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MOTOR-OPERATOR GEARBOX EFFICIENCY

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ABSTRACT

Researchers at the Idaho National Engineering Laboratory recently conducted tests investigating the operating efficiency of the power train (gearbox) in motor-operators typically used in nuclear power plants to power motor-operated valves. Actual efficiency ratios were determined from in-line measurements of electric motor torque (input to the operator gearbox) and valve stem torque (output from the gearbox) while the operators were subjected to gradually increasing loads until the electric motor stalled. The testing included parametric studies under reduced voltage and elevated temperature conditions. As part of the analysis of the results, we compared efficiency values determined from testing to the values published by the operator manufacturer and typically used by the industry in calculations for estimating motor-operator capabilities. The operators we tested under load ran at efficiencies lower than the running efficiency (typically 50%) published by the operator manufacturer.

INTRODUCTION

The Idaho National Engineering Laboratory (INEL) is conducting confirmatory research, sponsored by the U.S. Nuclear Regulatory Commission (NRC), to develop the technical basis for assessing the capability of motor-operated valves (MOVs) to meet the provisions of Generic Letter 89-10, "Safety-Related Motor-Operated Valve Testing and Surveillance." Figure 1 shows the main components of a typical motor-operated gate valve. Several valve manufacturers supply valve assemblies to the utilities, but almost all the operator assemblies are supplied by Limitorque.

There are several factors that can contribute to a gate valve's capability to fulfill its design basis functions, including (a) the magnitude of the differential pressure across the disc, (b) the friction at disc/guide and disc/seat interfaces, (c) the friction at the stem/stem-nut interface, (d) the efficiency of the power train in the operator gearbox, (e) the torque switch setting, (f) the size (torque output) of the operator motor, and (g) the power supply to the operator motor. Over the past ten years the INEL has performed full-scale and separate effects tests to evaluate each of these factors. This paper presents the results of tests conducted to investigate item (d), the efficiency of the power train in the operator gearbox. The paper is written with gate valves in mind, but the results are also applicable to other types of motor-operated valves.

The main drive train components of a motor-operator gearbox are shown in Figure 2. Motor-operator gearbox performance is measured in terms of efficiency. Gearbox efficiency is the ratio of the output torque divided by the product of the input torque times the overall gear ratio. The overall gear ratio is the total gear reduction in the gearbox—the number of motor revolutions required for one revolution of the stem nut. The input torque consists of the torque delivered by the electric motor to the input side of the gearbox, and the output torque consists of the torque delivered to the stem nut (through the worm gear) by the worm. Thus, the calculation of gearbox efficiency accounts for losses to friction at the helical gear set, the worm/spline interface, the worm/worm-gear interface, and the associated bearings. It does not include the motor electrical to mechanical efficiency or the stem-nut to stem efficiency, which are separate calculations.

In the documentation supporting their motor-operators, Limitorque publishes three efficiency factors, referred to as the pullout efficiency, stall efficiency, and running efficiency. The pullout efficiency is the lowest of the three. Limitorque assumes that this value applies when the motor is lugging at very low speed under a load or starting up against a load. The stall efficiency is higher than the others because it includes consideration of motor inertia during a sudden stall; it is typically used in evaluations of possible overload problems. Limitorque uses the running efficiency to estimate the efficiency of the gearbox at normal motor speed and normal loads.

TEST PROGRAM

As part of a larger test program investigating motor-operator performance (Steele et al. 1995), we tested five typical motor-operator configurations and evaluated the efficiency of their gearboxes. The testing was performed with the operators installed in the motor-operated valve load simulator (MOVLS), a test stand owned by the NRC and designed and built by INEL (see Figure 3). Output torque was measured by a calibrated torque arm attached to the valve stem (the reaction torque measured in the valve stem is the same as the torque applied by the stem nut), and input torque was measured by an in-line torque cell attached between the motor and the gearbox. By these means we were able to calculate operator efficiency from continuous measurements of the actual input torque and the actual output torque.

The testing included parametric studies where the motor terminal voltages were varied from 60 to 100 percent for the ac motors and 50 to 100 percent for the dc motor. Elevated temperature tests were performed by heating the motors and in one case, heating the entire gearbox.

Table 1 lists the motor-operators we tested and the published operating efficiencies (running, pull-out, and stall) for these motor-operators, along with other pertinent information. These efficiency values are from published Limitorque engineering data (Limitorque SEL-7, November 1989; Limitorque Technical Update #92-02, October 9, 1992). The running efficiencies of the operators vary between 50 and 60%. These published values indicate that it takes about half the input motor power to overcome losses (primarily friction) in the gearbox.

Table 1 also lists the application factor for each motor-operator. The application factor is a multiplier recommended by the operator manufacturer for use in calculations of operator output and can be thought of as the service factor of the electric motor. It takes into account variations in the motor starting torque at varying voltage levels and various operator speeds and conditions. The application factor also makes allowances for any special application considerations. Limitorque Technical Update #93-03, September 1993, states that the application factor can be set to 1.0 if the motor terminal voltage is less than 90 percent (and the voltage squared calculation is used).

Table 1. Test hardware.

	SMB-00-5ac	SMB-0-25ac	SMB-1-60ac	SMB-1-40ac	SMB-1-40dc
Motor RPM	1800	1800	1800	3600	1900
Motor Gear Set	22/43	25/47 37/35	32/40	37/35	32/40
Overall Ratio	87.8	69.56 34.96	42.50	32.13	42.50
Stall Efficiency	0.50	0.50 0.55	0.50	0.60	0.50
Run Efficiency	0.50	0.50 0.55	0.50	0.60	0.50
Pullout Efficiency	0.40	0.40 0.40	0.40	0.45	0.40
Application Factor	0.90	0.90 0.90	0.90	0.90	0.90

Table 1 shows two different sets of values for the SMB-0-25 operator. The second set is listed for a second configuration (a different set of helical gears) tested by the INEL.

