APPLYING STATOR END-WINDING VIBRATION MONITORING TECHNOLOGY AT J.H. CAMPBELL GENERATION PLANT

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ABSTRACT

Movement of stator windings has been clearly linked to erosion of semi-conductive layer, abrasion of insulation and packing, increased partial discharges and ultimately generator failure. It is widely known that the coils and end-windings are subject to strong electromagnetic forces at twice the synchronous frequency. The end-windings experience significant vibration as a result of these forces, which eventually lead to a weakened blocking and bracing system, insulation cracks, cooling leaks and potentially short-circuits.

In recent years, fiber optic accelerometers have been developed to monitor end-winding vibration since this is the only type of accelerometer that can be safely coupled to the end-windings themselves. This paper describes the application of end-winding vibration monitoring at J.H. Campbell Plant in Michigan, USA. Preliminary data from this on-going project is presented.

INTRODUCTION

J.H. Campbell Generating Plant is located in Western Michigan, USA, adjacent to Lake Michigan. The plant, owned by Consumers Energy, has three (3) coal-fired generators. Unit 1 of Westinghouse design has one boiler, two turbines, two generators (rated at 156 MVA each) and was commissioned in 1962. Unit 2 also of Westinghouse design is rated at 492 MVA and was commissioned in 1967. Unit 3, a 1025 MVA generator of GE design, was commissioned in 1980.

Over the past decade, Campbell plant engineers had experienced increasing dissatisfaction with the lack of information about the generator-related vibration of their machines. The engineers eventually decided they required an independent generator end-winding vibration monitoring system installed in order to collect data about the vibration behavior of the generators under different operating conditions. With such information, the plant engineers would be capable of gathering sufficient information required to discuss with the manufacturers about their machine quality and to enforce warranty-repair, if necessary.

A major outage was scheduled for Unit 3 in 2000. Such major outages are only scheduled by Consumers Energy once every 10 years so the Campbell engineers wished to take advantage of new generator end-winding technology available from VibroSystM. In particular, Campbell engineers were interested in installing the FOA-100 fiber optic accelerometer.

In 2001, a major outage was scheduled for the two generators of Unit 1. Again, the plant engineers elected to take the opportunity to install FOA-100 fiber optic accelerometers for direct end-winding measurement.

BRIEF DESCRIPTION OF ACCELEROMETER FOR END-WINDING VIBRATION

The overhang portion on either end of large turbogenerators is particularly susceptible to radial vibration induced by electromagnetic forces occurring at twice the synchronous frequency. The FOA-100 fiber optic accelerometer was designed to permit safe direct measurement of the vibration amplitude of these components. Neither the head of the FOA-100 accelerometer nor its integral fiber optic cable contains any conductive elements. This permits the accelerometer to be safely coupled directly to the high voltage end-windings thereby ensuring uninterrupted generator operation and safety of personnel.

The accelerometer operates on a method of light reflection from a mirror mounted at the end of a cantilever beam inside the accelerometer head. The rate of change in the intensity of deflected light detected by the optoelectronics of the integral feedthrough/signal conditioner is deciphered to determine the proportional acceleration. The output of the FOA-100 signal conditioner is 100 mV/g, a standard for general purpose accelerometers. Therefore, this accelerometer is fully compatible with any common vibration analyzer or on-line vibration monitor.

FIGURE 1 – Unibody FOA-100 Fiber Optic Accelerometer with ceramic sensor head, 10-m optical cable, and sealed feedthrough connector with built-in optoelectronic conditioner.

SAFETY ISSUES RELATED TO USE OF END-WINDING VIBRATION ACCELEROMETERS

In certain countries, it has been popular to use piezoelectric accelerometers to monitor the end-winding vibration. However, due to the conductive nature and construction of such sensors, there are personnel and machine safety issues related to installing such equipment on high-voltage, 18-kV generators and particularly if such conductive devices were to be installed directly upon the end-winding themselves. Therefore, use of piezoelectric accelerometers has generally been limited to indirect monitoring of the end-winding vibration by actually monitoring the motion of the brackets and support structures of the end-windings. This method, although shown to be useful in the past, is not as effective a measure of true end-winding vibration as having the accelerometer head firmly coupled to the end-winding itself. Additionally, certain installations of piezoelectric accelerometers have shown a high failure rate over the long-term possibly due to the harsh operating environment inside the turbogenerator.

These are a few of the reasons Campbell Plant opted to use FOA-100 fiber optic accelerometers for end-winding vibration. Another was that GE had performed extensive in-house testing of the FOA-100 and had successful experiences using it at other plants. 100% non-conductive sensors ensure greater safety of personnel and reduce the risk of phase-to-ground short circuits.

