BNL-44436
Informal Report

TEST REPORT: GENERATOR STATOR BAR LEAK QUANTIFICATION AND PINPOINTING

W. M. LOSS and R. N. DIETZ

MARCH 1990

DEPARTMENT OF APPLIED SCIENCE

BROOKHAVEN NATIONAL LABORATORY
UPTON, LONG ISLAND, NEW YORK 11973

BNL--44436

DE90 010017

TEST REPORT: GENERATOR STATOR BAR LEAK QUANTIFICATION AND PINPOINTING

W. M. Loss and R. N. Dietz

March 1990

(Conducted at Union Electric Labadie Station,
Unit No. 4, January 24-25, 1990;
Submitted to Union Electric, St. Louis, MO)

TRACER TECHNOLOGY CENTER
DEPARTMENT OF APPLIED SCIENCE
BROOKHAVEN NATIONAL LABORATORY
UPTON, NY 11973

Under Contract No. DE-AC02-76CH00016 with
the U.S. Department of Energy.

ABSTRACT

Tests to detect generator stator bar leaks were conducted at the Union Electric Labadie Power Plant during a two-day period in January. The stator bar assembly of the unit No. 4 generator was pressurized to 5 psi with nitrogen containing 300 ppm of PMCP (perfluoromethylcyclopentane). The presence of the tracer in the generator shell was discovered with passive samplers that were attached to stator bars on both ends of the assembly. The arrangement allowed the detection of areas of increased concentration necessary for subsequent pinpointing of leaks. Leak pinpointing was achieved by sampling air in these areas of higher concentration with the Dual Trap Analyzer. A second tracer, PMCH (perfluoromethylcyclohexane), contained in a 1-liter cylinder with a known emission rate was used to quantify the leak rates from the stator bar assembly. The average leak rate was determined to be 50 liters/day (about 2 ft^3/day) at a nominal pressure of 100 psi. Investigation of several accessible leaks showed leak rates about 1000 times smaller than the overall leak rate. Hence, none of the leaks in the upper accessible half of the generator shell was the major leak.

1. INTRODUCTION

In 1989, Consolidated Edison approached the Tracer Technology Center (TTC) at Brookhaven National Laboratory to conduct leak tests of a stator bar that had failed the high pot test (due to water leakage) and had been removed from the Ravenswood #1 generator. Hydraulic pressure decay testing at an independent laboratory had failed to detect any leakage points, but subsequent testing with Brookhaven's perfluorocarbon tracers (PFTs) succeeded in verifying and pinpointing a leak. The size of the leak was 1 liter of gas/day (0.04 ft^3/day) at 689.4 kPa (100 psi) and its location was 3.6 cm (1.5 inches) away from the turbine end water box.

The next phase of the Con Ed project - testing of whole stator bar assemblies in situ at Ravenswood - was delayed because the generator manufacturer (General Electric) was concerned about assessing any possible side effects of the PFT gases within their product. When written approval was finally given, the Con Ed unit was already into the re-assembly stage.

Subsequently, GE alerted Brookhaven's Tracer Group to an opportunity to test stator bar windings in situ at the Union Electric's Labadie power plant near St. Louis, Missouri. The major objectives of the test were an evaluation of the PFT technology to 1) quantify the total stator bar system leak rate, 2) localize the regions of the leaks(s), and 3) pinpoint the leaking bar(s).

The tests with the PFT gas were undertaken at the plant during two days in January. The experimental approach was to first quantify the total leak rate and find areas of increased tracer concentration within the generator shell. This was to be done with Brookhaven's passive and active samplers as well as real-time analyzers. After having localized areas of higher concentration, pinpointing and quantification of individual leaks was to be conducted with real-time analyzers.

2. PRELIMINARY TESTS BY PLANT OPERATORS

In summer and fall of 1989 plant personnel measured high flow rates of up to 3 liters/min (170 ft^3/day) at the cooling water vent of generator #4. GE specifications for hydrogen in-leakage range around 0.05 liters of hydrogen/min (2 - 3 ft^3/day) at operating conditions. Although a portion of the flow leaving the vent was assumed to be air from leaking pump seals, concern was raised as to the possibility of substantial hydrogen flow into the cooling water and hence the existence of a leak within the stator bar assembly.