RESULTS

Figure 4 shows the stem torque measured during the 100 percent voltage test of the SMB-1 operator with the 60 ft-lb ac motor. The negative convention for this measurement indicates that the valve was being operated in the closing direction. Note how the stem torque gradually increases in a manner representative of a closure under design basis flow. Figure 5 shows the motor torque measured during the same test. Figure 6 shows the operator efficiency calculation made from the data in Figures 4 and 5; the published running and pullout efficiencies are also shown for comparison. The motor operator efficiency begins at about 0.41 at low load and slowly rises to 0.51 while the operator is still under moderate load. However, the efficiency drops as the load increases, actually dropping below the pullout efficiency at stall.

Figure 7 shows the same information as Figures 4 through 6, but in a slightly different format. Here we have plotted output torque versus input torque during the reduced voltage parametric study. The slope of the data is the gearbox overall ratio times the actual operator efficiency. Figure 7 also shows the results of four calculations using the overall gear ratio times (a) the running efficiency, (b) the running efficiency and application factor, (c) the pullout efficiency, and (d) the pullout efficiency and application factor. For each of the tests, the measured efficiency is near the published running value only at lower loads.

A careful examination of this figure reveals a relationship between efficiency and the speed of the motor operator. In each of the reduced voltage tests the measured efficiency is near the running

efficiency when the motor is near its normal speed, but drops toward the pullout value as the motor approaches stall. In the 60 percent voltage test, the efficiency approaches the pullout value at a motor torque of 22 ft-lb, the 70 percent test at 29 ft-lb, and so on. This indicates that the operator efficiency is related to both operator load and operator speed. For this motor operator, the pullout efficiency seems applicable for all tests up to motor rated torque.

Similar comparisons for the other ac motor operator combinations are presented in Figures 8 through 10. For the SMB-00-5, the motor torque required to spin the gear train without producing output torque (sometimes called the hotel load) is a significant percentage of the total motor torque. This distorts the data to a point where meaningful comparisons cannot be made. Thus, Figure 8 includes a 0.44 ft-lb offset, based on no-load motor torque measurements, to account for the hotel load. This hotel load is not normally considered in calculations for determining operator capabilities.

Figures 8 through 10 show that for each ac motor-operator combination, the published running efficiency does not bound operator performance at higher loads and lower speeds. The two smaller operators exhibited efficiencies lower than the pullout efficiency. The SMB-00-5 and SMB-0-25 motor operators' measured efficiencies are closer to the pullout efficiency times the application factor. Note that the application factor is not intended by the operator manufacturer to provide conservatism to the calculation of operator efficiency. We mention the application factor in our discussion only as a point of reference.

Figure 11 presents the data from testing of the SMB-1-40 dc motor operator. The shape of the curves looks slightly different, due to the speed versus torque relationship of dc motors, but the general trends are similar to those seen in the ac motor operators. The actual operator gearbox efficiency is always lower than the running efficiency. As the motor speed drops under high load, efficiency drops to values representative of the pullout times application factor calculation. Since dc motor speed is linear with motor torque, the traces shown in Figure 11 for the various low voltages are more distinctly separate than in the ac motor tests, clearly showing the relationship between gear speed and operator gearbox efficiency.

Figure 12 shows the results of testing to determine if operator efficiency is affected by elevated temperature. Three tests were performed on the SMB-0-25 motor operator. The first test was a baseline test to show operator efficiency at ambient temperature. The second and third tests were performed with the operator gearbox heated to 350°F. The third test was performed immediately after the second to evaluate repeatability. The second gear ratio shown in Table 1 was used during this test. For this configuration, the measured efficiency was slightly higher than the published pullout efficiency. By comparing this figure to Figure 9, we get an indication of the variation that can occur between different gear sets used in the same operator. Figure 12 shows that the operator efficiency was not affected by elevated temperature.

CONCLUSIONS

These data show that actual efficiencies can differ from those published by the operator manufacturer. For the operators we tested, the only published value that consistently provided a conservative prediction of the actual efficiency over the entire operating range was the pull-out efficiency times the application factor.

The application factor is not intended by the operator manufacturer to provide conservatism to the calculation of operator efficiency. We mention the application factor in our discussion only as a point of reference. We do not recommend that utilities rely on the application factor to compensate for lack of conservatism in the efficiency value they use in their calculations.

Gearbox efficiency is dependent on operator speed as well as torque. Under reduced voltages the measured efficiency near motor stall drops well below the values measured at full voltage for the same motor torque. Here again, the pullout efficiency times the application factor consistently provided a conservative prediction of the actual efficiency.

We found that the operator no-load motor torque, or hotel load, can be significant for smaller motors. Hotel load consumed almost ten percent of the motor rated torque for our SMB-00-5 motor operator. We also found that the operator gearbox efficiency was not affected by elevated temperatures.

REFERENCES

Steele, R. Jr., K. G. DeWall, J. C. Watkins, M. J. Russell, D. L. Bramwell (1995), *Gate Valve and Motor-Operator Research Findings*, NUREG/CR-6100.



