Experience with PDA Diagnostic Testing on Hydraulic Generators

By J.f. Lyles, G.C. Stone, and M. Kurtz, Ontario Hydro, Canada From IEEE Transactions on Energy Conversion, Vol. 3, No. 4, December 1988 Pages (824–832)

ABSTRACT: This paper describes the capability of the PDA test [1.2,9] to distinguish between the various operative mechanisms of Stator winding insulation deterioration (if any). The ability to distinguish between the various mechanisms yields significant benefits in scheduling priorities for inspection, repairs, and possible locations of deterioration. The application of this partial discharge test to Ontario Hydro Generator Maintenance has been discussed briefly in Reference [3]. Two Normalized Quantity Number (NQN) [4,5] charts are presented; one for polyester and epoxy Stator insulations systems, and one for asphaltmica and mica foliwn Stator insulation systems. Their stated insulation damage relationships are based on Ontario Hydro's operating experience over the past 15 years.

KEYWORDS

Stator winding Insulation, partial discharge, deterioration mechanisms.

INTRODUCTION

Ontario Hydro's Partial Discharge Analyzer (PDA) diagnostic insulation test has been in existence for the past 10-15 years. The present PDA diagnostic test was developed with partial funding by the Canadian Electrical Association. This paper presents the capability of the PDA to distinguish between insulation deterioration mechanisms (if present) and presents a method which can be used for long-term stator winding condition monitoring.

I. IDENTIFICATION OF DETERIORATION MECHANISMS

*(a) Semi-Conducting Coating/Slot Discharge

For this condition, the PDA test data gives positive (+VE) pulse predominance as Indicated by the +VE plots of Figure 1.

*(b) .Internal Ground Wan Partial Discharge

Internal partial discharges can occur within the ground wall Insulation at delaminations or areas where the bonding material 1s missing or Incompletely cured. Such discharge activity Is particularly common In older Insulation systems such as mica follum and asphalt-mica. The main characteristic of this mechanism 1s that the positive (+VE) and negative (-VE) partial discharge activity Is about equal, Figure 2.



Sir Adam Beck Niagara II GS Unit A

X, +VE 0. -VE







DeCew Falls GS Unit B



*(d) Loose Minding/Tight Winding

Test data Indicates that this discharge activity Is more sensitive to winding temperature than to load change.

Copper Stack/Insulation Interface Partial Discharge These discharges occur at the Interface of the copper strands and the turn Insulation In multi-turn coils. For Roebel bar windings the copper strands Interface directly

with the ground wall Insulation. For this condition, the PDA test data plots give negative (-VE) pulse predominance. We have observed such conditions on 26 to 35 year old asphalt-mica insulated and polyester/epoxy Insulated multi-turn windings as well

as poorly bonded epoxy Insulated Roebel bar windings.

Figure 3.



Blenheim-Gilboa Unit C

Comparison of the no-load and full-load PDA positive (+VE) test data obtained under full load temperature stabilized operating conditions Is used to determine If the winding is tight or loose.

For a tight winding, the full load test data, when superimposed upon the no-load test data, will coincide with it or be very closely parallel to It. The pulse magnitude and frequency. In most cases, will be low.

For a loose winding, the no-load and full-load PDA test positive (+VE) pulse data will diverge away from one another with the number of high magnitude pulses Increasing for the full load conditions, Figure 4.

II NORMALIZED QUANTITY NUMBER (NQN)

The NQN is a measure of Integrated discharge activity given by the area under the relevant PDA curves (7]. To more easily track the winding condition over time, the PDA curves can be summarized as a single number.

Figure 5 Illustrates a method of calculating the quantity NQN via Integration of the area under the positive (*VE) PDA data plot. The value NQN can then be related to a probable winding condition for a given Insulation system as described In Charts I and II. The charts also relate maximum coll side force/inch length to corrective action time as per Ontario Hydro's experience for thermoset systems. The probability of success for in situ repair, based on Ontario Hydro's experience is also given.

The positive (+VE) and negative (-VE) pulse PDA test data is considered in the NQN calculation. The negative (-VE) pulse data is related, with regard to the PDA test method, to conditions which exist within the around wall or at the copper stack insulation interface. Such conditions are considered to be non-repairable, and as such can only be



of Normalized Qua (NON)

monitored.