During a maintenance outage in January of 1990 it was planned to gain more information about the potential leak. The upper half of the generator was opened without removing the rotor. The stator windings were drained, purged of water by repeated pressurizations and blow-downs, and dried of any remaining water by applying 27.5 inches Hg of vacuum for about 30 hours. A helium pressure decay test at 90 lbs of pressure resulted in a pressure drop of 15 psi over 64 hours. The equivalent leak rate, normalized to a test pressure of 100 psi, was calculated using the following relationship:

$$V_l = \frac{V_{sys} * (P_2 - P_1)}{P_{atm} * (t_2 - t_1)}$$

where

V_l = Leak Rate

V_{sys} = Total Volume of Stator Bar Conduits

P = Pressure, at time 2 or 1 or atmospheric pressure

t = time

According to this equation a pressure change of 1 atmosphere (about 15 psi) in any system amounts to a change in gas content equivalent to the system volume. Assuming a system volume of about 300 liters (10 ft^3) it follows that a pressure drop of 15 psi during the helium pressure decay test was caused by a loss of helium equivalent to the system volume, namely 300 liters. As the test lasted over 64 hours (about 2.5 days) a loss rate of 120 liters/day (4 ft^3/day) was experienced at 80 psi average internal pressure. Normalized to 100 psi internal pressure the leak rate would have amounted to about 150 liters/day (roughly 5 ft^3/day).

Normalization of leak rates to a "common denominator", namely an operating pressure of 100 psi has the advantage that results from different experiments can be readily compared.

A second test with helium was directed toward identifying the major leakage area in order to separate the more serious exciter end or water inlet leaks from leaks occurring at the water outlet or turbine end. That test was accomplished by inserting a He leak detector into the generator shell at both ends. Helium was found at the turbine end but not the exciter end; the magnitude of the difference in leak rates could not be determined with this detector.

The stator bars were then evacuated and filled with SF_6. A pressure decay test with SF_6 led to a (normalized) leak rate of 100 liters/day (about 3 ft^3/day), a value somewhat smaller than the helium leak of 150 liters/day.

In addition to specifying the total leak rate, leak pinpointing was attempted with a hand-held halogen leak detector. Since only the top bars were conveniently accessible, leak pinpointing was limited to this part of the generator. In that upper half of the generator 5 leaks were discovered at the turbine end and 3 leaks at the exciter end. The relative magnitude of the leaks was assumed to be "small" to "medium" according to the audible signals and the settings of the halogen detector. The relevance of these instrument settings will be discussed in the chapter on conclusions.

3. PERFLUOROCARBON TESTS

3.1 Tagging

After completion of the SF_6 tests, the stator bar windings were evacuated for several hours. PFT tagging of the stator bar assembly was accomplished by introducing nitrogen containing 300 ppm of the perfluorocarbon gas PMCP (perfluoro-methylcyclopentane). Because of the high leak rate indicated by the pressure decay tests it was assumed that a low pressure of 5 psi would be sufficient to create easily-detectable concentration levels in the generator shell. Hence, a pressure of 5 psi was maintained in the stator bar assembly throughout the test.

In order to quantify the stator bar leaks, a known "simulated leak" in the form of a gas cylinder containing 1 ppm of another tracer (PMCH, perfluoro-methylcyclohexane) was inserted into the generator shell. The flow rate from this source was carefully adjusted (measured with a bubble flow meter) to an average value of 2.28 ml/min. Since in any enclosure, at steady state, the concentration of gases must be proportional to their source rates it also follows that the ratio of the concentrations must be proportional to the ratio of the source rates. Thus, measuring the two concentrations and knowing the one source rate reveals the magnitude of the other source rate. In the case of the present experiment, determination of the PMCP and PMCH concentrations and knowledge of the "simulated" PMCH leak rate enabled the calculation of the leak rate of PMCP, the gas with which the stators were filled. Clearly, the procedure allowed the direct determination of the total stator bar leak(s) within the generator shell.

3.2 Sampling

3.2.1 Phase 1 - Leak Rate Quantification and Approximate Localizing of Leaks:

Sampling was conducted in two phases. During the first phase the generator shell was separated from the surrounding atmosphere by closing both ends with plastic sheets. The leaking PMCP and PMCH gas could accumulate in the enclosure for a period of about 16 hours. This approach allowed not only the accurate determination of average concentrations and their ratios necessary for exact leak rate quantification but also the spotting of concentration peaks for pinpointing. Active and passive samplers and the Dual Trap Analyzer were employed during this phase, each one to suit different objectives. Equipment and test objectives will be outlined in the following paragraphs.