Sleeve bearings

Stem nut

Sleeve

Worm gear

Worm shaft spline

Belleville spring pack

MOTOR TORQUE

Worm

Valve stem

SPRING COMPRESSION

STEM THRUST

Torque switch

Helical gear set

Z657-WHT-496-12

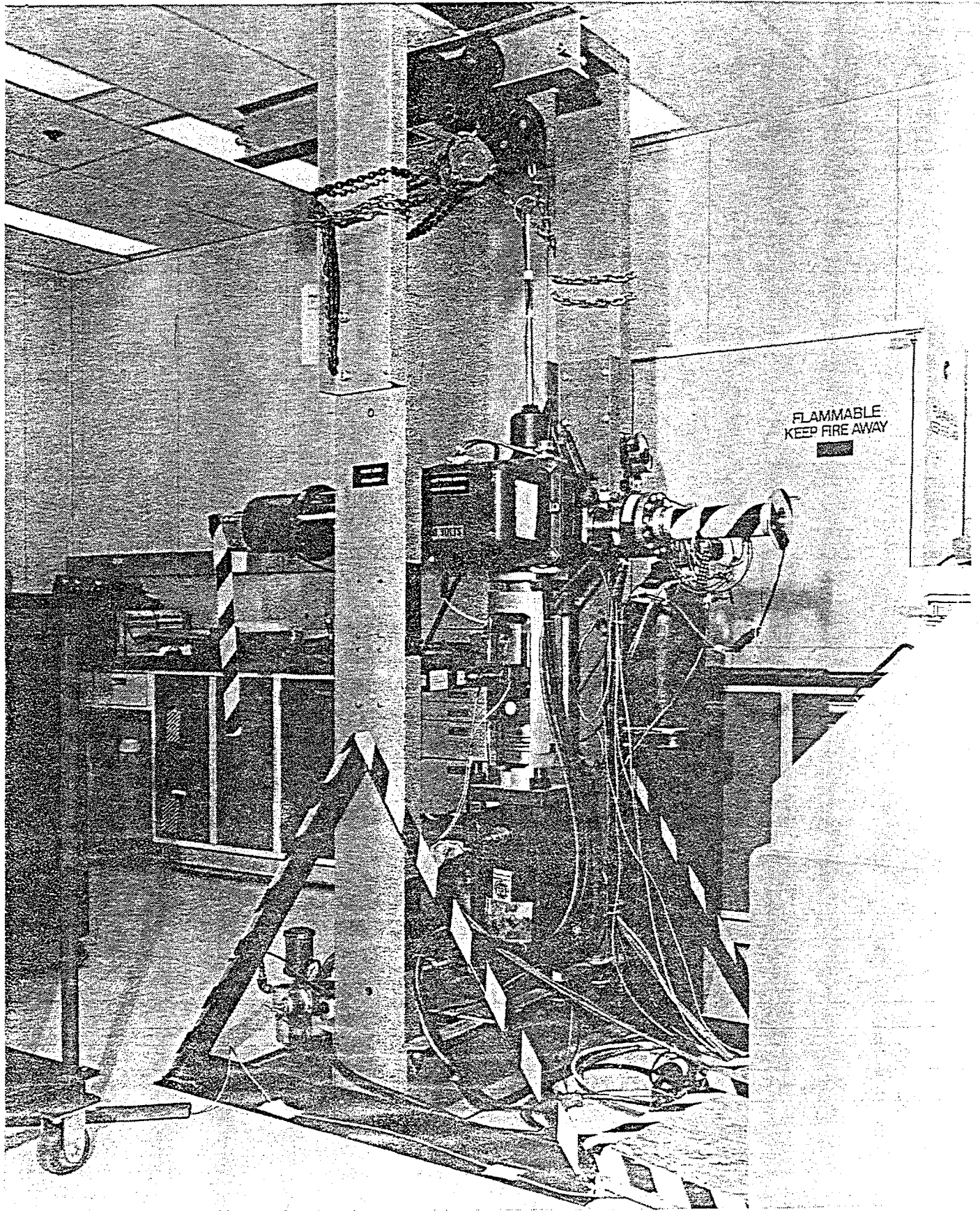


Figure 3. The motor-operated valve load simulator (MOVLS).

