Aging effects on the attenuation coefficient and splice losses in installed submarine optical cables

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Abstract: Aging effects in submarine optical cables were evaluated with OTDR measurements along 12 years. Penalties from splice losses were twofold higher than those from fiber attenuation. Cables are expected to last more than 25 years. © 2022 The Authors

1. Introduction

For many years and even nowadays, it is generally agreed in the optical cable market that the operational lifetime of properly designed and constructed fiber optic cables with the best quality processes is around 20 to 25 years. This statement is given by manufacturers and international standardization bodies in the area of Telecommunication such as the ITU-T (International Telecommunication Union) [1]. On the other hand, technical publications state that optical cables can remain operational for more than 25 years, reaching 40 years or more [2,3]. However, there is no easy and simple way to estimate with a high degree of certainty the operational lifetime of optical cables. Measurements in terrestrial cables during 16 years showed that there was little significant degradation of the attenuation coefficient, but relevant degradations for the punctual attenuations in the splice boxes [4]. Few aging studies were performed in submarine cables, where the operation conditions are quite different in term of pressure, temperature and third-party interventions. Losses in 1550 nm in submarine cable splices were reported to vary 0.026 dB per splice per year and were associated to hydrogen induced losses [5]. This work present results on the aging of installed submarine cables and warehouse stocked spare cables between 2010 and 2022.

2. Experimental Methods

The submarine optical cables were supplied in 2010, together with complete specifications data tables for all G-655 standard fibers in the eight cable stretches of the link. The first four stretches (S1 to S4) were double armored cables whereas the four others (S5 to S8) were single armored cables. The link was completely installed in 2012 in an exploration area of the oil & gas industry in the Brazilian offshore Campos Sedimentary Basin. Complete bidirectional OTDR measurements in 6 of the 18 fibers of the cables were performed in 2012, 2013, 2018 and 2022 with full characterization of fibers and splice losses. From the full 36-km link four stretches (S4 to S7) were chosen according to the minimum length required to provide accurate OTDR measurements of attenuation coefficients without interference of splice losses, totalizing a length of 27.6 km. Loss data from four splice boxes (SB3/4, SB4/5, SB5/6 and SB6/7) were also selected.

All OTDR measurements were performed in both directions to provide fiber attenuation and splice loss tables along the time. Indeed, this procedure is usual in cable inspection, mainly because measurements of splice loss between different fibers depend on the direction and the mean value should be used. However, the variation of the fiber or splice loss is the same whichever direction is used because all factors regarding the Rayleigh backscattering capture coefficients cancel out. Hence, the original data traces in a single direction were used to evaluate the variation of losses along time, the ones providing the best signal-to-noise ratio, keeping, of course, the same direction along all measurements.

3. Results and Discussions

After the link installation in 2012 the average attenuation coefficient of the deployed fibers was almost the same as the average value at the factory premises in 2010, meaning that the effect of the handling and transport was negligible. Fig. 1 (left) displays the distribution of the variations in attenuation coefficients ($\Delta\alpha$) for the ensemble of measured fibers between the deployed state in 2012 and 2022, with the trend curve with measured intermediate points shown in the righthand side. This distribution clearly present two different behaviors, certain fibers degrading much more than others. Indeed, the greater variations were observed in fibers from the same stretch (S4), corresponding to the double armored cable deployed in shallow waters. The mean variation was 0,004 dB/km within 10 years, which is considerably close to the ITU-T limit of 0,005 within 25 years. Using a logarithmic trend to describe the aging effects as shown in Fig. 1 (right), the observed mean data are still compatible with the ITU-T expectations with a determination coefficient $R^2 > 0,90$ and eventually will reach the limit value in a time much longer than expected. It is worth noting that even though the shallow stretch cable is double armored it suffered much greater variations than the deeper single armored ones. The proximity of shore end, fishing and traffic of small boats could explain this difference.

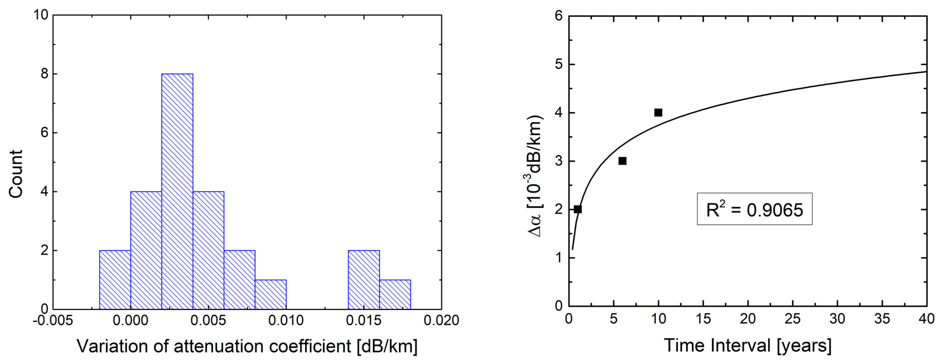

Fig. 1: (Left) Histogram of Δα for all fibers in all sections between 2012 and 2022. (right) Trend curve for the mean penalty.