Semi-conducting coating damage, can, in our experience, be successfully repaired if remedial action Is Implemented early upon damage Indication.

It should be recognized that the NQN value cannot be used In Isolation. It must always be used In association with the relative positions of the »'VE and -VE PDA pulse curves plotted from no-load and full-load PDA test data.

Figure 6 presents examples of positive (*VE) data NON long-term monitoring plots for two Ontario Hydro multiunit stations, one Incorporating thermoplastic and the other thermoset stator winding Insulation systems of 1954 and 1958 vintage.

400-ns wide input pulse. When a narrower pulse, or the spark-gap source is employed, the ringing immediately oscillates about zero (similar to Figure 6). For a 100-V input pulse, the slip-ring signal results in an output at the coupler about 50% greater than for simulated PD injected at the phase end. Injecting voltage pulses directly onto the rotor shaft produced the same response.

The capacitive coupler response to a signal injected to the stator frame (essentially a dead short to the voltage source) is shown in Figure 6. Again, the first peaks from all three phases have the same polarity and similar magnitudes. In most other respects also, the response resembles that from the rotor noise. The responses shown in Figures 5 and 6 from Machine B were typical of those found in the other generators.

RF Current Transformer Detection

For each of the PD and noise injection situations described above, the response of the RF CT was also measured. Figure 7 shows the response of the CT to simulated PD injected at three points on the Red phase of Machine B. The output voltage into 50 ohms is relatively small (about 5 mV) and oscillates at about 30 MHz (the upper cutoff frequency of the CT). The magnitude of the initial peaks are independent of the PD injection point. Thus the RF CT appears capable of detecting PD throughout the entire winding.

The response of the CT to simulated noise was quite





different. Very large responses, more than 100 times greater than for simulated PD with the same injected voltages, were measured (Figure 8), The outputs recorded mimic the 400-ns wide, 100-V pulses injected into the slip ring and the stator frame, except for the longer output rise time. The RF CT clearly responds preferentially to noise.

(a) inject at phase end

(b) inject 1 coil down from phase end

(c) inject 6 coils down from phase end (1 coil from neutral)

CONCLUSIONS

- (a) On-line PDA monitoring Is required for early detection of stator winding deterioration and Identification of failure mechanisms present.
- (b) On-line PDA monitoring Is required for long-term monitoring of effectiveness of in situ stator winding repair procedures.

		Polyester and Epoxy Insulation Systems			
		Normalized Quantity Number (NQN)	Comments Regarding Most Likely State of the Winding	Maximum Bar Force [8]	Corrective Action Time
		0 to 100	Winding will be tight and in good condition. +VE and -VE NQN typically of equal magnitude.		
Semi-Conducting Coating Erosive Discharge	Repair Prob of Success 90 to 99%	101 to 250	Very early semi-conducting coating damage will be present in the top 10% of any circuit string. +VE and -VE NQN not equal. +VE NQN probably 15% to 20% greater in magnitude.	2.0 lbs/inch 2.5 to 4.5 lbs/inch 4.5 to 6.0 lbs/inch and greater	3 years 18 months 9 months
	Repair Prob of Success 75 to 90%	251 to 400	Semi-conducting coating damage will be present in the top 20 to 25% of any circuit string. Damage will be easily visible on affected coil sides. Some early internal ground wall or conductor insulation interface delamination is highly probable on 25- to 30-year-old windings. +VE NQN probably 30 to 40% greater than -VE NQN.	2.5 to 4.5 lbs/inch 4.5 to 6.0 lbs/inch and greater	15 months 6 months
 (a) Semi-Conducting Coating Erosive Discharge. Std Corrective Repair Has High Prob of Only Temporary Halt to Surface Deterioration. Complete CRTV Injection Corrective Repair [8] Has Achieved a High Success Prob for Ontario Hydro. (b) In Loose Windings High Prob of Hydro. 		451 and above	Same as for 251 to 400 NQN range, except a larger area of the winding will be involved. For long stator core machines 90 inches (238.6 cm) and greater, internal copper stack insu- lation interface delamina- tion will most probably be present on 8- to 10-year or older windings. Standard corrective action will have a high probability of producing only a temporary halt to the surface deteri- oration involved. Our experience has been that only a complete CRTV injection at every core package - coil side inter- face achieved a high suc- cess probability when NON has been greater than 451.	2.5 to 4.5 lbs/inch 4.5 to 6.0 lbs/inch and greater	9 months 3 months

- * couplers located at the end of the circuit ring bus
- (c) Experience has shown that PDA monitoring has successfully .Identified semi-conducting coating type discharge. Internal ground wall delamination/void type discharge, copper stack insulation Interface delamination type discharge [4].
- (d) It Is our considered opinion that Ontario Hydro, as a result of Its use of the PDA monitoring test, has now achieved a position where thermoset and thermoplastic stator winding problems are manageable at minimum cost.

