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SUBJECT: Performance Test of 220-v Three-Phase Stator for Use with 5-gpm
In-Pile Loop Pump

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TABLE OF CONTENTSPERFORMANCE TEST OF 220-V THREE-PHASE STATOR
FOR USE WITH 5-GPM IN-PILE LOOP PUMP

By A. Weitzberg and H. C. Savage

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1. SUMMARY

The ORNL 5-gpm canned-rotor pumps have been failing during in-pile operation. While some of these failures are believed to be the result of mechanical drag of the rotating parts, several others are believed to be the result of electrical short circuits in the stator windings. In an attempt to solve this problem, two modifications were proposed. The first was to change from single-phase to three-phase stators, and the second was to use class-H high-temperature insulation instead of the present class-A insulation.

Two experimental three-phase stators were wound and tested with the standard ORNL pump assembly. The results show that pumps with three-phase stators give better hydraulic output, better torque, are more resistant to stalling, and use less power than the present single-phase stator. In addition, the class-H insulation is much more resistant to heat than the class-A insulation now in use.

Based on these reasons, the present single-phase stator with class-A insulation will be replaced with a three-phase stator with class-H insulation to improve the pump performance and to reduce the number of pump failures which may be caused by high-temperature breakdown of the electrical insulation and/or mechanical drag of the rotating parts.

2. INTRODUCTION

The ORNL 5-gpm pump, designed and developed by the Reactor Experimental Engineering Division, is a totally enclosed, canned-rotor centrifugal pump, which has been used in in-pile loops for several years. Some of these pumps failed in service after 700 to 1000 hr of in-pile operation. It was first believed that these failures were mechanical, namely, a locked rotor condition due to binding at the bearings, but further investigation indicated that at least some of the failures were electrical in nature. It is now believed that the pump failures in loops L-2-14, L-2-15, L-4-16, and L-2-17 were due to significant electrical breakdowns in the windings, either coil-to-coil or winding-to-winding short circuits.¹ Pump failures in loops EE and L-4-8 were attributed to mechanical seizure and/or drag of the pump bearings.⁵

A change to three-phase operation was suggested as a possible solution to the problem, since the three-phase pumps do not require the additional start windings and capacitors, and because they usually give a higher torque output with greater efficiency. In addition, a change from class-A to class-H insulation was recommended, since the class-H insulator has a much greater resistance to heat.

The aim of this investigation was to evaluate the suggested modifications of the ORNL pump stator to three-phase windings and class-H insulation.

3. DESCRIPTION OF PUMPS TESTED

3.1 ORNL 5-gpm Pump with Single-Phase Stator

This pump is the standard canned-rotor pump which has been used for in-pile work for the past few years. The rotor is totally enclosed in a stainless steel can and is contained in a stainless steel housing, over which the motor stator is slipped. The specific pump used was a double-bearing model with aluminum oxide bearings and journals, designed for 2000-psi operation.² The stainless steel pump housing can is 0.104 in. thick.

The wiring diagram for the single-phase, capacitor-start motor is shown in Fig. 1. The stator is wound with class-A insulated wire.

3.2 Three-Phase Pump Stator with Class-A Insulation

One of the single-phase stators was rewound for three-phase operation with class-A insulation and was used with an ORNL 5-gpm pump. The pump used was the single-bearing model with a Graphitar No. 14 bearing and chrome-plated journal.³ It is designed for 1000-psi operation, and the stainless steel pump container can is 0.063 in. thick. This pump model is no longer in use in the in-pile loops, but was included in the test program to evaluate the effect of the decreased can thickness on pump and motor performance for information purposes.

The method of winding was arbitrarily chosen so as to give the maximum amount of copper for the space limitations of the stator. The stator coils, connected in a parallel star connection, were wound one-in-hand with 70 turns of AWG No. 21 wire, and were insulated with Formar, a phenolic resin (class A) varnish.

The wiring diagram for this stator, designated as stator A, is shown in Fig. 2.

3.3 Three-Phase Pump Stator with Class-H Insulation

Another of the single-phase stators was rewound for three-phase operation with class-H insulation and was used in conjunction with both the single- and double-bearing ORNL 5-gpm pumps.^{2,3} Due to the added bulk of the wires with the glass-wrapped class-H insulation, it was again necessary to change the wiring design. As in the case of the class-A insulation, the stator was wound with a maximum amount of copper for the space available. The resulting coils were wound one-in-hand with 33 turns of AWG No. 19 wire, and were joined in a series star connection. The insulation was silicone-impregnated glass, mica, and silicone varnish.