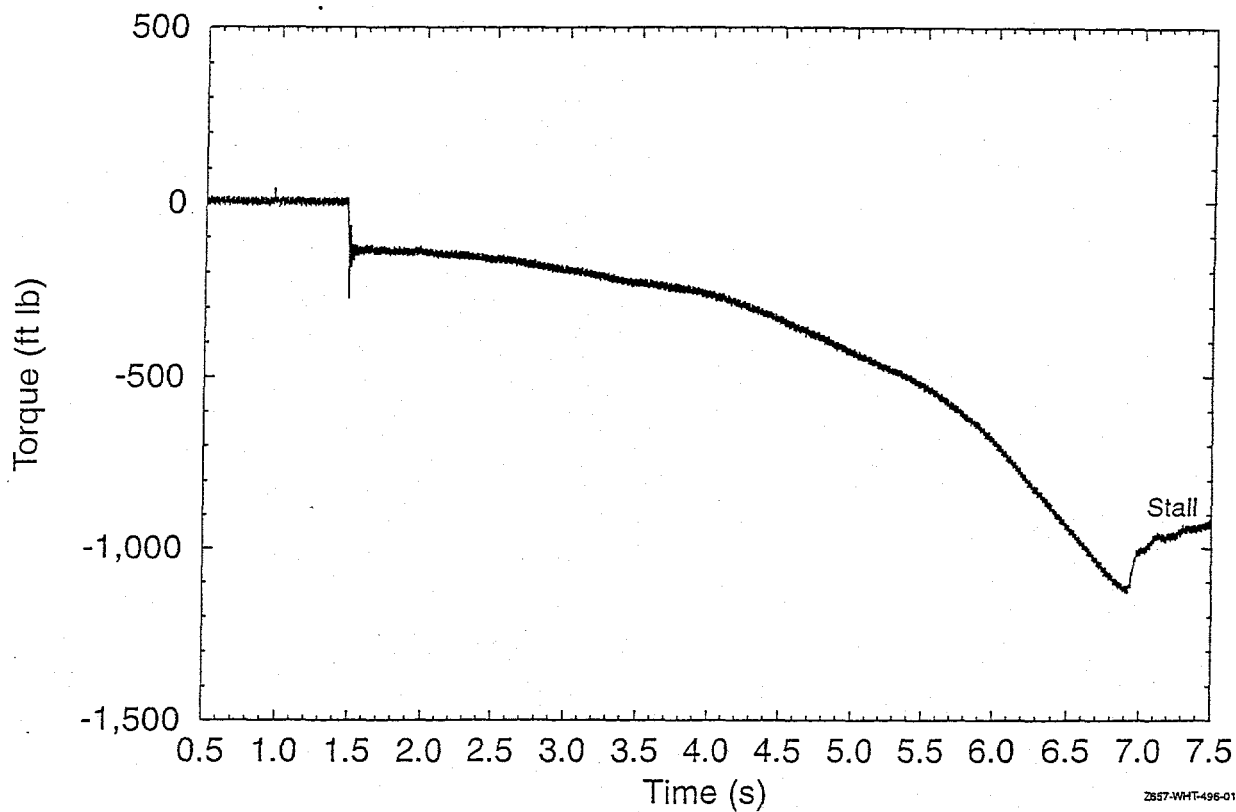


Figure 4. Operator output torque measured during stall testing of the SMB-1-60 ac motor operator.

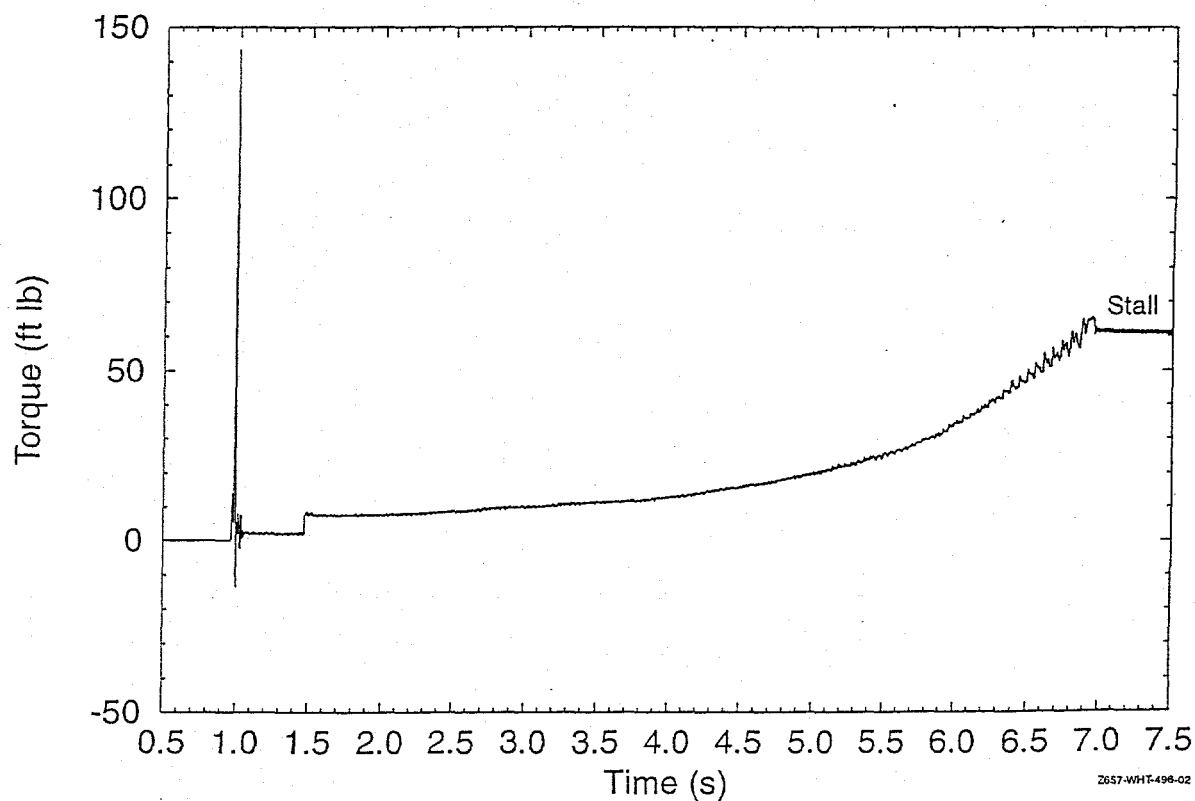


Figure 5. Operator input torque measured during stall testing of the SMB-1-60 ac motor operator.