Chart II

	Considering Asphalt-mica and Mica-folium Systems		
	Normalized Quantity Number (NQN)	Comments Regarding Most Likely State of the Windings	
Semi-Conducting Coating Erosive Discharge. Ground Wall Void Discharge Activity is the Primary Mechanism of Insulation Deterioration.	0 to 200 201 to 500 501 and above	 Winding will be tight. However, there will be signs of internal void development for the 125 to 200 range windings. Winding should be rewedged with a piggy-back wedge system if it is 20 to 25 years of age. Typically, +VE and -VE NQN are of equal magnitude. Winding will be in the 30 to 35 year + class, and will be experiencing a higher level of internal void development than those on the NQN 125 to 200 range. Depending upon the winding's histogram, and if its NQN falls between 201 and 350 a rewedge operation may be possible in order to extend its life to 50 years. Typically, +VE and -VE NQN are of equal magnitude. Winding will be experiencing significant internal delamination and in fact, may have already experienced turn to turn failures. If winding has reached 35 years of service, then consideration should be given to rewinding unit within the next 10 years. 	

ACKNOWLEDGEMENT

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REFERENCES

1. Kurtz, M., Stone G.C., Diagnostic Testing of ficnerator Insulation Part II - An Improved Partial Discharge Test", CEA Research Report, *Contract RP76-17, September 1978.

2. Kurtz, M., Stone 6.C., Diagnostic Testing of Generator Insulation Part III, "The Partial Discharge Analyzer and Coupling Systems", CEA Research Report •Contract RP76-17, December 1980.

3. Kurtz, M., Stone G., C., Lyles, J.F., "Application of Partial 8. Lyles, J.F., "Slot Discharge In Hydraulic Generator Discharge Testing to Hydro Generator Maintenance", IEEE Transactions on Power Apparatus and Systems VOL PAS 103, Ho. 8, August 1984, pages 2148 to 2157.

4. Lyles, 3.T., "Ontario Hydro's Experience Regarding PDA Test Data Correlation as Applied to Hydraulic Generator Stator Windings", CEA-EPRI-Ontarto Hydro PDA and RF Monitor User's Workshop, Toronto, Canada, September 22-24, 1986.

5. Smith, J.W.R., "CEGB Experience with POA/Coupler Stator Insulation Monitoring System as Applied to Large Hydro Generators", CEA-EPRI-Ontarlo Hydro PDA and RF Monitor User's Workshop, Toronto, Canada, September 22-24, 1986.

6. Lyles, 3.P., "Experience with Partial Discharge Analyzer Testing as applied to Hydraulic Generator Stator Windings", Presented at 53rd Ooble Conference. Boston Mass, April 7-11, 1986, Rotating Machinery Section.

7. Bartnikas, R.. McMahon, E., "Engineering Dielectrics -Volume 1, Corona Measurement and Interpretation", ASTM 669, 1979.

Windings", CEA International Symposium on Insulation Tests, June 12-13, 1980, Toronto, Canada.

9. Kurtz, M., Lyles, J.F., "Generator Insulation PDA Data Acquisition", CEA Research Report, Contract 038 G 228, April, 1986.

* Available from Canadian Electrical Association, R&D Division, Suite 580, 1 Westmount Square, Montreal, Quebec, Canada, H3Z 2P9.

J.F. Lyles. John Lyles joined the Canadian General Electric Co., Peterborough, Ontario in 1955. From 1956 to 1963 he was engaged in induction motor design with their Design and Development Section. He was then transferred to Canadian General Eleciric's Large Generator Engineering Department, Hydraulic Generator Design, where he worked until 1969 at which time he joined H.G. Acres Ltd as a Senior Engineer Electrical in their Electrical Engineering Department. Since 1971 he has been with Ontario Hydro, where he is presently Supervising Engineer Electrical of the Hydraulic Plant Equipment Department.