3.2.1.1. Active Samplers.

An active sampler unit pulled air from inside the generator shell to get information regarding the rate of concentration build-up over time. Active samplers draw air at a known rate through tubes filled with an adsorptive material. There are over twenty such tubes in one unit and the time of exposure of each of the tubes can be preprogrammed.

In addition to obtaining concentration vs. time correlations the active sampler was used during the early, non-steady state stage of the experiment for an exact differentiation of the major leakage areas at a time when concentration uniformity was not yet established. The idea was to switch the unit from the turbine end to the exciter end and let it sample into two or more sequential tubes in order to quantify the tracer concentration as a function of time at the two opposite ends of the generator.

Following this reasoning the unit was transferred from the turbine end to the exciter end about 1 hour after the start of the experiment. It was discovered that the PMCP concentration at the turbine end was 1350 times larger than at the exciter end. (73.97 pL/L at turbine end vs.0.0557 pL/L at the exciter end). Consequently, the leak at the turbine end was over 1000 times larger than the leaks occurring at the exciter end.

The time required for the PMCP tracer to first be detected was also ascertained by the active sampler. A 30-minute sample collected before the stator bar system was tagged with PMCP showed no tracer as expected. The next sample tube ran for about 10 min after the bars were tagged; a small amount (0.34 pL/L) of PMCP was detected. The next 15-min sample gave 29.4 pL/L. Thus, breakthrough of tracer occurred in less than 15 minutes after tagging.

3.2.1.2 Passive samplers

Passive samplers are little glass vials with embedded adsorptive material. The passive samplers were attached to every third bar on the upper, accessible half of the generator, both on the turbine and exciter end (see Figure 1). The results of the sampler analysis in the laboratory allowed the calculation of the average PMCP/PMCH concentration ratios and hence the determination of the leak rate (knowing the PMCH source rate). Particularly pertinent were the concentrations at the end with lower and more uniform readings (the exciter end, Figure 1). On the opposite turbine end, the end with the major leak, peak values were indicative of "hot spots" around which pinpointing was to be intensified.

The average concentration of the samplers on the exciter end - the end with only minor leaks and hence greater concentration uniformity - led to the calculation of normalized leak rates ranging between 40 and 60 liters/day (about 2 ft^3/day, see Figure 1 and Table 1). Normalized