INSTALLATION

Campbell engineers decided to install a total of 12 x FOA-100 on each generator, six (6) per end, to monitor the radial vibration. Generally, the sensors were mounted upon the high-voltage coils with one or two relocated to ensure a good distribution of sensors around the circumference of the stator-core. To date, accelerometers have only been mounted on Units 1 and 3, although Unit 2 is scheduled for a similar installation at the next available outage.

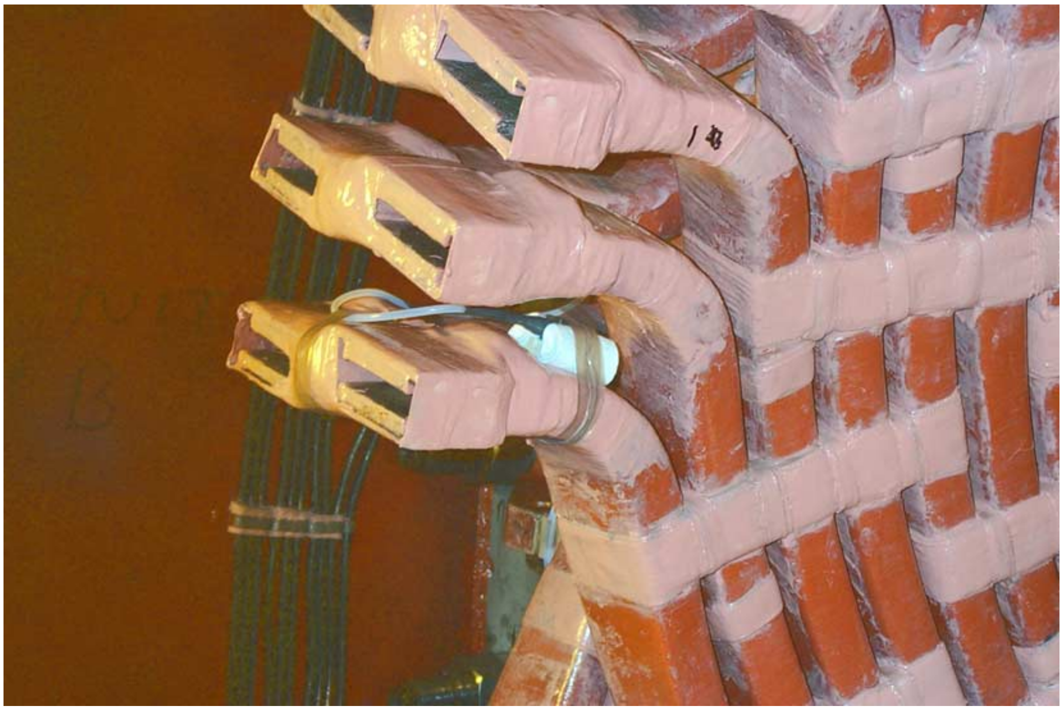

FIGURE 2 – Sensor head and optical cable temporarily secured to the end-winding

Major considerations for installing FOA-100 accelerometers are maintaining fiber optic cable bending radius, ensuring a hydrogen sealed flange for safe signal exit and establishing a rigid coupling between the end-winding and accelerometer. The minimum bending radius of 3.15-inch of the fibre optic cable must be respected since the fiber optic cable would otherwise be damaged and jeopardize the accuracy of the readings. A special metallic flange had been manufactured to permit the routing of the fiber optic cable through the generator casing [see FIGURE 3] and permit the safe transfer of vibration signals from the hydrogen environment (explosion-risk zone) to the ambient air (safe-zone). This flange permits the easy connection of portable vibration analyzers from the safe-zone without risking a leak in the generator cover. Finally, special care must be taken during the installation of the accelerometer to minimize any dampening of the motion of the end-windings. These considerations include ensuring the installation of the FOA-100 in the correct sensitive axis and verifying the epoxy & taping between the FOA-100 and the end-winding [see FIGURE 4].

FIGURE 3 – Sealed flange welded on the generator casing with feedthrough connectors ready to connect. When external instrumentation is not connected, a sealed plate is placed over the opening to provide additional security

FIGURE 4 – Final installation of the sensor head and optical cable with same impregnated material used to brace the end-windings

PRELIMINARY DATA AND COMMENTARY

The levels of vibration collected are shown in TABLES I through IV.