The wiring diagram for this stator, designated as stator H, is shown in Fig. 3.

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NOTE: AWG #21 WIRE,
CLASS A,
FORMVAR INSULATION

SWITCH OPERATION

<u>POSITION</u>	<u>OPEN</u>	<u>CLOSED</u>
OFF	1, 2, 3	—
RUN	3	1, 2
START	—	1, 2, 3

Fig. 1. Wiring Diagram for 110v, Single Phase Capacitor Start Stator.

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Fig. 2. Wiring Diagram for 220 V, Three Phase Stator (Stator A)

4. RESULTS

4.1 Pump Characteristics

The different pump assemblies were checked out on the pump test stand, and data were obtained for head, flow, power, speed, current, and stator-winding temperature. In addition, tests were made to determine the effect on pump performance of varying the power supply voltage and frequency.

A summary of the performance tests, head and pump power as a function of flow rate, is shown in Fig. 4. A direct comparison of the results obtained with the present 110-v single-phase stator and the modified 220-v three-phase stator H can be made from curves 4 and 5 and curves 2 and 3, since they were obtained with the same double-bearing pump. At the same rate of flow, the pump with stator H consistently gave several more feet of head than the pump with the single-phase stator. In addition, the power consumption was about 100 watts less at all flow rates for the three-phase stator.

Curve 1 and curves 6 and 7, obtained with the single-bearing pump, show that the pumps with the three-phase stators (designated A and H) gave more head than pumps with the single-phase stator. The power consumption was less for the single-bearing pump than for the double-bearing pump, which is directly attributable to the pump can thickness. The can thickness of the 1000-psi single-bearing pump is ~ 0.040 in. less than that of the 2000-psi double-bearing pump.

The temperature of the windings of the three-phase stators (A and H) was lower than the winding temperature of the present single-phase stator at a given pump output. An approximate stator-winding temperature measurement was obtained by placing a thermocouple as far as possible into the windings at various points until a maximum value was obtained. The results of these tests are given in Table 1. They indicate that the winding temperature varies almost directly with the power consumption, with a 100-w increase in power causing an approximate 10°C rise.

Further tests were conducted to determine the effects of varied voltages and frequencies on the output of the pump with a three-phase 220-v stator. The results are summarized in the appendix. Decreasing the voltage produced only small decreases in pump output but significantly lowered the power consumption and thereby lowered the temperature of the windings. A 20-v drop was accompanied by about a 100-w decrease in power and a 10°C decrease in temperature.

The effect of increased frequency on both stator A and stator H was to increase the pump head by about 6 ft for each 5 cps at any given flow rate.

A check was made on the pump speed vs flow, using a stroboscope and a thrust jig attached to the rotor and projecting through the rear of the pump. With both the class-A and class-H three-phase stators,

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Fig. 4. Comparison of Test Results of ORNL 5 GPM Pumps with Single, Phase and Three Phase Stators

Table 1
Comparison of Winding Temperatures
at Ambient Air Temperature of 40°C

Stator	Pump Model	Voltage	Power (watts) at 5 gpm H ₂ O	Winding Temp. (°C)
single phase	2 bearings	110	1060	125
A	1 bearing	220	560	60
H	1 bearing	200	640	80
H	1 bearing	220	750	90
H	1 bearing	240	860	100
H	2 bearings	160	575	77
H	2 bearings	180	690	83
H	2 bearings	220	950	107
H	2 bearings	240	1090	121

and with both the single- and double-bearing pumps, the pump speed varied from about 3500 to 3400 rpm from shutoff to maximum flow (~ 13.5 gpm). Little difference was noted from one assembly to the other.

4.2 Motor Characteristics

To determine the torque characteristics of the pump motors, they were tested on a Potter and Rayfield dynamometer. Data were obtained on motor speed, torque, and current. In order to perform these tests, the pump was used without the impeller housing and with the pump rotor and bearing cavity filled with a high-temperature oil to insure lubrication of the bearings. The dynamometer tests were made using a single-bearing pump (0.063-in.-thick can) with both stator A and stator H, and a double-bearing pump (0.104-in.-thick can) with stator H and the single-phase stator.

The results of these tests are presented in Fig. 5, which shows the relationships between motor speed, torque, and current. The principal difference between the single-phase and the three-phase motor is that the three-phase motors operate at much higher loads without a tendency to stall. In other words, the three-phase motors are able to operate at lower speeds without stalling.