Mr. Lyles has authored and co-authored more than 14 papers on insulation diagnostic testing and generator rewind maintenance practices. He is a member of the IEE England, senior member of the IEEE and a Registered Professional Engineer in the Province of Ontario.

John Lyles was born in Hatfield. England on February 12,1932.

G.C. Stone. Mr. Stone graduated from the University of Waterloo with a B.A.Sc. and M.A.Sc. in electrical engineering in 1975 and 1978, respectively. Since joining the Research Division of Ontario Hydro in 1975, he has been active in developing test methods for insulation systems. Greg Stone has participated in the creation of several IEEE Standards. He is presently Vice-President, Administration of the IF.F.P. Dielectrics and Electrical Insulation Society. He is a registered professional engineer in Ontario, Canada.

M. Kurtz, born 64 years ago in Toronto, Canada, graduated from the University of Toronto in 1948 with a B.A.Sc. in Engineering Physics, and is a registered Professional Engineer in Ontario.

Mr. Kurtz has worked in Ontario Hydro's Research Division for almost 40 years, primarily in the area of solid electrical insulation, including failure analysis of high voltage apparatus and the development of diagnostic test methods and instrumentation for such tests.

Mo is Chairman of the CSA Committee on Electrical Insulation, and is a member of other CSA Committees on Power Cable, etc, ASTM Sub-committee D-9, and the IEC Canadian Subcommittees on TC15, TC63 and TC20 as well as several Working Groups. He founded and has been Chairman of the Central Ontario Chapter of the IEEE Electrical Insulation Society for the last 10 years, and serves on the Editorial Board for the El Transactions. He has authored and co-authored more than 30 papers and articles in his areas of interest He was elected recently to Fellow Grade in the DEEE.

Discussion

W. McDennid (Manitoba Hydro, Winnipeg, Canada): The CEA PDA and associated permanent coupling systems represent one of the more important developments in recent years for on-line monitoring of rotating machine insulation. The authors are to be congratulated for publishing new data on the interpretation of PDA results which will be very useful reference material for the many users of this test.

The NQN data in the paper are based on a pulse magnitude in terms of millivolts, measured at the input of the PDA. In Chart I it is stated that the permanent couplers are located at the end of the circuit ring bus. Presumably this means that the couplers are attached to the circuit ring bus at the point at which the bus connects Co the line end scator coil or bar. Comparison of NQN data between different machines would seem to be based on the assumption that the response of couplers at this location in terms of "millivolts per picocoulomb" will be a constant value.

In Manitoba Hydro, due to the geometry and pulse response characteristics of many of our hydro generator Stator windings our differentially connected couplers are frequently located at the first span jumper which means that the coupler is located two or three coils away from the line end. Alternately where single turn roebel bars are involved the end-cap coupler [1] may be employed and this is located one half turn from the line end. In some cases it has been much more economic to retrofit directional couplers on the isolated phase bus [2]. The response of couplers differs between these various locations, and also to some extent between couplers in much the same location but on different machine types [3].

Comparative PDA results were provided in [3] for Kettle Unit 1 where there are differentially connected couplers located in the winding two coils from the line end, as well as directionally connected couplers located on the isolated phase bus. In the case of B0 there is a coupler located two coils from the line in a circuit where there is no circuit ring bus, and the machine end isolated phase bus coupler is separated from the line end of this circuit by approximately 1 m. (The circuit ring bus lengths of the other seven circuits in B0 range from 4 m Co 18 m;) If we calculate NQN in terms of millivolts at the PDA input, as is defined in the paper, for the data obtained from the two coupler?, described above, which are separated by two coils and about 1 m of terminal busbar we obtain NQN(mV) = 65 for the terminal coupler, and NQN(mV) = 214 for the winding coupler. If we were to adopt the alternative, suggested in Reference 5 of the paper, of expressing pulse magnitude in terms of picocoulombs, rather than millivolts at the input to the PDA, and if we ensure that this magnitude is "apparent picocoulombs at the coupler" based on individual calibrations [3], then for the above example we obtain NQN(pC) ° 245 for the terminal coupler, and NQN(pC) = 398 for the winding coupler. In the normalization process the term "1400/gain" has been replaced by the equivalent picocoulomb value divided by two.