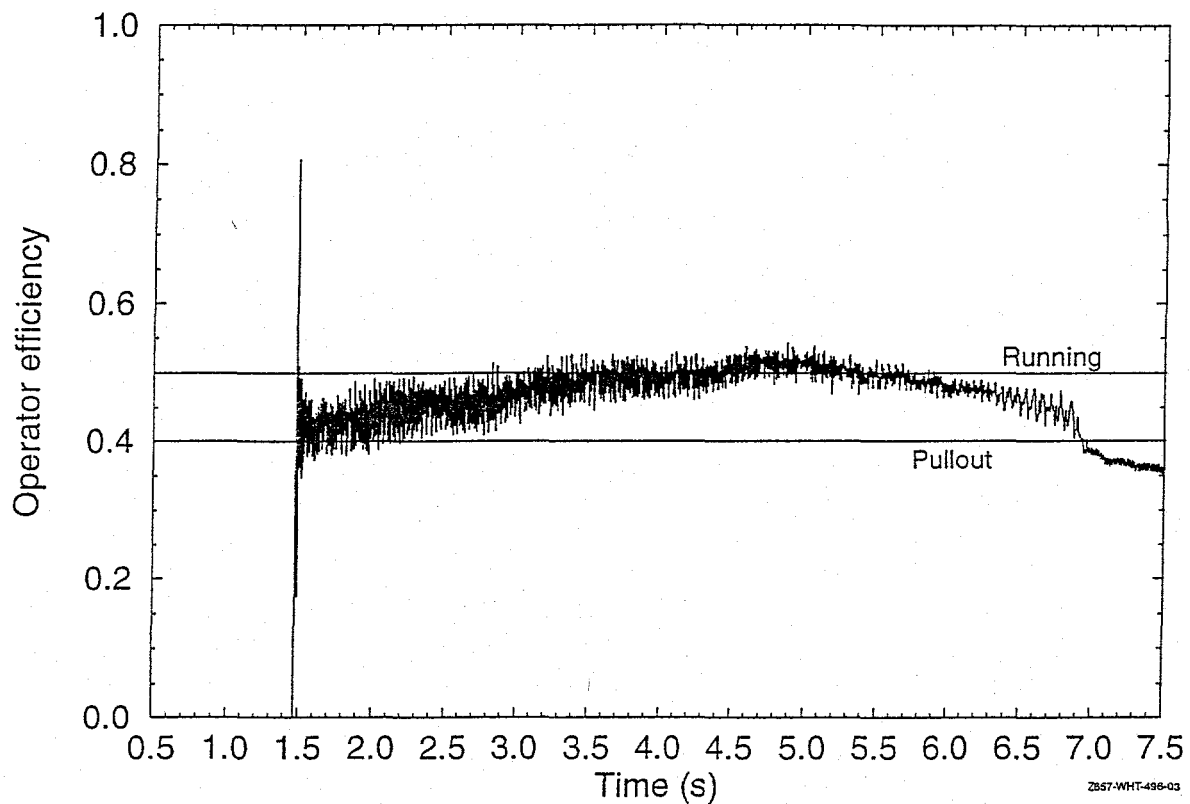


Figure 6. Operator gearbox efficiency measured during stall testing of the SMB-1-60 ac motor operator.

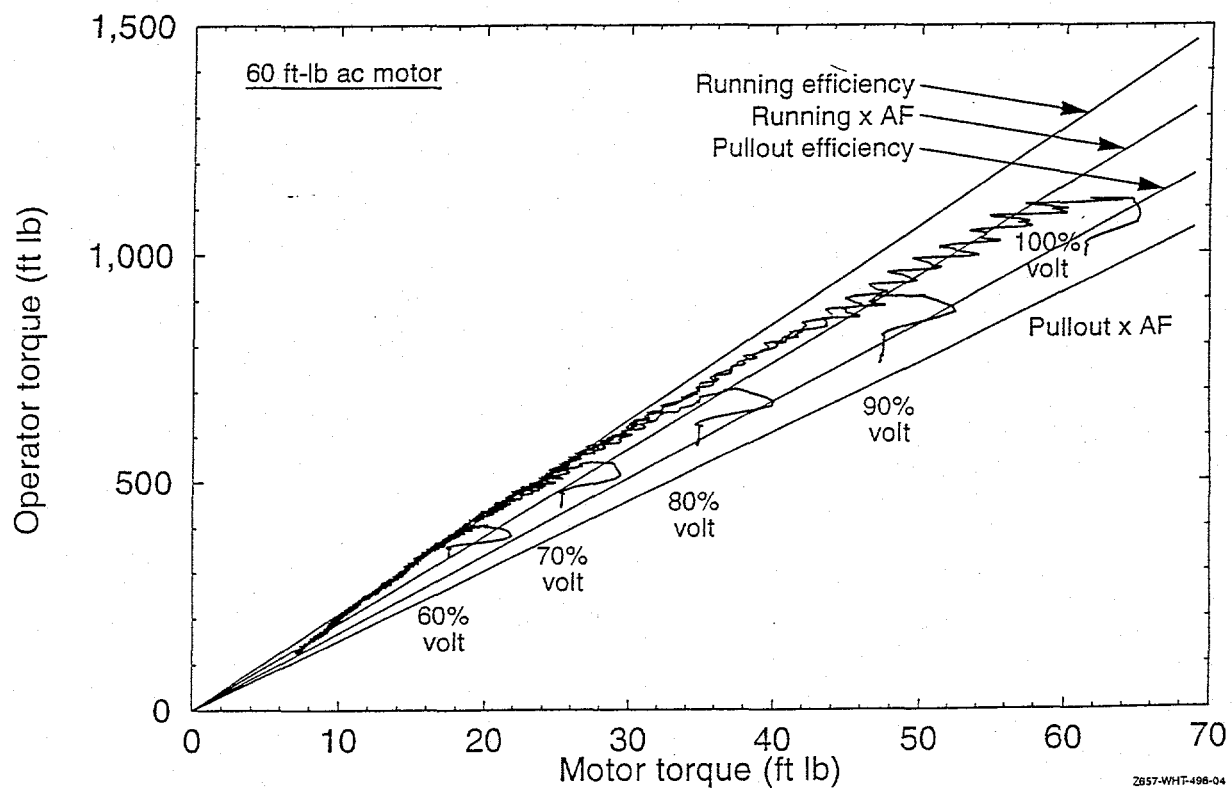


Figure 7. Actual gearbox efficiencies measured during stall testing of the SMB-1-60 ac motor operator.

