3-35 shows an example of a comparison of the NRC/INEEL dynamometer-type test results with the performance data published by the actuator manufacturer.

These data represent the 25-ft-lb ac motor we are using in our example evaluation. The published theoretical data show a torque output of about 25 ft-lb at the knee of the curve, that is, at the point where the speed of the ac motor begins to drop significantly as the load increases. This part of the motor data is important, because it represents the approximate peak torque output of the motor before it lugs down to a stall condition. For the three 1800-rpm ac motors we tested, the knee of the curve occurred between 1200 and 1000 rpm. Figure 3-35 shows that the actual output of the 25-ft-lb motor at the knee of the curve was about 30 ft-lb. The difference between the actual output of 30 ft-lb and the rated output of 25 ft-lb is important to the evaluation described in the following paragraphs.

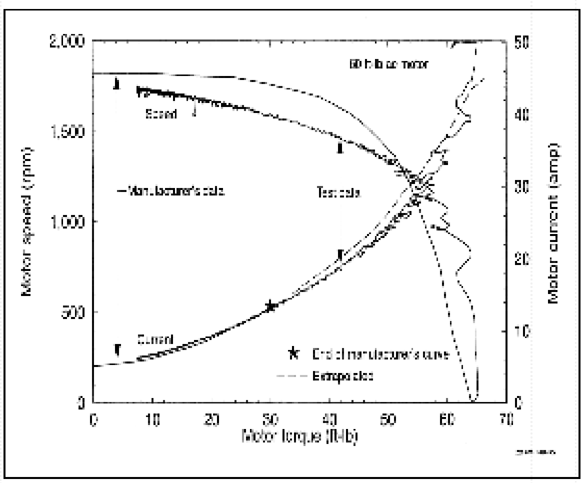

Figure 3-36 60 ft-lb AC Motor Torque Curve

Not all motors have excess torque capability above the nameplate rated torque. Figure 3-36 shows the same data for the 60-ft-lb ac motor we tested. In this instance, the actual torque and the torque indicated by the theoretical curve both fall near the rated torque of 60 ft-lb (no margin). Figure 3-37 shows the same data for the 5-ft-lb ac motor we tested. In this instance, both the theoretical performance curve and the test data indicate an output torque (at the knee of the curve) well above the rated torque of 5 ft-lb.

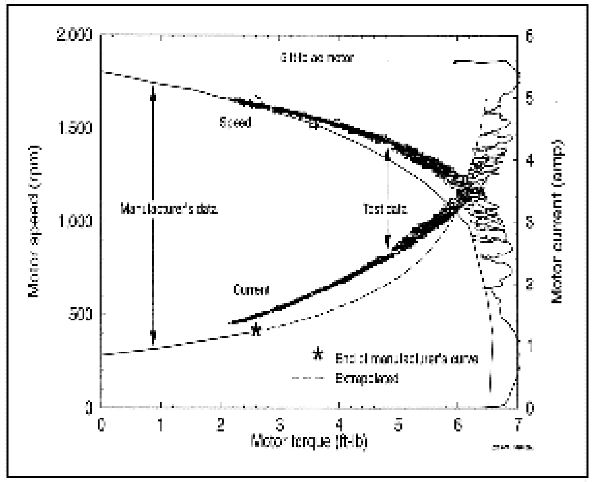

Figure 3-37 5 ft-lb AC Motor Torque Curve

Degraded voltage

The term $(V_{act} / V_{rat})^n$ is a factor that accounts for torque losses due to operation at reduced voltage. This term times the motor's rated torque (Tq_{rated}) is intended to produce an estimate of the motor toque output at degraded voltage. The industry typically uses an exponent of 2 for ac motors, hence the term voltage squared method to describe the conventional use of this part of the formula. The results of our 1996 NRC/INEEL testing of four ac motors of four different sizes showed that an exponent of 2 is adequate only if the motor's actual output torque at normal voltage is significantly higher than the rated torque, and if the rated torque, not the actual torque at normal voltage, is used as the basis for the calculation (Tq_{rated}). In effect, the motor margin (the positive margin between the actual torque and the rated torque of the motor) compensates for the inadequacy of the voltage squared calculation. If the analysis uses the actual torque at normal voltage for the Tq_{rated} term instead of the rated torque, an exponent higher than 2 is necessary. For motors with little margin between the actual torque and the rated torque, the voltage squared calculation is simply inadequate.

