DISSOLVED GAS-IN-OIL ANALYSIS TO ASSESS THE HEALTH OF THE LANSCE HIGH VOLTAGE SYSTEMS *

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Abstract

The LANSCE linac RF system consists of four 201.25 MHz RF stations that supply RF power to the drift tube linac(DTL), and forty-four 805 MHz RF stations, that supply RF power to the coupled-cavity linac(CCL). There are four large high voltage power supplies for the DTL RF systems. Seven high voltage power supplies provide the power for the 805 MHz klystrons. All power supplies consist of a transformer / rectifier (TR), Inductrol Voltage Regulator (IVR) and a capacitor bank with crowbar protection. The TR units step up and rectify 4160 VAC into 90 kV DC. The IVR units regulate the voltage 33% above and below the nominal voltage of 4160 VAC. After 39 years of operation, some components are approaching the end of life and will be refurbished through the Los Alamos Neutron Science Center Refurbishment (LANSCE-R) project to ensure the reliability of the machine until 2025. An analysis of the oil in the high voltage power supply units was performed to assess their health to determine if units need to be replaced or repaired as part of LANSCE-R. Since 1998 the oil in each unit has been sampled and tested annually, and reprocessed when required. Gas-in-oil data for these units from 1998 to present was analyzed. The levels of each gas component and the significance of the each dissolved gas are discussed. The health of the units is assessed and a plan is developed to maintain the reliability of the units through 2025.

INTRODUCTION

The LANSCE-R project will provide an opportunity to replace or rebuild five of the eleven TRs and IVRs. The project will span over five outages and one unit of each type can be taken off line, replaced with the spare during each outage, and rebuilt during the following run cycle. The dissolved gas-in-oil analysis can be used to predict failures in the oil filled units and thus prevent an *in situ* failure resulting in a greater down time to the accelerator and a very costly repair. This gas-in-oil analysis is the bases for the development of the maintenance plan to ensure the reliability of the units through 2025.

BACKGROUND

The design life of transformers is 25-30 years. Due to major growth in the transformer population in the 1940-1950s, a significant percentage of the transformer population is now aged beyond the design life. A statistical technique was used to make a life assessment on transformers based on a derived insulation age[1]. A Weibull probability analysis was performed to predict the performance of aged 33/11 kV transformers based on the derived insulation age. After an age of 30 years, the failure probability significantly increases. Since the LANSCE accelerator has been in operation for approximately 39 years, a significant portion of the TR and IVR units are well past the design life and will have an increased probability of failure.

Transformer failure is usually due to the mechanical failure of the paper insulating material. Mechanical failures of the paper account for 85% of transformer failures, and the remaining 15% is due to infant mortality (defects, transportation and installation), sudden dielectric failure and fault conditions [2]. The mechanical strength of paper is measured by the tensile strength. The tensile strength is directly related to the Degree of Polymerization (DP). Paper is weakened by four conditions: Heat, oxygen, moisture (water) and oxidation products. Operating oil temperatures 8 °C above the design temperature (i.e, 95 °C at the top of oil and 110 °C at hot spots) will cut the life of the paper in half. Paper with low oxygen (approximately 300 ppm) will have 10 times the life time of paper with high oxygen (approximately 3000 ppm). Roughly doubling the percentage of moisture will decrease the life by 50%. Acidity in the oil above 0.05 mg/KOH/g oil from oxidation decay products significantly reduces the strength and the life of the paper [2]. The life of the paper, thus the transformer, is maximized by monitoring and controlling the temperature, oxygen level, moisture and oxidation products.

GAS-IN-OIL ANALYSIS

Dissolved Gas Limits and Data Interpretation

The amount of dissolved gasses are compared the IEEE Standard C57.104 – 1991 Revision Draft, as listed in Table 1. This standard is used in this analysis since it is the most accepted standard in the US for units of this type and is internationally recognized. This standard was released in 1991 and then withdrawn because of differences in opinion regarding the limit of acetylene. The current draft lowered the limit of acetylene from 35 ppm to 1 ppm.