It is suggested that normalizing in terms of picocoulombs at the coupler may produce a NQN value which is somewhat more related to actual partial discharge activity near the coupler than is obtained by using millivolts at thePDA input.

In [2] data were reported for Kettle Unit 9 before and after the repair of the semi-conducting coating and addition of side packing at two coils near the line end of an A0 circuit. The damage was primarily restricted to one coil where the semi-con coating had been totally lost and which had side clearances of up to 1.1 mm. This is the third coil from the line end, and with approximately 13 m of circuit ring bus to the terminal where the directional coupler is located. In this case prior to repair NQN(mV) = 102, and after repair NQN(mV) - 78. These calculations are based on a simple straight line fit of the graphical data. Expressed in NQN(pC) the values before and after repair were 431 and 327 respectively. It is clear from this example that serious deterioration involving a single coil can be detected provided that there are sufficient historical PDA data, supplemented by inspections and other tests as may appear appropriate.

References

 N.R. Selkirk, "Development of End Cap Couplers", CEA Research Report for Contact 008G229, March 1984
 W. McDermid and J.C. Bromley, "Monitoring Rotating Machine Insulation with the CEA PDA through the use of Directional Couplers", Proceedings of the 18th Electrical/ Electronics Insulation Conference, Chicago, Oct 5-8, 1987
 W. McDermid, "Installation of Permanent Couplers in Manitoba Hydro", CEA/EPRI PDA/RFM Users' Workshop,Toronto, Sept 22-24, 1986

Manuscript received February 17, 1988.

A. W. W. Cameron (Retired, London, ON, Canada): The reported lack of correlation between short-time AC breakdown voltage and other experience or diagnosis of remaining insulation service life may be explained by known Voltage Endurance characteristics. The high short lime AC strength of an insulation sample is determined mainly by the effective thickness of solid insulation in it. The droop of any AC voltage endurance curve towards reduced breakdown voltages of identical samples, after long times of stressing, is caused by progressive ionic erosion of voids, by localized heating by void discharges, and by dielectric heating approaching runaway in remaining solid insulation.

This supports the Authors' suggestion that low AC strength of a sample from an aged machine would indicate that it would soon have failed in service. I would suggest that longtime AC voltage endurance tests of such samples might be more informative for less advanced deterioration and longer prospects.

It should be emphasized that Direct Voltage tests have the sole purpose of detecting cracks and fissures through the groundwall. Such damage is usually caused by mechanical vibration or impact, aggravated by localized heating from discharges, strand faults, or core faults. Direct overvoltage tests by the Ramp Method give reliable non-destructive indications when done on a winding which has cooled to ambient temperature while open to air of normal humidity, to provide a little moisture to enhance conduction in any fissure. These facts are well known to the Authors, but still not widely enough appreciated.

These two Papers present very valuable means of assessing the future trend of a stator winding's reliability, in terms of probable ability to withstand "events" incidental to operation, such as overvoltages and overcurrents from external causes. There are now two requirements for a Utility to realize die economic benefits of such information:

- 1) Assessment of the probabilities of such events and their probable severities in future periods of time.
- 2) Realistic estimates of the dollar values of reliability levels of given machines at future times, whereby the indicated repairs and rewinds can be timed for optimum cost/benefit ratio.

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David W. Jackson, R. W. Beck and Associates, Waltham, MA. There appear to be some anomalies in the NQN history plots of Fig. 6. Among the thermoplastic insulations. Generator 13 experienced a doubling of NQN from 1983 to 1984. It then declined to half the original value by 1987. No remedial work is indicated. Is there an explanation? Generator 15 was rewedged in 1980 but between mid 1981 and mid 1983 its NQN doubled, and then declined sharply in one year to its original value. Is there a known reason?

Similar questions apply to the thermoset insulation systems. Here no historical record of remedial procedures is presented. It appears that three of the four machines reported, G12, G15 and G16, all experienced a doubling of recorded NQN in the 1985-86 period. Does this represent actual changes in insulation quality or some change in the test procedure?