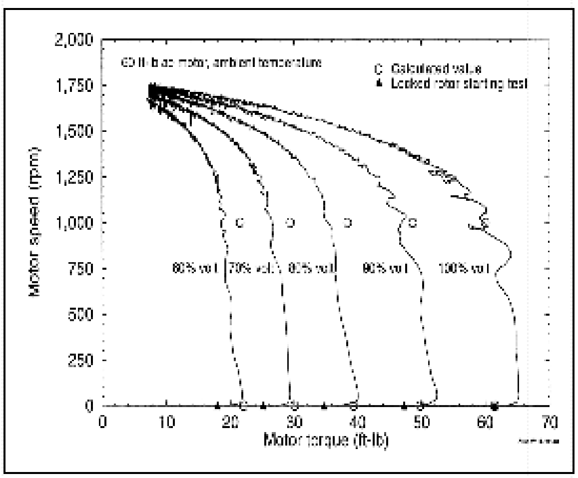

Figure 3-38 Degraded Voltage Testing Results for 60 ft-lb AC Motor

Limitorque has recognized this inadequacy (Limitorque Technical Update 98-01) and has published a list of motors for which the voltage squared method does not apply. For those motors, Limitorque provides other guidance. The 60-ft-lb motor we tested in 1996 is one such motor. The results of our reduced voltage testing of the 60-ft-lb motor are shown in Figure 3-38. The voltage squared method (an exponent of 2) applied to operation at 80% voltage (368 volts) produces an estimate of 38.4 ft-lb. The actual torque measured in dynamometer-type testing of this motor at 80% voltage was 36 ft-lb. For this motor, an exponent of 2.4 would be applicable, producing an appropriately conservative estimate of 35.1 ft-lb. This exponent of 2.4 is applicable only to the 60-ft-lb motor that produced the test results; the reader should not infer that this exponent is applicable to other motors. A discussion of the use of test results to derive exponents other than 2 is provided in NUREG/CR-6478, *Motor-Operated Valve (MOV) Actuator Motor Gearbox Testing*.

Elevated temperature

The term F_{temp} is a factor that accounts for losses due to operation at elevated temperature. For some actuator motors, operation at elevated temperature is one of the design-basis conditions that must be considered in analytical evaluations of MOV capability. The output of the electric motor tends to degrade at higher temperature, mostly because of the increased resistance in the motor windings. This is the case regardless of whether the increase in the motor temperature is caused by ambient conditions or by motor operation for extended periods or at high loads.

In the U.S. nuclear industry, the standard practice for Limitorque actuators is to use data published by Limitorque to identify the appropriate F_{temp} term. The Limitorque data consist of predictions of percent loss in motor torque and motor current for a motor temperature increase above 40ºC (104ºF). A comparison of similar (but not identical) predictions with results of NRC/INEEL dynamometer tests is provided in NUREC/CR-6478. For the four motors tested in that test project, those predictions were reasonably accurate and mostly conservative.

Application factor. The application factor (F_{app}) has been typically used to account for voltage losses down to 90% voltage and to account for other considerations in specific applications. Different application factors apply to actuators of different types; for example, the application factor specified by Limitorque for a 1700-rpm motor installed in a standard SMB actuator is 0.9, while the application factor for a 900-rpm motor is 0.8. For our example SMB-0-25 ac actuator, driving a gate valve, we use the application factor of 0.9, as specified by Limitorque: 15.7 ft-lb times 0.9 equals 14.12 ft-lb. One of the effects of the application factor is to add conservatism to the estimate, compensating for lack of conservatism in other parts of the formula, the voltage squared calculation, for example.

Motor Stall Analysis

In practice, a motor stall analysis is typically performed if during setup, testing, or plant operation, a motor stall occurs. The occurrence of a motor stall might be caused, for example, by a mechanical failure, or by too high a torque switch setting. The torque switch mechanism is typically equipped with a limit plate intended to prevent someone from setting the torque switch too high for that particular actuator. Note, however, that the limit plate can be (and often is) modified or removed.

The overload calculation determines whether the motor stall might have included torque and thrust loads in excess of the limits specified by the valve and actuator manufacturers. If so, disassembly and inspection might be appropriate. The motor stall analysis assumes that the torque switch fails to shut off the motor (due to torque switch malfunction, incorrect torque switch setting, motor controller malfunction, hydraulic lock in the spring pack, etc.), such that the valve and actuator are subjected to the maximum possible torque and thrust loads the motor and gearbox are capable of producing.

The torque and thrust limits of the valve are specified by the valve manufacturer. The torque and thrust limits of the actuator are specified by the actuator manufacturer. Too much thrust can damage thrust bearing in the gearbox, damage the disc or the seat, bend the stem, or even break the valve body (by driving the wedge too deeply into the seats and through the bottom of the valve). Too much torque can cause premature aging (cracking) on the gear teeth, twist the stem, or damage shafts or bearings in the gearbox.