Turbine End		Exciter End	
Bar of Slot	**Vibration (mil pk-pk)**	**Bar of Slot**	**Vibration (mil pk-pk)**
35	4.3	35	2.3
23	3.3	23	2.4
11	4.8	11	2
29	6.7	29	2.8
5	3.3	5	2.9
17	4	17	1.7

TABLE I – End-winding vibration of Generator 1A at 120 Hz (October 2001)

Turbine End		Exciter End	
Bar of Slot	**Vibration (mil pk-pk)**	**Bar of Slot**	**Vibration (mil pk-pk)**
35	3.3	35	3.7
23	4.5	23	3.1
11	4.9	11	5.1
29	4.1	29	7
5	3.3	5	7.1
17	4.1	17	3.4

TABLE II – End-winding vibration of Generator 1B at 120 Hz (October 2001)

No industry consensus on acceptable end-winding vibration levels exists primarily due to the wide variety of end-winding bracing systems. The manufacturer advised acceptable levels for this machine design are in the range of 6 to 8 mil. Since all the Campbell Unit 1 data fall below these levels, the plant engineers have a certain level of comfort with the condition of the end-windings.

For Unit 1 generators A & B [TABLE I & II], vibration readings have not changed much over time under full load conditions and seem to be relatively stable. From the plant engineers' perspective, one of the main goals was to access the information about variation of vibration with respect to changes in operating condition. This would permit users to optimize the machine operation without risking the destructive effects of high end-winding vibration.

An interesting observation not reflected in the data shown is that windings showing relatively low vibration (< 3 mils) see no change in vibration levels with increased hot gas temperature; on the other hand, windings showing relatively high vibration (3 to 7.5 mils) will have vibration levels reduced by as much as 2 mils with an 8 ºC increase of gas temperature. This surprised both Consumers Energy and VibroSystM.

The preliminary explanation of the sensor manufacturer and the user is that the 'tight' windings are less affected by temperature change since these windings are already well-braced. On the other hand, the 'looser' windings actually decrease in vibration with increased gas temperature since the resulting coil expansion reduces clearances between the end-winding and bracing system, thus reducing vibration levels. Further observation of load/temperature/vibration relationships will be required before this theory can be confirmed. In any case, it would be premature to conclude, based only on preliminary data, that running at high temperatures for extended periods will actually reduce end-winding vibration since other destructive factors arise which would cancel out this benefit.

Unit 3 also shows similarly stable vibration readings as can be seen by comparing data taken 3-months apart in TABLES III & IV.

Turbine End		Exciter End	
Bar of Slot	**Vibration (mil pk-pk)**	**Bar of Slot**	**Vibration (mil pk-pk)**
16	2.2	28	3.3
48	0.5	44	4.9
35	0.9	9	2.8
19	2.5	25	0.7
3	2.5	41	1.0
32	N/A	12	2.8

TABLE III – End-winding 120 Hz vibration of Generator 3, full load (taken May 4, 2001)

Turbine End		Exciter End	
Bar of Slot	**Vibration (mil pk-pk)**	**Bar of Slot**	**Vibration (mil pk-pk)**
16	2.1	28	3.2
48	0.5	44	4.9
35	0.8	9	2.6
19	2.5	25	0.7
3	2.6	41	1.0
32	N/A	12	2.8

TABLE IV – End-winding 120 Hz vibration of Generator 3, full load (taken July 24, 2001)

The sensor on the end-winding of slot 32 was not functioning and the cause of this could not be verified. Vibration on all end-windings is quite low and well-below the 6-8 mils range previously recommended. Over the 3 month period, the vibration levels show excellent stability. Neither corrective action nor further inspection is required at this time. Nevertheless, vibration information will become even more important as the machine approaches the end of its 10-year operation cycle.

CONCLUSION

Collection of end-winding vibration data at J.H. Campbell Plant is still in its early stages. Data has shown the behavior of the end-windings is at acceptable levels for Units 1 and 3, which have remained stable so far. By equipping their generators with FOA-100 accelerometers, the Campbell engineers now have a means of acquiring on-line end-winding vibration data and can judge the impact of different operating conditions upon this type of vibration. Clearly, should these levels start trending upwards, closer inspection of the end-winding shall be required.

Additionally, innovative in-slot bar vibration sensors have been installed at Campbell Plant. However, this data has been judged too preliminary to present at this time. These sensors are installed upon the same coils as the end-winding accelerometers. Once data has been collected and verified, Campbell plant engineers shall have excellent information about stator coil vibration, both in-slot and at the end-windings, that will permit them to optimize the generator operation without increasing risk of generator failure. This shall be the topic of a future paper.

REFERENCES

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