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J.F. LYLES, G.C. STONE, M. KURTZ, (Ontario Hydro, Toronto, Canada)

The authors thank MR. M. MCDERMID. MR. A.W.W. CAMERON, MR. D.W. JACKSON, and MR. R.W. BECK for their Interest In the paper.

Our reply to Mr. A.W.W. Cameron will be Included In the discussion reply to a companion paper No. 88 MM 0267. We agree with Mr. McDernnd that given sufficient historical

PDA data. Insulation deterioration Involving only a single coil can be detected and subsequent repairs can be monitored via the PDA test.

With regard to NQN (mV) versus NQN (pc), we comment as follows. Ontario Hydro have equipped 150 hydraulic generator windings with permanent couplers located at the circuit ring, line end coil bar Interface. Subsequent In house correlation of mv plots to observe damage for Ontario Hydro's universe of generators proved to be very good. Such work provided the basis for the NQN (mV) damage relationship presented In Charts I and II. Application of Charts I and II to PDA test data obtained from USA, British, and Australian utility hydraulic generators, together with physical examination and stator coil/bar disections present and to a degree the extent of the damage within the windings. (We have never stated that the PDA test 1s capable of predicting extent of damage area.)

In 50 plus winding deterioration mechanism predictions, (based on the PDA mV positive (+ve) and negative (-ve), data plot relationships), subsequent removed coil/bar disectlons have confirmed the presence of predicted deterioration mechanisms. Comparison of full load and no load positive (-ve) pulse PDA mV data has also predicted correctly the condition of their stator wedge systems.

We believe the usefulness of the NQN value, be It (mv) or (pc) based, 1s In their ability to summate the PDA test data Into a single value thus facilitating the plotting of a trend line for a given winding. Establishment of a NQN value damage relationship should greatly enhance the ability of a maintenance engineer 1n determining the urgency to Implement repairs.

The NQN trend line should be used as an indicator to Initiate a unit Inspection and other tests as may be appropriate prior to Implementation of specific repair procedures.

All the critical NQN (mV) levels referred to in Charts I and II are based on capacitive couplers installed on the circuit ring bus at the connection to the parallel. NQN levels for couplers Installed in different locations are likely to be quite different, due to attenuation or impedance miss-matches. Mr. McDermid's suggestion of calibrating the mV reading into picoCoulombs may improve the situation. However, our past experience with calibration has been disappointing, since the ratio depends strongly on how the calibration pulse Is injected, local resonances, detector Impedances, etc. Thus wider experience is required before comparison of NQNs from different types of couplers can be relied upon.

In reply to Mr. O.W. Jackson and associates' discussion, we comment as follows. The NQN data presented in Figure 6 was calculated from the original PDA (1981) test instrument. This instrument was found to suffer from a shorter than expected recallbrat1on requirement i.e., it tended to drift over time. This deficiency has been corrected In the PDA-H model. Furthermore, the concept of the NQN value was not conceived until the second quarter of 1986. Thus, the NQN values presented were calculated from PDA data obtained from 1981 through 1986. It is the SAB II PDA Instrument's tendency to drift which Is partially responsible for the noted anomalies. We have also noted in the past that the deterioration function Is not continuous over time but has a step function characteristic as a result of void conditioning due to trapped discharge by-products in the thermoplastic insulation system. This characteristic we feel has also contributed to the SAB II GS data anomalies.

For the R.H. Saunders GS thermoset HQH data plots, we feel that the concrete creep induced station distortion [2] is a cause of the noted anomalies as well as the stator rewedgtng which was performed on the units at the time indicated by the vertical parallel paired lines. Stator rewedging usually produces erratic PDA data for up to 6 months upon a unit's return to service. Such erratic PDA data being the result of stator winding settling. However, 1n this case, due to the release of stresses in the stator core as a result of modifications to each unit's stator sole plates, the stator winding settling 1s being extended over a longer period of time.

References

 1.3. Kemp, B.K. Gupta, G.C. Stone, "Calibration Difficulties Associated with Partial Discharge Detectors In Rotating Machines," PRO IEEE Electrical Insulation Conference, Chicago, October 1987, pages 92 to 97
 Hydro Review Waterpower 85 Special Issue, "Stator Frame Distortion - Solving the Problem of Concrete Creep," by J.F. Lyles, Ontario Hydro, Toronto, Ontario, Canada, pages 92 to 96

Manuscript received April 8, 1988.