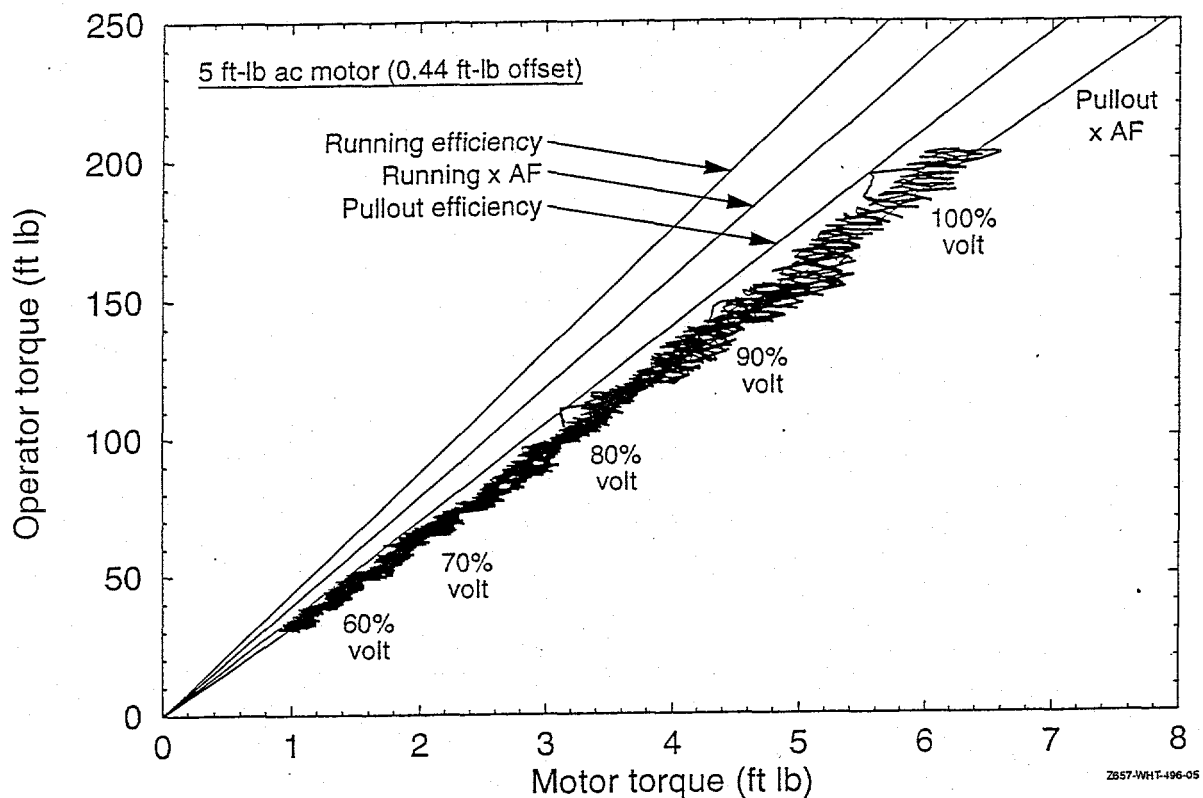


Figure 8. Actual gearbox efficiencies measured during stall testing of the SMB-00-5 ac motor operator.