If the valve is instrumented to measure actuator torque and stem thrust, closing the valve against no flow load and no pressure can provide data that are useful for an overload calculation. Specifically, it can provide a stem factor or stem friction value that is representative of overthrust conditions. Friction tends to be lower under such conditions.

A worst case overload scenario is similar to the no-load test mentioned in the previous paragraph. In such a test, the only resistance to stem motion during most of the stroke is the packing load. The load increases suddenly when wedging occurs, and the torque switch trips during this sudden increase in the load. This kind of load profile produces the lowest possible stem friction and the highest possible stem thrust at torque switch trip, along with accompanying discussion). Similarly, gearbox efficiency is high at these conditions, representing the stall efficiency conditions addressed by Limitorque's gearbox efficiency recommendations. Motor and gearbox momentum effects are included in the stall efficiency value. In contrast, a load profile with a load that steadily increases (as in the second, third, and fourth traces in Figure 3-30) produces higher friction at torque switch trip, because the more of the grease has been squeezed out of the interface by the high load before torque switch trip. In addition, the effects of motor momentum are smaller, because the flow load has already slowed the motor down before the disc wedges in the seat.

In contrast to the typical no-load closing stroke described in the previous paragraphs, the motor stall analysis assumes that the torque switch did not trip; that is, that the motor stalled after the torque switch, for whatever reason, failed to trip. Thus, the stem friction, gearbox efficiency, and motor momentum issues demonstrated in the previous discussion all come into play, combined with the maximum output of the electric motor at optimum conditions (room temperature, maximum voltage).

The forgoing example looks at the actuator gearbox structural limits. In the event of an inadvertent motor stall, a similar evaluation would be necessary to address the valve's structural limits. To repeat, the motor stall analysis described here is typically performed as part of a follow-up investigation after an inadvertent motor stall. It is not part of the design basis evaluation, nor part of a routine evaluation of diagnostic testing.

Note that we use a lower stem friction value for the motor stall analysis than we use for the design basis calculations. For the motor stall analysis, the lowest expected friction is conservative, while for the design basis calculation, the highest expected friction is conservative. Note also that we use the published gearbox stall efficiency for the overload calculation, while we use the published pullout efficiency for the design basis calculation. The published stall efficiency is intended by the actuator manufacturer for use in overload calculations, because it assumes a sudden stall following little or no load, accounting for the gearbox friction and motor momentum effects that would accompany such a sequence. The stall efficiency is not intended for application to other kinds of loads or sequences. Specifically, the analyst should not use the published stall efficiency in an evaluation of actuator capability for the design basis case.

3.4.1.2 DC Motors

Most of the information presented for ac motor actuators applies to dc-powered valve actuators as well as to ac-powered actuators. However, the performance of dc-powered actuators differs from that of ac-powered actuators in three important ways:

- While the peak torque output of an ac motor occurs at a moderate motor speed (about 1000 rpm for a 1700-rpm motor), the peak torque output of a dc motor occurs at very low speeds, at or near motor stall. Gearbox friction can be very high at motor speeds below about 300 rpm.
- The response of a dc motor to degraded voltage conditions is different than the response of an ac motor.
- The response of a dc motor to elevated temperature conditions is different than the response of an ac motor.

Recent (1998) NRC-sponsored tests at the INEEL investigated gearbox friction, degraded voltage, elevated temperature, and other issues as they pertain to the performance of dc-powered valve actuators. A full discussion of those tests is available in NUREG/CR-6620, *Testing of DC -Powered Actuators for Motor-Operated Valves*. A partial summary is included here.

Output at low motor speeds

Figure 3-39 shows a typical data trace of motor speed versus torque for an ac motor (upper plot), for comparison with a dc motor data trace (lower plot). In both cases, the motor was installed in a valve actuator subjected to a gradually increasing load that reduced the motor speed until the motor stalled. Motor torque measurements were taken by a torque cell installed in the output shaft of the motor, between the motor and the gearbox. Notice that this ac motor (with a rated torque of 25-ft-lb) maintains a high to moderate speed as it approaches and reaches it's peak output torque of about 31 ft-lb at about 1000 rpm at the knee of the curve, after