At any given speed the pumps with stator H put out a little greater torque than the pump with stator A, and also drew a little more current. The effect of changing from the single-bearing pump to the double-bearing pump with stator H was to increase the current per winding by about 0.5 amp. The difference in torque output was negligible. The maximum torques that the motors delivered before stalling were 1.0, 2.8, and 3.5 lb-ft with the single-phase stator, stator A, and stator H, respectively. In the range of speed and torque at which the motors can be compared, the single-phase motor draws from 3 to 4 times as much current as does each individual phase of the three-phase motors.

Locked-rotor tests were made on three-phase motors at 240-v, 60 cycles. For stator H the torque was 5.8 lb-ft and the current per phase was 12.5 amp, while for stator A the torque was 4.2 lb-ft and the current per phase was 10.4 amp. When the rotor was locked with the single-phase 110-v stator, it drew about 35 amps, while the torque was too low and unstable to be measured except when the start windings were energized.

5. DISCUSSION

From the test results, it can be concluded that the pumps with the three-phase stators give satisfactory hydraulic outputs and are, in fact, slightly better in this respect than the pumps now in use. The three-phase pumps also require less power for the greater output. The tests show that the increase in pump can wall thickness (and therefore the size of the motor air gap) from the single-bearing pump to the double-bearing pump did not significantly alter the torque or hydraulic

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Fig. 5. Comparison of Speed, Current, and Torque for ORNL Pumps with Single Phase and Three Phase Stators

outputs. The only consequence was to increase the amount of current drawn and hence the power required.

The three-phase stators operate at slightly lower temperatures than the present single-phase stators. During the tests at rated voltages with the double-bearing pump, stator H ran at 107°C, while the single-phase stator ran at 125°C. Using the single-bearing pump, stator A ran at 60°C and stator H at 90°C. The 125°C stator winding temperature observed with an ambient air temperature of ~ 40°C, of the present single-phase stator is in excess of the recommended hot-spot temperature of 105°C.⁴ At the higher in-pile ambient temperature it is evident that the temperature of the class-A insulation is too high for long-term operation. The class-H insulation, on the other hand, operates at a temperature well below that required for long life, as can be seen in Fig. 6. Figure 6^o gives a rough comparison of the expected life of the different insulation as a function of hot-spot temperature. Based on the data of Fig. 6, even at a temperature of 250°C the class-H insulation would have an expected life of from 2 to 3 years.

The greatly increased torque of the three-phase stators as tested (see Fig. 5) over the present single-phase stator is very desirable. It is evident that a small amount of mechanical drag or friction between the various rotating parts of the pump (bearings, rotor and can, and/or impeller and impeller housing) could result in stalling of the present single-phase pump motor assembly. With its increased torque, on the other hand, the three-phase stator would be more apt to continue operating until "wear-in" of the parts could relieve the situation.

In the event the mechanical drag continued to worsen, limited operation of the pump as required for loop draining and flushing operations would be possible with the three-phase stator under conditions that would prohibit operation of the present pump with the single-phase stator.

6. CONCLUSIONS

The three-phase 220-v stator with class-H insulation gives increased hydraulic output, a higher torque, and is more resistant to stalling than the present single-phase 110-v stator.

These mechanical improvements, along with the increased heat resistance of the class-H insulation as compared to the present class-A insulation, justify a change to the three-phase 220-v stator with class-H insulation. Present plans are to make this change starting with in-pile loop L-2-22.

The increased torque and heat resistance of the three-phase stator should reduce the number of pump failures resulting from mechanical drag of the rotating parts and/or thermal breakdown of the electrical insulation.

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Fig. 6. Thermal Endurance of
Electrical Insulation

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⁵A. R. Olsen, "Examination of In-Pile Loop Pumps from Loops EE and L-4-11," ORNL CF-56-6-135 (June 18, 1956).

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8. APPENDIX

Pump Calibration Curves - Figures 7 through 11

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Fig. 7. Performance Test of ORNL 5 GPM Single Bearing Pump with Three Phase Stator (Stator A)

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Fig. 8. Performance Test of ORNL 5 GPM Double Bearing Pump with
Three Phase Stator (Stator H)

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Fig. 9. Performance Test of ORNL 5 GPM Single Bearing Pump with Three Phase Stator (Stator H)

Fig. 10. Effect of Frequency on Performance of ORNL 5 GPM Double Bearing Pump with Three Phase Stator (Stator H)

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Fig. 11. Effect of Frequency on Performance of ORNL 5 GPM Single Bearing Pump with Three Phase Stator (Stator A)

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