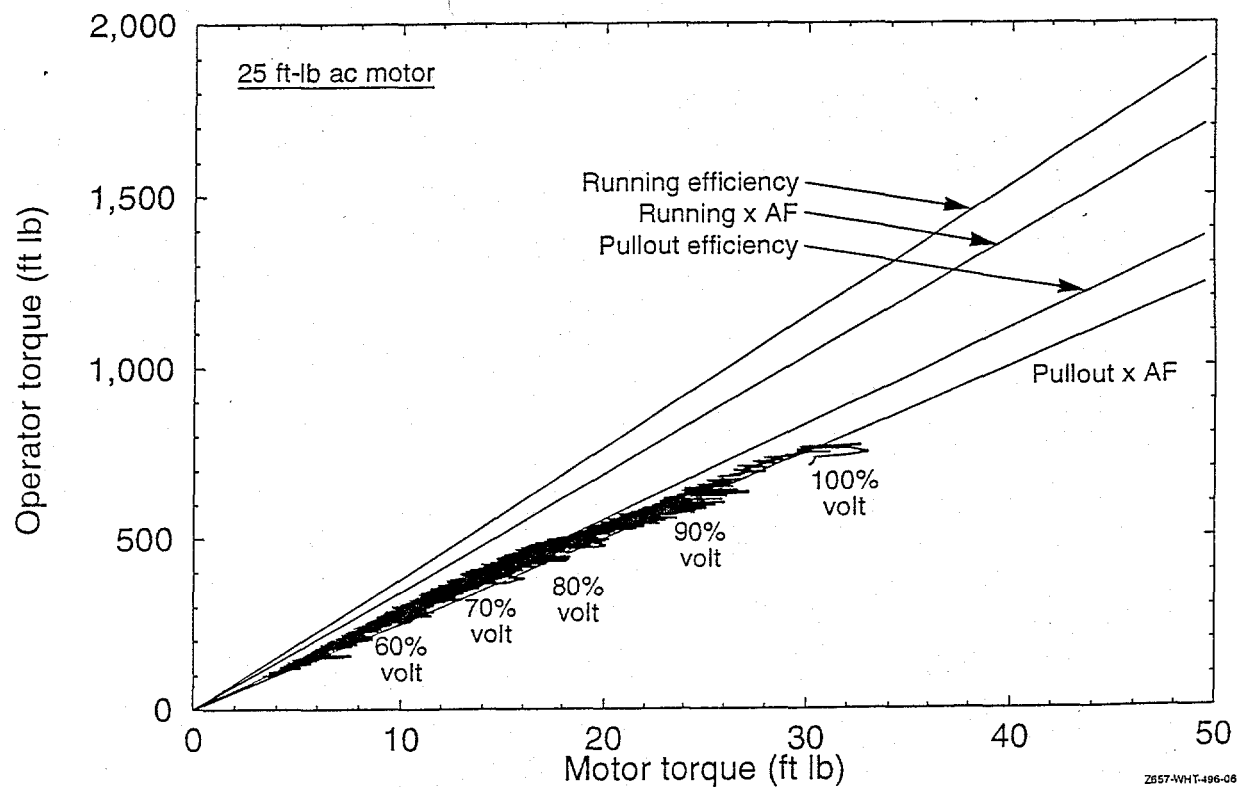


Figure 9. Actual gearbox efficiencies measured during stall testing of the SMB-0-25 ac motor operator.

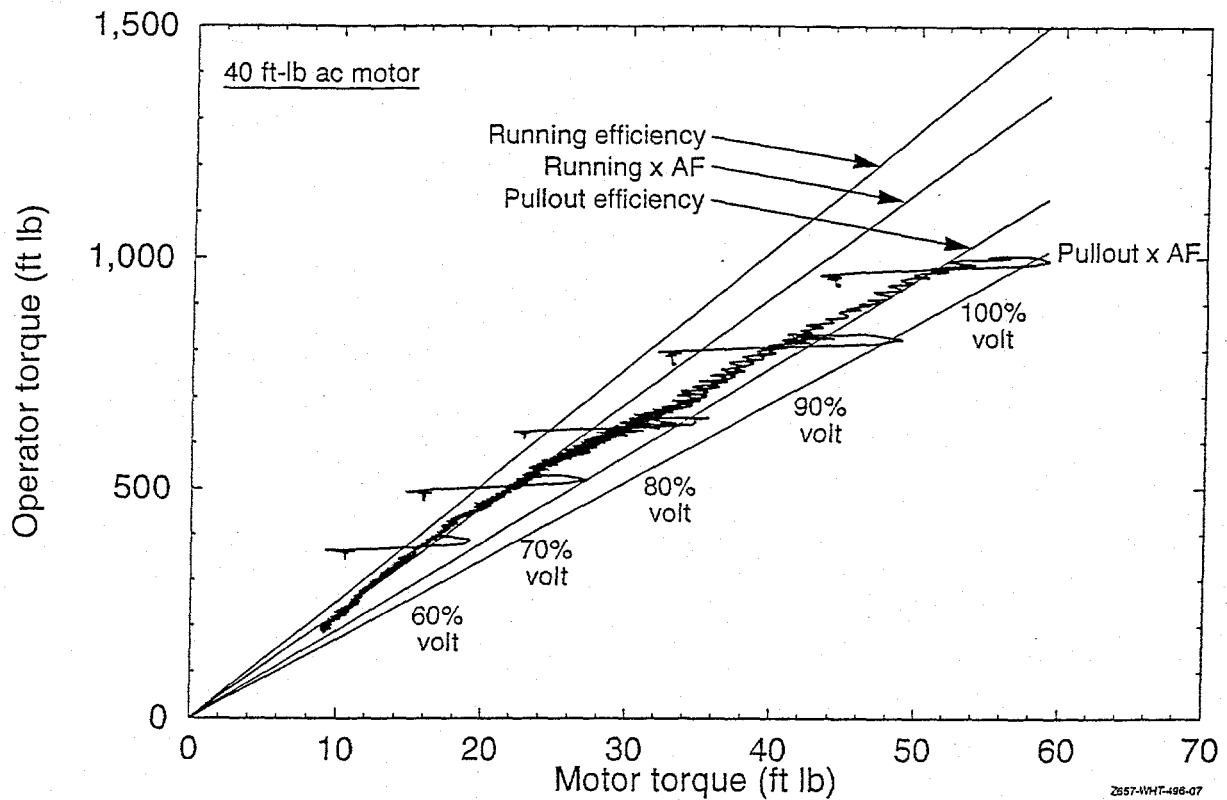


Figure 10. Actual gearbox efficiencies measured during stall testing of the SMB-1-40 ac high speed motor operator.