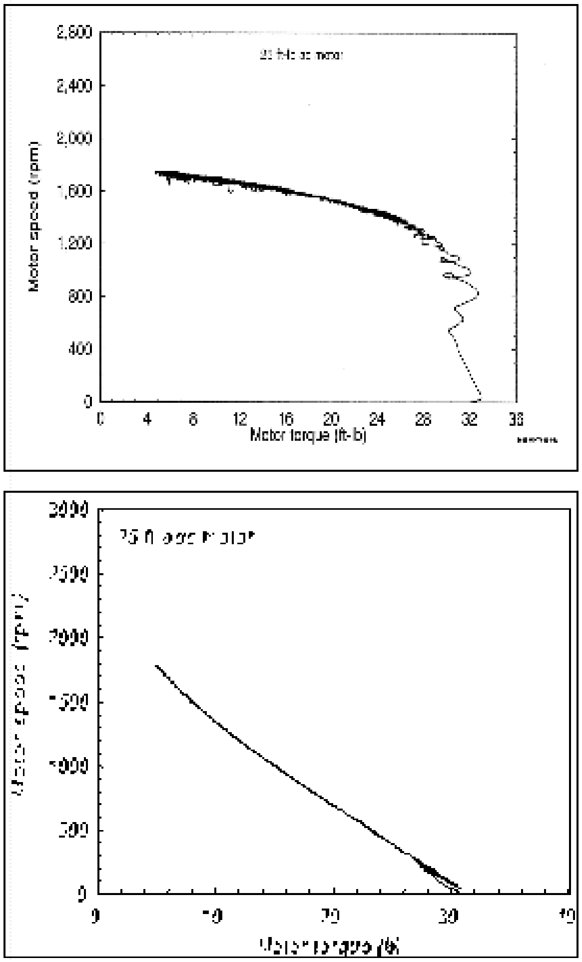

Figure 3-39 AC & DC Motor Torque Curves

which the motor speed abruptly drops off to a stall. In contrast, the dc motor (with a rated output torque of 25 ft-lb) continues to produce additional torque at lower and lower motor speed, gradually lugging down until it produces its peak torque of about 30 ft-lb at or near motor stall.

As we look at the data trace representing the ac motor performance, it is fairly easy to judge that the motor produces its maximum useful torque at about 1000 rpm, at a point in the data trace we call the knee of the curve. One of the possible outcomes in an unsuccessful valve closure occurs if the motor lugs down to this motor speed before flow isolation occurs. In that case, once the motor speed declines to the point represented by the knee of the curve, the motor will quickly lug down and stall, leaving the valve partly open. (In this scenario, the output of the actuator is insufficient to either close the valve or trip the torque switch.) However, in a successful valve closure, the actuator closes the valve well before the motor lugs down to this motor speed, and the torque switch shuts off the motor after the valve seats. The knee of the curve represents the threshold motor speed below which the motor produces no useful additional torque.

With dc motors, it is not so easy to make this kind of judgment. The data trace presented in Figure 3-39 (lower plot) shows this 25-ft-lb dc motor producing 28 to 30 ft-lb torque at a very low motor speed. A very important question arises in this context. Can the valve analyst depend on this high torque at low dc motor speed to close a valve?

The results of our recent dc-powered valve actuator tests clearly show that the answer to this question is no. Figure 3-40 shows the results of tests of the 25-ft-lb dc-powered actuator described in the previous paragraphs. The traces represent the results of five tests at different input voltages, ranging from 100% to 60% of the rated voltage of 125 vdc. Note that in this figure, the traces represent actuator torque versus motor speed, not motor torque versus motor speed. (As a reminder, motor torque represents the torque applied to the input side of the actuator gearbox, while actuator torque represents the output of the actuator gearbox.) The data show that below a motor speed threshold of about 300 rpm, the actuator does not produce additional output torque. This phenomenon occurs even though the motor does, in fact, provide additional input torque to the gearbox at lower speeds (Figure3-39, lower plot). Analysis of the test results showed that an increase in gearbox friction at very low speeds and very high loads consumes the additional torque produced by the motor at low motor speeds.

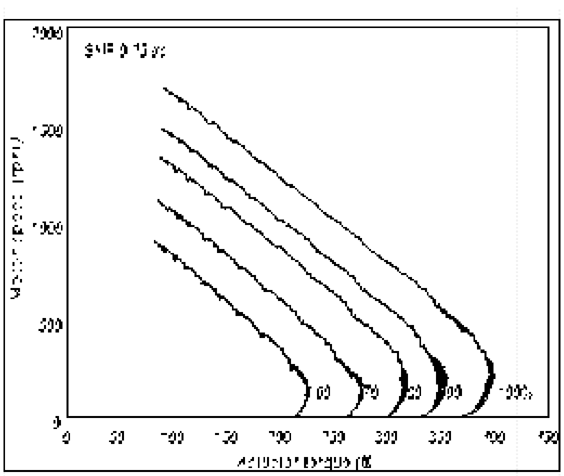

Figure 3-40 25 ft-lb DC Actuator Results

The data shown in Figure 3-40 were produced during the recent test program at the INEEL. The program included testing of three other dc-powered valve actuators, in addition to the one described above. The results from all four actuators were similar. Overall, the results showed a motor speed threshold of about 200 to 300 rpm below which the actuator produced no additional usable output. The specific motor speed at which the threshold appeared varied somewhat, depending on the magnitude of the torque load and on the gear ratio of the particular gearbox. For convenience, we call it a 300-rpm motor speed threshold.

