Impact of Cable Material, Optical Fiber Design, and Cable Design on High Temperature Accident Survivability of Optical Fiber Cables

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Typical maximum rated optical fiber operational temperatures are 70°C to 80°C. In special applications such as in nuclear power or industrial environments, accident conditions can produce temperatures above normal cable rated operational temperatures. In these accident conditions, typically the entire length of cable is not subjected to the accident condition temperature, but network functionality may still be required. Another factor that may come into play is that temperature excursions during accident conditions may be much more rapid than temperature changes during typical testing of cable spools in traditional temperature cycling tests for optical fiber cables.

Both loose-tube and tight buffered cable designs were investigated in this study. The tight buffered break-out cable design tested is shown in Figure 1 and the loose-tube cable design tested is shown in Figure 2. The smallest loose-tube cable in the design family is the 5@1 cable design which is used for all fiber counts Ò 60. For both the breakout cables and the loose-tube cables the nuclear, LSZH cable designs were selected for thermal excursion testing as these are the most commonly deployed designs in nuclear environments.

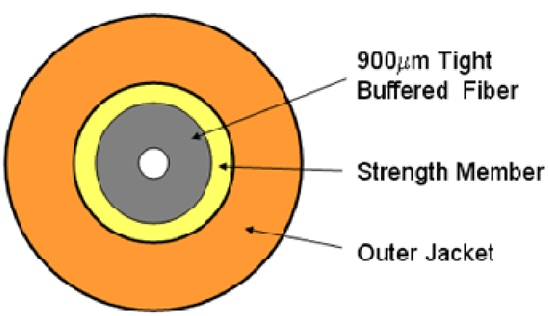

Figure 2: 1 Fiber LSZH Tight Buffer Breakout Nuclear Cable Design.

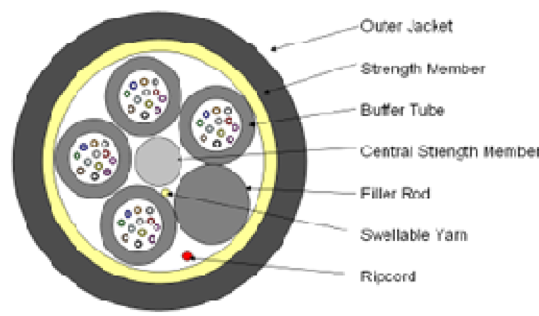

Figure 2: 48 Fiber LSZH Nuclear Loose Tube Cable Design.

The rapid thermal excursion testing performed was more severe than standard temperature cycling testing performed according to requirements defined in GR-409.[1] Cable temperature cycle testing performed according to GR-409 requires at least 500m of cable sample typically wound on a drum. The large sample and chamber size required when using a large cable sample on a drum typically results in rather low heating and cooling rates as well as long thermal equilibration times which reduces thermal stresses within the sample. During the rapid thermal excursion testing, measurements were recorded during the rapid heating and cooling of the samples when temperatures are in transition. In contrast, at least an 8 hour hold time at the test temperature is required before measurements for normal temperature cycle testing of cables according to GR-409. Rapid heating rates and measurement of attenuation before samples reach thermal equilibrium can make transient increases of attenuation more substantial. These transient attenuation changes during rapid thermal excursions can be the most important consideration for cable functionality during accident conditions.

Tight buffer cables can be very sensitive to fiber stresses during cable thermal cycling. Due to intimate contact of the tight buffer material with the optical fiber, both material and process optimization is required to produce a tight buffer that does not have excessive initial attenuation and also has stable attenuation during thermal cycling. Exposure of tight buffered fibers to extended temperature testing as well as more rapid thermal excursion can increase the risk for elevated optical fiber attenuation. The optical fiber type may also impact cabled attenuation during thermal excursions. Bend insensitive fibers can show improved performance relative to standard fibers with regard to factors such as cable material relaxation or shrinkage which may be substantial factors at elevated thermal excursion temperatures.[2,3,4,5,6].

Both transient and long-term attenuation data for the tight buffered fibers in rapid thermal excursion testing to 180°C are shown in Figure 3. Clearly the LSZH tight buffer sample made with a bend insensitive fiber (Tight Buffer D) showed the lowest magnitude of attenuation change during the thermal excursion testing. No statistically significant differences were noted in the performance of F doped or Ge doped multimode tight buffered fibers in this thermal excursion testing. Surprisingly, both the LSZH and PVDF tight buffers showed no large attenuation increases when heated above the melting point of the tight buffer materials. The thermoplastic elastomer tight buffer showed a decrease in attenuation when heated above about 110°C. This decrease in attenuation is attributed to relaxation of residual stresses within the tight buffered fiber and is a non-reversible phenomenon.