Gasses above the IEEE limit can be an indication of arcing, paper degradation, corona, thermal heating. Hydrogen gas is produced form the corona effect on oil and cellulose. Methane and ethane are produced from low temperature thermal heating of oil. Methane, ethane, ethylene, and hydrogen are produced from high temperature thermal heating of oil. Acetylene is

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produced only at the very high temperatures that occur in the presence of an arc. Carbon dioxide is produced from low temperature thermal degradation of cellulose products or a leak. Carbon monoxide is produced from high temperature degradation of cellulose products [3].

Moisture content is another important factor that can be used to evaluate the units. If the moisture content is high, the degradation of the paper products is significantly increased. The oil can be processed to reduce the moisture content as long as the percentage moisture is less than 5%.

Furans are the by product of paper degradation and the furan levels indicate the amount of paper decomposition. The percent life remaining of the paper insulation can be calculated from the furan levels and the DP. The acid test and interfacial tension tests indicate of the amount of oil oxidation.

Table 1: IEEE Limits for Gases and the Interpretation of the Gas (Standard C57.104 – 1991 Revision Draft).

Gas	IEEE Limit (ppm)	Interpretation
Hydrogen (H_2)	100	Arcing, Corona
Methane (CH_4)	120	Sparking
Ethane (C_2H_6)	65	Local Overheating
Ethylene (C_2H_4)	50	Severe Overheating
Acetylene (C_2H_2)	1	Electrical Arcing
Carbon Monoxide (CO)	350	Severe Overheating
Carbon Dioxide (CO_2)	2500	Severe Overheating
Total Dissolved Combustible Gas	720	Severe Decomposition

Quantitative Gas Analysis Methodology

Three methods were used to compare the gases to obtain a relative health score for each unit. The first step, common to all three methods was to categorize amount of each gas on each unit into three categories. The first category contains acceptable gas levels. The second category is for gas levels that are approaching a concern limit. The third category is unacceptable gas limits. The second step is to assign a score to each unit to make a relative health comparison. Three methods were used to calculate this score.

In Method 1, gasses in the unacceptable category were assigned 1 point. Gasses in the concern category were assigned ½ point and gasses in the acceptable level were assigned 0 points. A total score is obtained for each unit by summing the individual scores of the gasses on each unit.

For Method 2, the gases formed only at high temperatures were weighted in the score. Ethylene, acetylene and carbon monoxide were given 2 points and the remaining gasses were scored as in Method 1.

In both Method 1 and Method 2 after calculating the relative health score, the units were categorised by the score for each unit. The score was divided into four levels and each level was assigned a color to differentiate them: Green – acceptable, Yellow – Slightly above the limit, Red – Significantly above limit, Purple – extremely above the limit

In Method 3 the score was obtained by the ratio of the gas concentration to the IEEE gas concentration limit. If the number was greater than 5 it was assigned a purple label. If it was between 7 and 4, it was assigned a red label. If it was between 4 and 1, it was assigned a yellow label.

For all three methods the final results are color labels that represents the relative health of the unit.

Qualitative Gas Analysis Methodology

The Key Gas Analysis method, a qualitative method, was used as a qualitative method to interpret the test data [2]. The logic flow chart for the method is show in Figure 1.

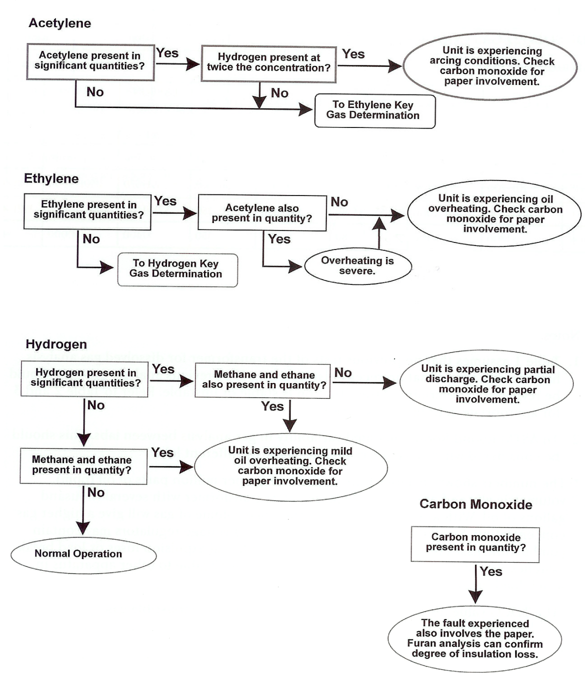

Figure 1: Flow Chart for the Key Gas Analysis [2].