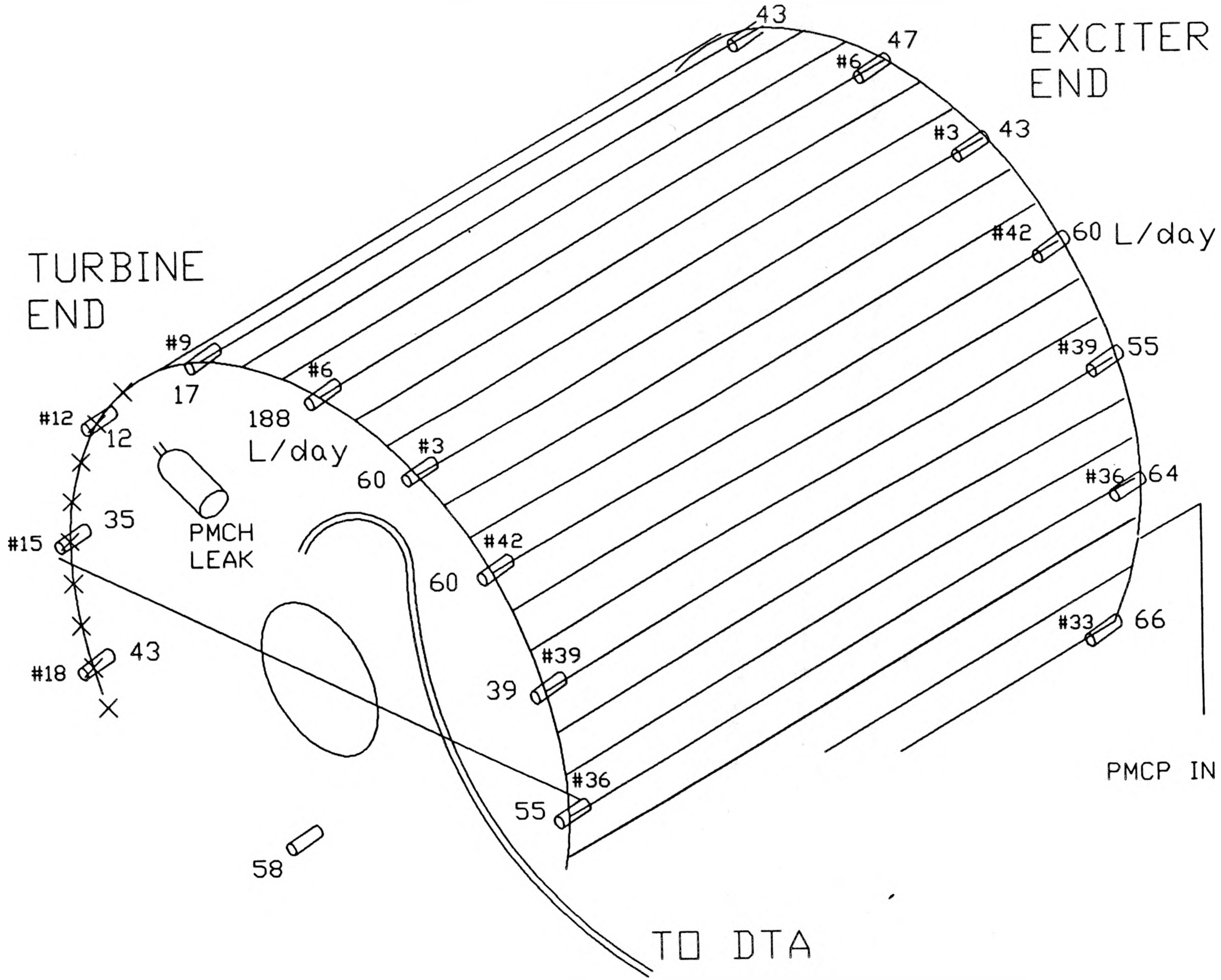

Figure 1: Experimental Setup

Table 1

PASSIVE SAMPLER MEASUREMENTS

	CONCENTRATIONS				LEAKRATES			
POS	PMCP PL/L	PMCH PL/L	PMCH - BCKGD PL/L	RATIO PMCP/PMCH	ml/min 5 psi	l/day 5 psi	l/day 100 psi	
TURBINE END								
18	84.2	0.4332	0.4292	196	1.49	2.15	43	
15	80.26	0.5051	0.5011	160	1.22	1.75	35	
12	92.13	1.7174	1.7134	54	0.41	0.59	12	*
9	93.36	1.2391	1.2351	76	0.57	0.83	17	*
6	505.4	0.5931	0.5891	858	6.52	9.39	188	
3	145.28	0.5368	0.5328	273	2.07	2.98	60	
42	237.82	0.8693	0.8653	275	2.09	3.01	60	
39	215.28	1.2046	1.2006	179	1.36	1.96	39	
36	163.58	0.6586	0.6546	250	1.90	2.73	55	
BOT	118.66	0.4544	0.4504	263	2.00	2.88	58	
						Average **	50 +/- 11	
EXCITER END								
18	16.05	0.0881	0.0841	191	1.45	2.09	42	
15	14.70	0.0810	0.077	191	1.45	2.09	42	
12	15.97	0.0866	0.0826	193	1.47	2.12	42	
9	17.99	0.0951	0.0911	197	1.50	2.16	43	
6	19.47	0.0944	0.0904	215	1.64	2.36	47	
3	20.13	0.1064	0.1024	197	1.49	2.15	43	
42	27.33	0.1036	0.0996	274	2.09	3.00	60	
39	25.66	0.1057	0.1017	252	1.92	2.76	55	
36	26.75	0.0958	0.0918	291	2.21	3.19	64	
33	29.07	0.1007	0.0967	301	2.28	3.29	66	
						Average	50 +/- 10	

* Positions 12 and 9 at turbine end excluded from average (biased by proximity to PMCH source)

** Average without position 6

again means that the working pressure inside the stator bars was theoretically increased to 100 psi.

As shown in Table 1, the average normalized total stator bar system leak rate at 100 psi was 50 +/- 10 liters/day, as determined at the exciter end, essentially identical to the average found at the turbine end of 50 +/- 11 liters/day (excluding positions 12, 9 and 6). Comparison of these values with the higher SF_6 and helium pressure decay results (100 - 150 liters/day) made the assumption imperative that additional leaks outside the generator shell must have occurred during the decay tests.