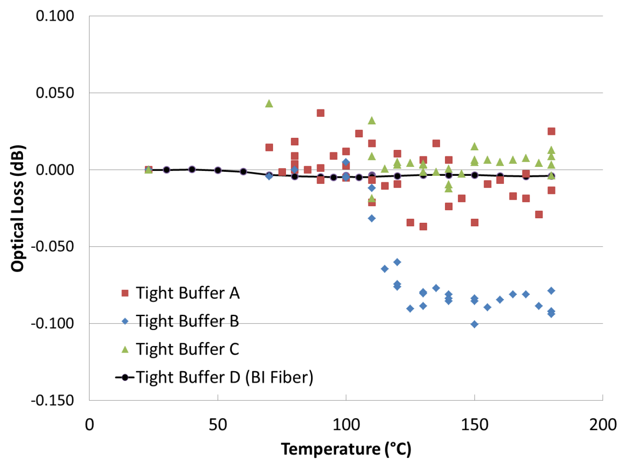

Figure 3: Tight Buffer Attenuation During Rapid Thermal Excursion Testing to 180°C:

- **A- LSZH Tight Buffer 50µm Ge Doped Fiber.**
- **B- Thermoplastic Elastomer Tight Buffer 50µm Ge Doped Fiber.**
- **C- PVDF Tight Buffer 50µm F Doped Fiber.**
- **D- LSZH Tight Buffer 50µm Ge Doped BI Fiber.**

A loose-tube and a breakout cable were subjected to a rapid thermal excursion test to 110°C to examine the impact of inclusion of tight buffered fibers in a cable construction on attenuation during thermal excursion testing and the impact of cable design on thermal excursion behavior. The 110°C excursion temperature was selected for the cable thermal excursion test to keep the LSZH outer jacket material used for both cable constructions below the melting point which is the maximum practical temperature limit for the cable designs investigated. Attenuation in both cable designs showed very similar trends and was slightly elevated relative to the attenuation observed in tight buffers as illustrated in Figure 4. In both the tight buffer and tight buffer breakout cable, attenuation decreased over time once the temperature of 110°C was reached as shown in Figure 5. This decrease in attenuation with time was observed at other hold temperatures, as well. The decrease in attenuation as a function of time after reaching thermal equilibrium is attributed to relaxation of thermal stresses caused by the rapid heating of the samples. As bend insensitive fibers are far less sensitive to thermal stresses, a lower initial attenuation and less recovery related to this relaxation of stresses is evident.

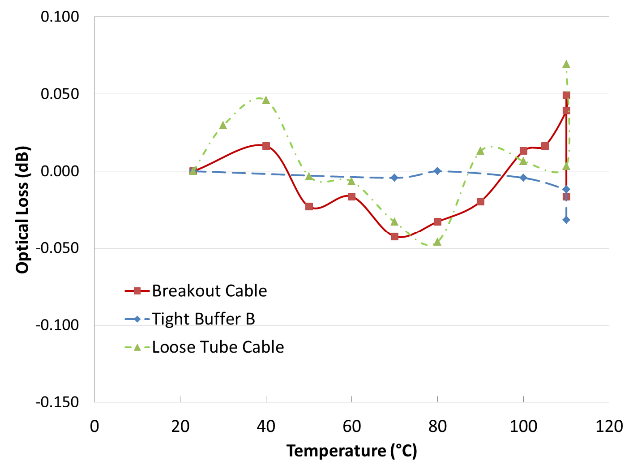

Figure 4: Tight Buffer and Cable Attenuation During Rapid Thermal Excursion Testing to 110°C

A 48f LSZH nuclear rated loose tube cable as shown in Figure 3 was subjected to a long term thermal excursion temperature of 100°C for 90 days (2160h) after radiation exposure in order to simulate conditions during a nuclear power plant accident. Optical fiber attenuation performance is summarized in Table 1. The maximum transient attenuation increase observed after the thermal excursion was 0.066db/km for the multimode fibers and 0.030dB/km for the singlemode fiber. The thermally induced attenuation changes were far less than the radiation induced attenuation values even for the radiation optimized F-doped fibers. During the course of the test the attenuation showed a continual decrease for many of the fibers tested due to an increase in thermal annealing rate for radiation induced attenuation (RIA) at the increased test temperature.