Analysis Results

The quantitative and qualitative analytical summary is shown in Table 2 for the IVRs and Table 3 for the TRs. The first column lists the unit location. The next three columns illustrate results of the three methods used to evaluate the health of units from the dissolved gas levels. The forth column lists the percent moisture content by dry weight along with the moisture grade, with A being the best and F the worst. The fifth column lists the qualitative analysis conclusion.

Table 2: Summary of the IVR Analysis.

	Gas Meth. 1	Gas Meth. 2	Gas Meth. 3	% Moisture / Grade	Qualitative Analysis
Mod 1				0 / A	paper involvement
Mod 2				0 / A	Overheating (300° C), paper involvement
Mod 3				0 / A	Overheating (300° C), paper involvement
Mod 4				4.2 / F	paper involvement
Sec B				0 / A	Overheating (300° C), paper involvement
Sec C				0 / A	Overheating (300° C), paper involvement
Sec D				0 / A	Overheating (300° C), paper involvement
Sec E				0 / A	Overheating (300° C)
Sec F				0 / A	Overheating (300° C)
Sec G				0 / A	Overheating (300° C)
Sec H				0 / A	no concern

Table 3: Summary of the Transformer Analysis

	Gas Meth. 1	Gas Meth. 2	Gas Meth. 3	% Moisture / Grade	Qualitative Analysis
Mod 1 Tran				3.54 / D	no concern
Mod 1 Rec				2.11 / C	no concern
Mod 2				5.27 / F	Paper involvement
Mod 3				0.91 / A	Overheating (300° C), paper involvement
Mod 4				0.54 / A	Paper involvement
Sec B				1.05 / A	Overheating (300° C), paper involvement
Sec C				0.85 / A	Paper involvement
Sec D				1.53 / A	Overheating (300° C), paper involvement
Sec E				0.5 / A	Overheating (300° C)
Sec F				0.64 / A	Arcing, temps > 700 °C.
Sec G				0.83 / A	paper involvement
Sec H				0 / A	no concern

Discussion

Since the furans are removed by oil processing and the units are processed regularly, the furan levels do not represent of the total furans produced by the unit or the percent of life remaining so they were not listed in the table. The acid test and interfacial tension test results for all units are all acceptable so the values are not listed. The oil operating temperature is very low compared to the design temperature in all the units.

The oil was sampled at a low temperature. Since the solubility of water in oil is low at low temperatures, a low moisture reading at a low oil temperature can have wetter oil than a high moisture reading at a high temperature. Thus, the oil may contain more water than the moisture readings reflect. It is important to reduce the moisture in units with high moisture to reduce the accelerated ageing of the paper.

Both the qualitative and quantitative analysis show that some units have elevated gas levels. It is difficult to determine if the elevated gas levels are from a previous problem or an existing problem. To determine this all units with elevated gas levels are being processed to develop a baseline. The units will be tested again immediately after processing and then again in six months. This data will be used to see which units have current problems and the rate of gas generation can be calculated.

Conclusion

The following plan is being implemented based on the gas-in-oil analysis. Oil leaks on the units were fixed to minimize the oxygen. An on line dehydration unit is being purchased to reduce the moisture in units with high moisture readings. All units with high gas levels are being processed to establish a baseline for future trending. The gas generation rate will be calculated and then an analysis on all units will be performed. Methods such as the Rogers Ratio, the Duval Triangle and the Dornenberg Ratio Method can be used to evaluate units with elevated gas levels. This analysis will be used to determine and prioritize which units should be rebuilt during the LANSCE-R project to ensure the reliability through 2025.

REFERENCES

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