With regard to the turbine end, another interesting finding and verification of theoretical considerations was the analysis result of the passive sampler attached to bar number 6 close to the top at the turbine end (Figure 1, Table 1). Its PMCP/PMCH concentration ratio yielded an integrated leak rate of 188 liters/day, a value almost 4 times higher than the average rate of 50 liters/day. The halogen leak detector pinpointing had identified <u>two</u> leaks on that particular bar not too far from the passive sampler which may have biased the result high. It is also interesting to note that the apparent leak rates of bar # 9 and # 12 are markedly lower than the average. The reason for this deviation from the average is the close proximity of the PMCH source to these bars and hence the smaller than average PMCP/PMCH concentration ratio.

3.2.1.3. Dual Trap Analyzer (DTA):

The Dual Trap Analyzer is a portable sample concentrator gas chromatograph with an electron capture detector. The instrument is able to collect samples and analyze perfluorocarbon concentrations as low as 60 - 100 femtoliters per liter (10^{-15} liters of PFT/ liter of air). The results are graphically portrayed on a strip chart recorder with a total sampling and analysis cycle time of about 5 minutes.

Although the major application of the DTA was reserved for the second phase (pinpointing, see below), concentration measurements with the DTA at the site portended the later active sampler result obtained after laboratory analysis. Very early during the experiments a concentration ratio of turbine versus exciter end of greater than 500 was measured, a result that compared favorably to the active sampler ratio of about 1000 (see 3.2.1.1).

3.2.2. Phase 2 - Quantification of Individual Leak Rates

During the second phase of the experiments the plastic covers were removed from the generator. The leaks previously identified by pinpointing with the halogen detector were now further investigated as to their exact leak rate. Most of these leaks did occur close to the interface between insulation and teflon hoses. Quantification was accomplished by sampling air at the points of egress with a 4 inch diameter funnel attached to the Dual Trap Analyzer inlet hose. This arrangement guaranteed that the area around the leaks could be thoroughly covered.

As shown in Table 2, all the leaks were at least 1000 times smaller than the overall leak rate of 40 to 60 liter/day calculated from the average concentration measurements with the passive samplers (see 3.2.1.2). It was inferred, therefore, that none of these leaks was the major leak.

Table 2
Rates of Pinpointed Leaks
(L/day, normalized to 100 psi)

Bar	Rate, L/day
8	0.0031
6[a]	0.0298
2	0.0012

[a] Total of 2 leaks on bar # 6

4. CONCLUSIONS

4.1 Turbine versus Exciter End Leak Location

The leak rate at the turbine or water outlet end was 1330 times larger than the one at the exciter end. Leaks at the water outlet end are of less concern because no more cooling is required at this point.

4.2 Delay Time to On-set of Leak Detection

The programmable sampler operating at the turbine end showed that a measurable signal from the leak was attained in less then 10 minutes from first pressurizing the bar with tracer. Thus, at these leak rates, the time needed to detect the presence of a leak was just several minutes. Smaller leaks would require a proportionately longer measurement time.

4.3 Overall Leak Rates of Pressure Decay Method Versus PFT Method

The leak rate within the generator shell of 40 - 60 liters/day as determined by the PFT method was only half of the SF_6 pressure decay leak rate of 100 liters/day. This discrepancy gives rise to the assumption that some of the leaks during the pressure decay test did occur in connections and fittings leading to and from the generator shell.

4.4 Magnitude of Individual Leak Rates

Quantification of previously identified turbine end leak locations by direct "sniffing" with the Dual Trap Analyzer gave leak rates ranging from 0.001 to 0.030 liters/day, more than one thousand-fold smaller than the overall total leak rate of about 50 liters/day. Consequently, none of the leaks investigated during the pinpointing stage was the major leak.

4.5 Accuracy of hand held Halogen Detector

Depending on the rate of air movement at the site of the leak, the concentrations around leaks might build up to substantial levels and easily mislead the instrument to indicate a large leak, where in reality only a small emission rate (flow per unit time) might exist. Hence, the settings small, medium and large on the instrument are meaningful only within the preprogrammed limitations, but these limiting conditions, like wind speed and temperature might never be met in the real world.

5. RECOMMENDATIONS

Although the PFT technology was able to quantify the magnitude of the total stator bar leakage and demonstrate that the major point of egress of the leak was at the turbine end, pinpointing of that major point of egress was not possible because of limited access to the bars. Future leak detection of in situ stator bars using tracers should be done with the rotor removed. This would enable unique identification of the major leaking component.