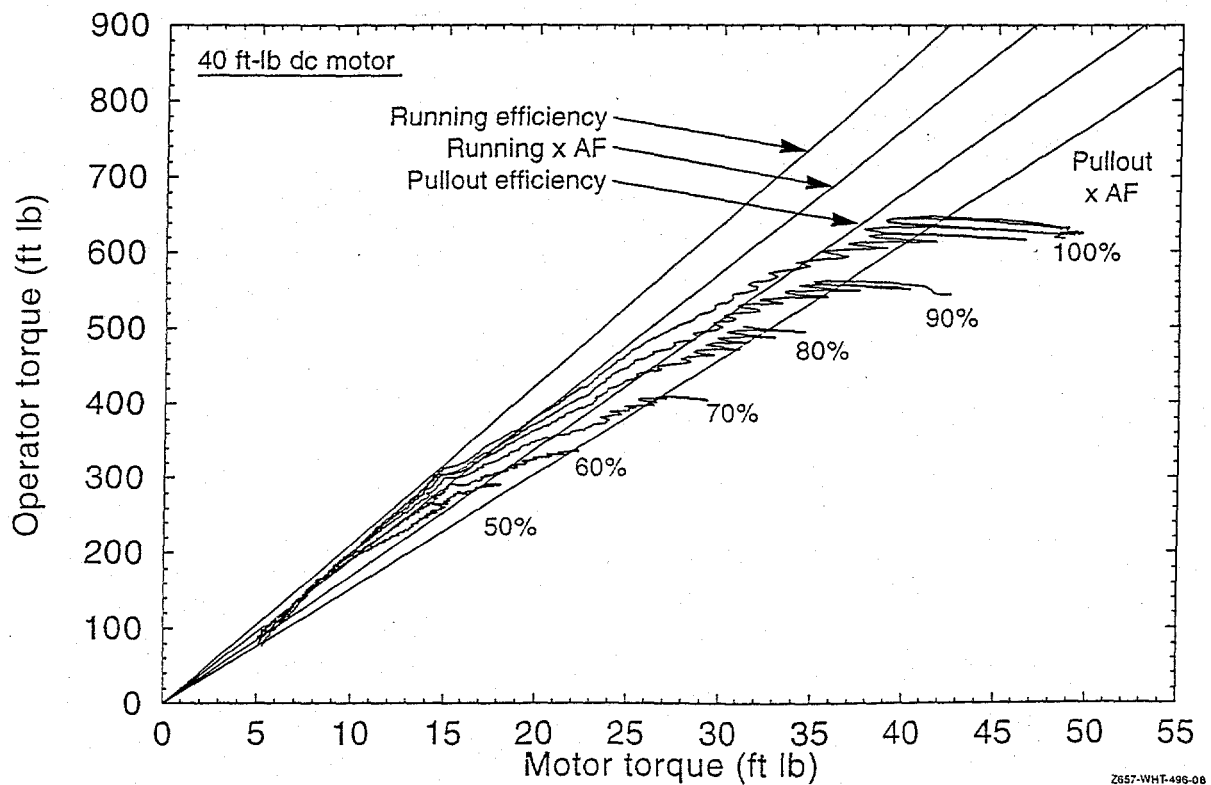


Figure 11. Actual gearbox efficiencies measured during stall testing of the SMB-1-40 dc motor operator.

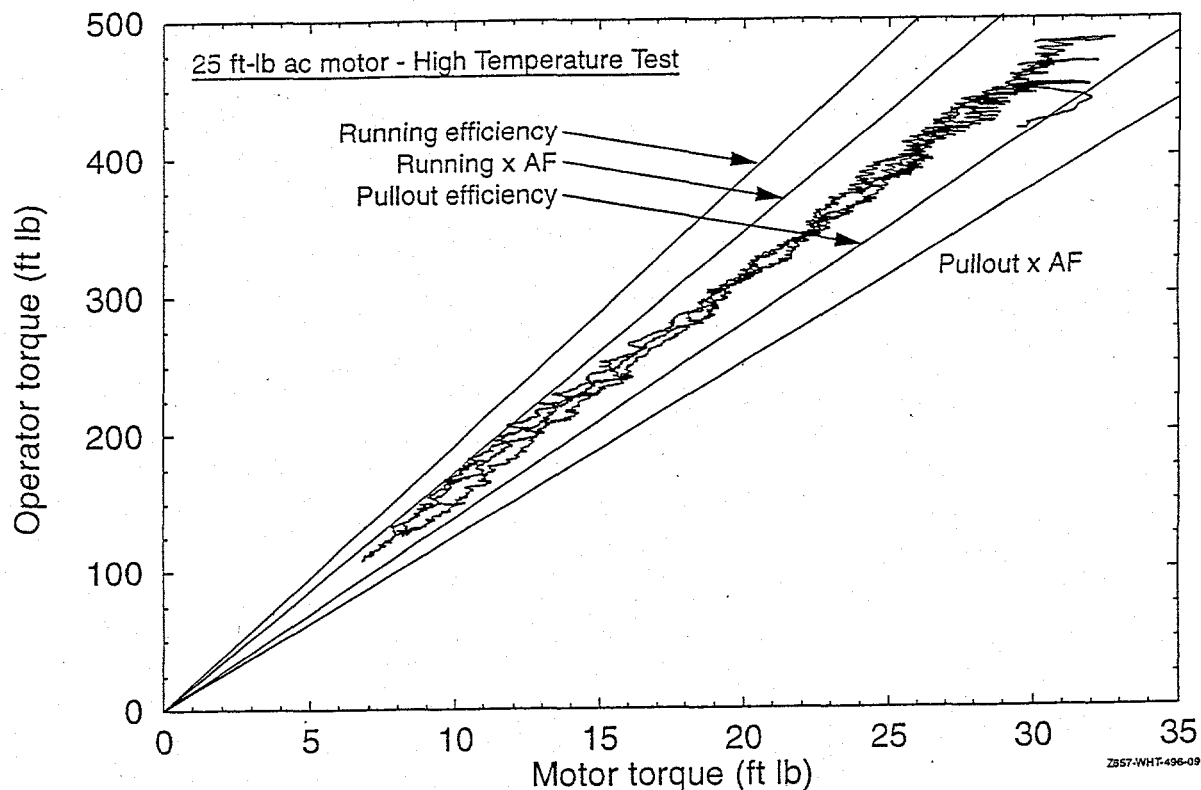


Figure 12. Actual gearbox efficiencies measured during elevated temperature stall testing of the SMB-0-25 ac motor operator.

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