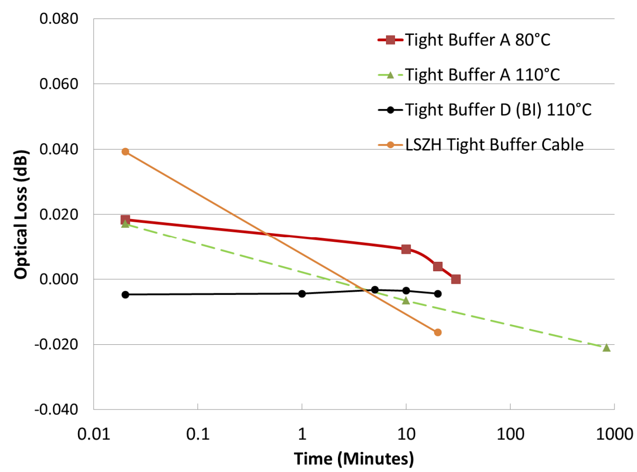

Figure 5: Tight Buffer Attenuation as a Function of Time after Thermal Equilibration at Various Temperatures for Standard and Bend-Insensitive 50µm Tight Buffered Fibers.

Table 1: Attenuation Measurements for a 48f LSZH Nuclear Rated Loose Tube Cable with Varying Radiation Resistant Fibers.

Optical Fiber Design	Initial Cabled Attenuation (dB/km)	RIA after 10KGy Irradiation and Before Long-Term Thermal Excursion (dB/100M)	Attenuation after Irradiation and Long-Term Thermal Excursion (dB/100M)
F-Doped SM	0.245	0.237	0.092
Ge-Doped 50µm	0.451	0.718	0.842
F-Doped 50µm	0.471	0.312	0.278
Ge-Doped 62.5µm	0.583	0.963	0.553

Reduced maximum attenuation change during longer term thermal excursion with lower heating and cooling rates is not a surprising result since in the thermal excursion testing at high heating rates, maximum changes in attenuation were generally associated with periods of temperature transition. If temperature was allowed to stabilize, attenuation generally decreased over a function of time as thermal stresses within the sample relaxed. This result shows that relying on measurements performed only after thermal equilibration may provide on overly optimistic measure of cable performance during high temperature, rapid heating rate accident conditions.

With the thermal excursion attenuation response of cables characterized, the impact on the system power budget and maximum link distance for operation during and after accident conditions can be considered. For all cable designs tested, permanent attenuation difference was minimal after thermal excursions below the melting point of the cable materials, and the transient attenuation increases at temperature were the most substantial. In all cases attenuation change remained below 1.2 dB/km, which is double the limit for normal temperature cycle performance of 0.6dB/km at 1300nm for multimode fibers. [4]

Conclusions

Measurements of optical fibers during thermal excursions were presented as a function of optical fiber design, cable material, and cable design in order to investigate the survivability of optical fiber networks to thermal excursions beyond normal use conditions. Cable functionality was demonstrated under accident thermal excursion conditions for multiple cable designs and materials to temperatures approaching the melting points of the materials of construction. Transient changes in attenuation during rapid heating and cooling were generally higher than those observed when cables reached thermal equilibrium, but remained below 1.2dB/km in all cases. Under similar test conditions, singlemode fibers showed less thermal excursion sensitivity than multimmode fibers, and bend insensitive fibers showed almost no change in attenuation due to thermal excursion testing of cables. Improvements in link distances can be attained through the use of F-doped, radiation optimized fibers due to lower radiation induced attenuation for this fiber type. Additionally, the use of bend insensitive, radiation optimized fibers can improve link distances due to lower thermal excursion and bending induced attenuation of fibers within the network.

1. References

[1] *Generic Requirements for Indoor Fiber Optic Cable, Telcordia Technologies Generic Requirements GR-409-CORE*, Issue 2, Telcordia Technologies, Inc. (2008).

[2] L.A. de Montmorillon, et. al., ñBend-Optimized G.652D Compatible Trench-Assisted Single Mode Fibersò, *Proceedings of the 55th International Wire and Cable Symposium*, (2006), 342-347.

[3] L.A. de Montmorillon, et. al., ñDifferent Implementations of G.657B Bend-Insensitive Single-Mode Fibers with Ultra-Low Bend Losses, Still Compatible to G.652Dò, *Proceedings of the 57th International Wire and Cable Symposium*, (2008), 283-288.

[4] U.S. Patents 8,406,593; 8,520,993; 8,639,079; and 8,644,664.

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