The existence of this motor speed threshold is important. It means that when a dc-powered actuator closes a valve against a design basis load, operating at design basis voltage and temperature conditions, the actuator must successfully isolate flow (and trip the torque switch) before the motor lugs down to a speed lower than the threshold. It also means that in evaluations of valve operability, analysts cannot legitimately use dc motor torque output values produced at motor speeds below the threshold.

Degraded voltage

Like ac motors, dc motors are subject to reduced output at degraded voltage conditions. Some nuclear power plant applications call for valve actuators to be powered by dc motors to assure operation in the event of a power outage. These motors might experience degraded voltage conditions, for example, because of line losses on long cable runs or because of large demand on the battery bank that powers the motors. The standard formula used in the U.S. nuclear industry for estimating the effects of degraded voltage on dc motor output is :

$$Tq_{motor} = Tq_{rated}\left(\frac{V_{act}}{V_{rat}}\right)^{n}$$

Equation (3-23)

Where

Tq_{motor} = estimated output torque of the dc motor

Tq_{rated} = rated torque of the dc motor

V_{act} = actual voltage supplied to the motor

V_{rat} = the rated voltage of the dc motor

n = 1 for dc motors

This formula is the same as the voltage squared formula for predicting the output of ac motors, except that the exponent is 1 instead of 2.

The difficulty with making predictions of dc motor performance is identifying the motor speed at which the prediction is applicable. For example, Figure 3-41 shows the results of dynamometer-type tests of a 25-ft-lb dc motor subjected to various stages of degraded voltage. Also shown are predictions of the reduced output, with the predictions calculated by the formula presented above. The two sets of predictions use as input (Tq_{rated} in the formula) a torque value of 15 ft-lb (an arbitrary choice) and a torque value of 25 ft-lb (the motor's rated torque). These torque values correspond with motor speeds of 979 rpm and 363 rpm, respectively. This data plot shows that if we expect the predicted torque to be produced at the same motor speed as the base torque (the torque that served as the basis of the calculation), we will be disappointed. Compare, for example, the 60% voltage trace with the prediction. We must regard the prediction as grossly unconservative if we expect the motor to achieve 15 ft-lb at 363 rpm. However, the motor does in fact achieve 15 ft-lb in the 60% voltage test, albeit at a lower motor speed.

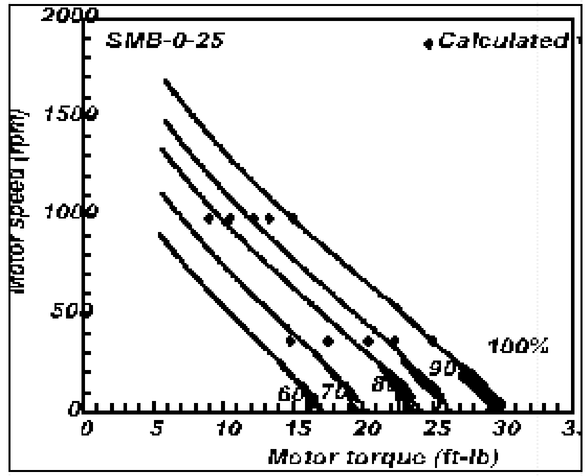

Figure 3-41 Dynamometer-type Test Results

As part of our dc motor test program at the INEEL, we developed a simple method that resolves this difficulty by predicting not only the reduced torque output of the motor at degraded voltage, but also the reduced motor speed at which the reduced torque is produced. The formula is for predicting the reduced motor speed is:

$$S_{act} = S_{rat}\left(\frac{V_{act}}{V_{rat}}\right)^{1}$$

Equation (3-24)

When

S_{act} = actual motor speed at degraded voltage

S_{rat} = motor speed at which the motor achieves its rated torque at full voltage

V_{act} = actual (degraded) voltage

V_{rat} = rated voltage

Figure 3-42 shows the results of this predictive method, for comparison with data from test results. The predictions match the data quite well.