It is interesting to compare the degradation of the shallow stretch with the degradation of the single armored spare cable in the warehouse. Fig. 2 displays the distribution of variation of attenuation coefficients of fibers in both cables. Indeed, a much broader distribution impacted the spare cable, with eventually tenfold increases in the degradation for the same period. While the spare cable was stored in a container with uncontrolled temperature, the deployed cable submarine environment was much more stable. It is clear that the storage conditions are of paramount importance for the reliability of the spare parts in long life cables installations.

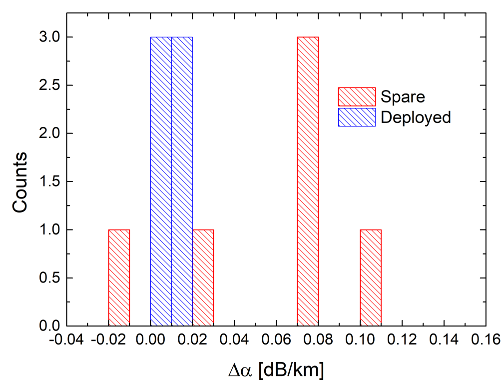

Fig. 2: Δα in the S4 cable on the seabed and in the spare cable

The variations of the losses in splice boxes were measured in the same traces as used for attenuation coefficients, hence in the same years. Fig. 3 (left) displays the variation in splice losses from 2012 to 2022, showing that the mean degradation per splice in 10 years was 0.054 dB, much smaller than the 0.26 dB previously reported data [5]. It is also interesting to consider the correlation between the loss degradation and the depth of the splice box. It is clear that an increase in degradation is observed as the boxes are installed in deeper waters.

Considering that several splices are installed in a submarine link, the overall impact of the splices may heavily impact the power margins of the link along the years. The power penalty from the 10 years aging of the four splice boxes in the 27.6-km partial link is 0.22 dB whereas the penalty from fiber attenuation in the 27.6-km cable is 0.11 dB, revealing a twofold greater aging impact from the splices than from the fiber attenuation. This means that better quality materials for underwater splice boxes, best practices and expertise during splicing, choice of the best route, and better quality in launching and accommodating splice boxes on the seabed are needed in order to mitigate aging losses.

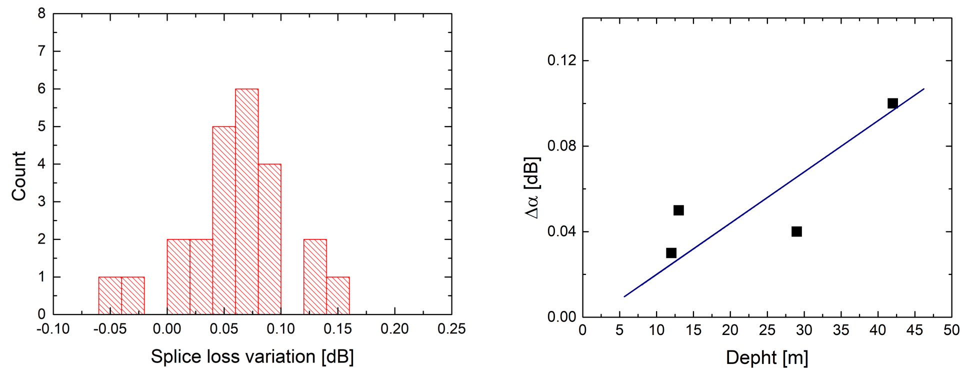

Fig.2: Histogram of the variation of losses in splice boxes (left) and variation of the losses with depth (right)

4. Conclusion

In this work, aging effects on the fiber attenuation and splice losses were evaluated from factory to field along 12 years. Immediately after the cable was deployed no significant degradation of the attenuation coefficient was observed, when comparing deployed cable data with data measured in the factory coils. Then, a fast degradation was observed in the first year from the deployment, which continued to grow afterwards, but at a slower rate over the subsequent 10 years of observation. It was also observed that the optical fibers from deeper sections presented a smaller degradation than those from the shallower sections. This is consistent with the fact that even though double armored cables were used in those shallow waters they are subject to more aggressions due to the proximity of the coast, the movement of waves or action of fishermen and crossing of existing submarine pipelines in the place.

Aging penalty coming from the average variation of the losses in the subsea splices was found to be twofold higher than what was verified for the variation of the degradation in the attenuation coefficient. It was also observed that there was a positive correlation between the aging effects and the depth of the deployed splice box. Therefore, one must be very careful with the quality of the materials as well as the quality of the installation procedures and maintenance of the splice boxes.

The analysis also showed that the aging is compatible with the ITU-T expectations and trend curves indicate that lifetimes to reach the ITU-T limits may be even longer than the 25-year standard. In fact, the trend curve indicates a stabilization of the aging power penalty coming from the attenuation coefficient, which means that an installed cable may be an asset with a lifetime much longer than that expected in the past. Benefits from the increased useful life for the backbone owner are maximizing profits, avoiding unnecessary investment losses upfront and allowing better planning for the future and greater appreciation of optical assets due to the guarantee of the performance of these fibers for much longer. It is worth mentioning that even though splices may suffer greater aging effects, they can always be repaired by a punctual intervention, whereas the fiber attenuation is a distributed effect that can only be repaired by a full cable replacement.

Finally, measurements in the warehouse stored spare cable showed that aging effects can be tenfold worse than aging effects in deployed cables, reinforcing the need for the spare cables to be properly stored, without direct sun light exposure and controlling the roorm temperature to avoid fluctuations.

5. References

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