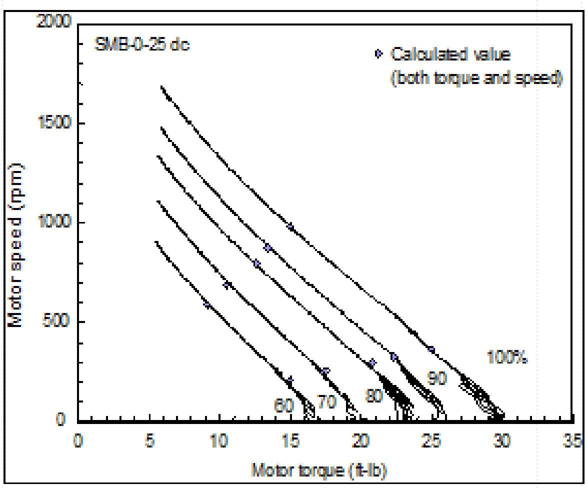

Figure 3-42 Predictive Method Results

For the sake of illustration, let us suppose that our example 6-in. RWCU gate valve is powered by a 25-ft-lb dc actuator instead of a 25-ft-lb ac actuator. Let us further suppose that our task is to use available information and methods to predict the performance of the dc motor at degraded voltage conditions, in the absence of test data. The manufacturer's theoretical performance data for this 25-ft-lb dc motor indicate that the motor will achieve its rated torque of 25 ft-lb at a speed of 610 rpm. In this exercise, we will assume that the manufacturer's performance data are a reasonably accurate representation of the motor's actual performance. We will also assume that the design basis requirement for this 125-vdc motor is to operate at 100 volts. Using Equations 18 and 19, we can predict that the motor's output at degraded voltage conditions to be 20 ft-lb at 488 rpm. This motor speed is safely above the 300 rpm motor speed threshold identified earlier in this chapter.

Elevated temperature

For some actuator motors, operation at elevated temperature is one of the design-basis conditions that the analyst must consider in an evaluation of MOV capability. The output of the electric motor tends to degrade at higher temperature, mostly because of the increased resistance in the motor windings. This is the case regardless of whether the increase in the motor temperature is caused by ambient conditions or by motor operation for extended periods or at high loads.

Our recent dc-powered actuator testing included tests at an elevated temperature. The results of those tests challenged the conventional practices used in the U.S. nuclear industry to account for elevated temperature effects on dc motors. The following discussion presents a possible method for predicting the output of a dc motor operating at elevated temperature conditions. More details about the industry's conventional practices, the test program, and the test results are available in NUREG/CR-6620, *Testing of DC-Powered Actuators for Motor-Operated Valves*.

Figure 3-43 shows the results of tests subjecting the 25-ft-lb dc motor to various stages of elevated temperature. The upper plot represents tests at 100% voltage, and the lower plot represents tests at 80% voltage, showing the combined effects of both elevated temperature and reduced voltage. Note that a small increase in temperature produces a significant decrease in output torque. Note also that the combined effects of a 20% voltage drop and a 250°F temperature increase reduced the peak output of the motor by half. The results from testing of the other three dc motors were similar to these.

The results indicate that a temperature increase has a linear effect on output torque, corresponding to the temperature effect on the resistance of the copper wire in the motor's shunt field. (Only the shunt field in a compound-wound dc motor is a strong function of resistance.) We therefore applied a linear relationship to estimate the actual torque from the rated torque, based on the ratio of the change in temperature in the motor's shunt field to the temperature above

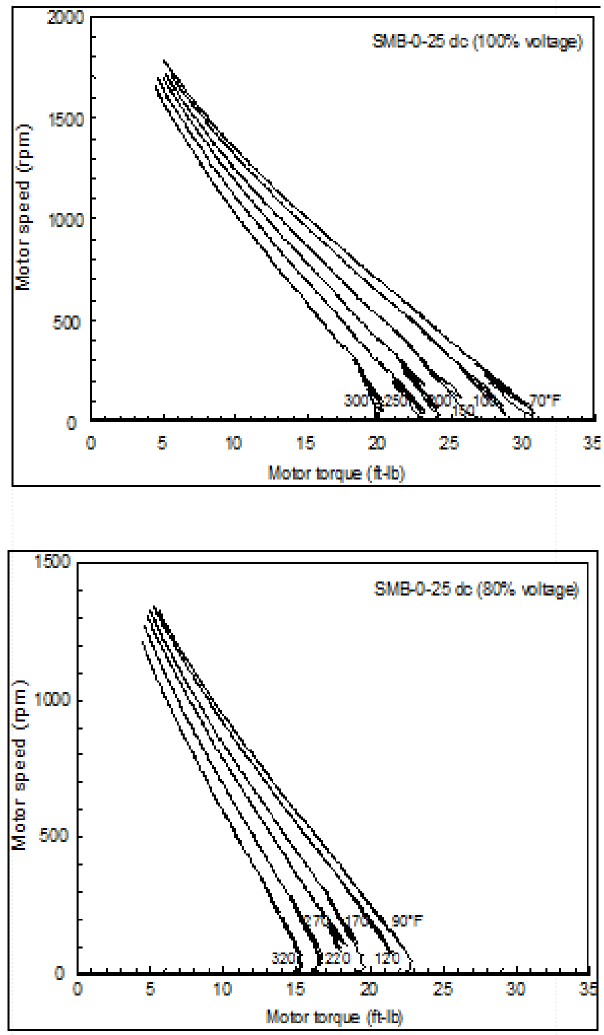

Figure 3-43 Elevated Temperature Results

absolute zero. This relationship is:

$$Tq_{act} = Tq_{rat}\left(1 - \frac{T_e - T_a}{T_a - T_z}\right)$$

Equation (3-25)

Where

Tq_{act} = actual motor torque

Tq_{rat} = rated motor torque

T_e = elevated temperature

T_a = ambient temperature (room temperature of about 70°F)

T_z = absolute zero (-273.15°C or -459.67°F).

Figure 3-44 shows the results of this calculation for the 25-ft-lb dc motor, for 100% (upper plot) and 80% voltage (lower plot). We

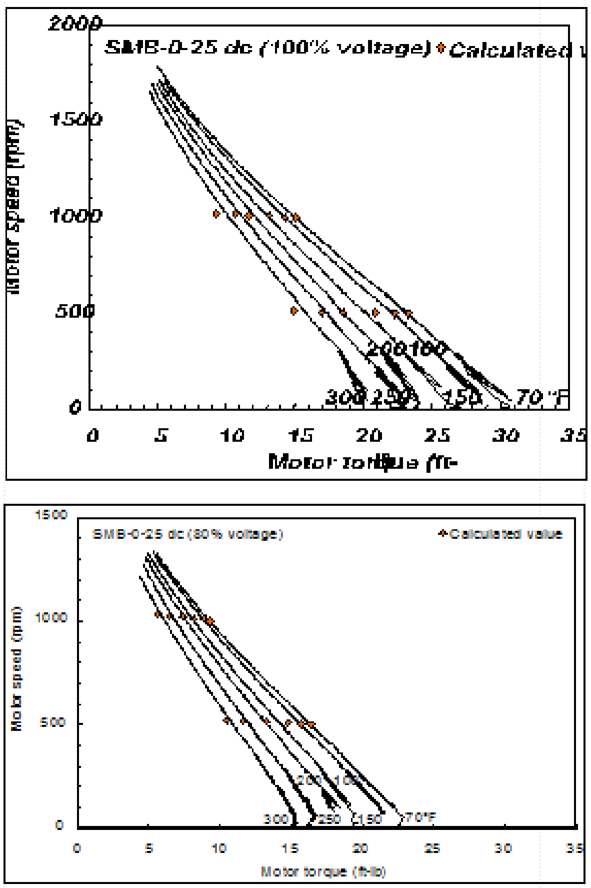

Figure 3-44 Estimated Temperature Results

have arbitrarily selected 500 and 1,000 rpm as the motor speeds for which we perform the analysis. In these data plots, Equation 20 has been applied to the motor torque to estimate the elevated temperature performance. This produces an estimate that is reasonably close to the actual measurements.

Other dc motor concerns

In addition to the issues already discussed in this chapter, a few other concerns related specifically to the operation of dc-powered actuators deserve our brief attention. Because dc motors turn slowly at high loads, operation at high loads is likely to increase the stroke time. This might be a concern for valves that must complete a stroke within a specified time period. Reduced voltage and elevated temperature conditions also reduce the motor speed (increase the stroke time). Motor heating occurs during operation, especially at high loads. Repeated stroking at high loads without time between strokes for the motor to cool could cause motor heating in excess of the temperatures anticipated by the valve evaluation.

3.4.2 Gearbox Performance

The discussion in the previous chapter evaluated the expected performance of our example SMB-0-25 ac actuator, beginning with the rated motor torque at normal conditions (25 ft-lb), multiplied by factors to account for torque reductions at degraded voltage and elevated temperature. The result is an estimate of motor torque at design basis voltage and temperature: an estimate of 14.12 ft-lb. This value represents the input torque to the gearbox. The formula that addresses gearbox performance consists of an efficiency factor to account for losses due to friction in the actuator gearbox, and a multiplier to account for the torque increase associated with the gear reduction in the gearbox. The product of this formula is the estimated output torque of the actuator (that is, the torque applied to the stem nut by the worm gear). Here is the formula:

$$Tq_{actuator} = Tq_{motor} Eff_{gearbox} OAR$$

Equation (3-26)

Where

$Tq_{actuator}$ = output torque of the valve actuator

Tq_{motor} = output torque of the electric motor

$Eff_{gearbox}$ = gearbox efficiency

OAR = overall gear ratio.

For a given actuator gearbox, the actuator manufacturer publishes three values for the gearbox efficiency ($Eff_{gearbox}$). These three values are referred to as the running efficiency, pull-out efficiency, and stall efficiency. The running efficiency represents the gearbox efficiency under normal motor load and speed. The pull-out efficiency applies to high load and low speed. The stall efficiency applies to sudden stall, with motor inertia considerations. The stall efficiency is applicable in addressing valve and actuator overload concerns. Usually, these values are in the range of 0.4 to 0.6, with the pull-out efficiency the lowest and the stall efficiency the highest. The overall gear ratio (*OAR*) in rising-stem MOV actuators is a number larger than one; it accounts for the torque increase produced by the gear reduction in the gearbox. The overall gear ratio is the number of turns on the motor per turn of the stem nut on the stem.

In general, the pull-out efficiency is applicable to evaluations of actuator capability at the loads we are concerned with, that is, the high load the actuator encounters at or near flow isolation while closing against high differential pressure. For the Limitorque SMB-0 actuator gearbox and overall gear ratio in question, the published pull-out efficiency is 0.40. This is the value we use in our estimate for addressing design basis operability of the valve.

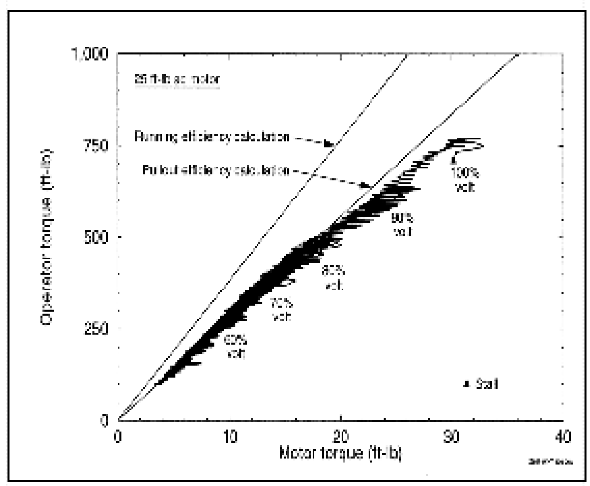

Figure 3-45 Motor Torque vs Operating Torque

running efficiency and (b) the published pull-out efficiency. The slope from the origin (0,0) to any given data point represents the overall gear ratio times the gearbox efficiency for that data point. The figure shows that at higher loads and lower speeds, the gearbox efficiency drops below the published pull-out efficiency.

As a point of interest, Figure 3-46 shows the same kind of data for three tests at normal voltage: one at room temperature and two at elevated temperature. These tests were performed with the same 25-ft-lb motor driving the same SMB-0 gearbox, but with a different set of helical gears, producing an overall gear ratio of 34.96-to-one instead of 69.56-to-one. The gearbox efficiency was clearly higher with the lower gear ratio. In general, our NRC/INEEL test results have shown lower efficiencies with higher loads, lower motor speeds, smaller motors, and higher gear ratios.

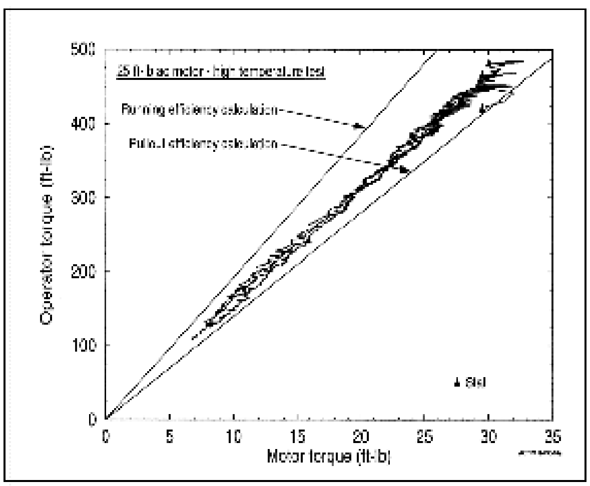

Figure 3-46 Motor Torque vs Operating Torque at Elevated Temperature

The overall gear ratio in our example SMB-0-25 ac actuator is 43.69-to-one (the ratio of the helical gear set is 33:39, and the worm gear ratio is 37:1). Applying the formula given above, the motor torque (14.12 ft-lb) times the gearbox efficiency (0.40) times the overall gear ratio (43.69) equals 246.8 ft-lb. This is an estimate of the torque the valve actuator is capable of delivering to the stem nut, subject to the limitations imposed by the torque switch setting. This is an estimate of the actuator torque at which the motor would stall if the torque switch did not shut off the motor.