УДК 004.322 **H.N. Rozorinov, Mohamed Aymen Fendri**

SERVICE TIME AND DEFORMATION OF NEW OPTICAL FIBRES

We study the dependence of the optical fibre lifetime on the tension. A method for calculating the elongation of the optical fibre depending on the bending radius is proposed. Recommendations on the bending radius choice of the fibre in the design of optical networks to increase their reliability are given. New optical fibres have reduced permissible bending radius, which results in considerable reduction of optical network lifetime, i.e., its reliability reduction.

Keywords: optical fibre, tension, bends radius, reliability, lifetime.

I. INTRODUCTION

Currently there are developed such types of optical fibres (OF), which could maintain high-speed technology of optical fibre communications. In particular, optical fibres in line with Recommendation ITU-T G.657 are of such type [1, 2]. They have fewer losses at small bending radiuses, and are intended for installation of optical equipment in the confined space – in buildings and distribution cabinets, and also in case of small closures and optical distribution boxes. Fibres can be divided into A1, A2, B2, B3 categories. G.657 OF type A1, A2 categories are used in access networks where bending with radius minimum 10 mm is allowed. G.657 type OF B2, B3 categories are intended for access networks where bending with radius minimum 7,5 mm is allowed. Small bending radius leads to considerable deformations of optical fibre and occurrence mechanical tension in it. Deformations of optical fibre and mechanical tensions are the reason for micro cracks in the fibre and their gradual enlargement, which eventually results in compete break of fibre [3]. Thus, optical fibre reliability and lifetime depend on its deformation associated with mechanical tension in it.

The goal of this paper is to assess reliability of optical fibre at various bending radiuses and development of recommendations for its use in conditions of mechanical loads.

II. MAIN PART

Reliability of optical fibre, which can be described with its fault probability, depends on mechanical load it is exposed to while in service [3]. Reliability and fault-free of optical fibre, exposed to tension, conforms to the theory of micro crack growth in the fibre. That's why during manufacturing all fibres are exposed to tension tests to reveal cracks and other damages. Such test is called Proof test, and it helps to find out, what tension can survive fibre for about one second [4]. Furthermore, the cracks in the fibre can produce its fault (breakout). This paper contains an attempt to forecast faults of OF long length, and such attempt is based on the results of OF strength tests. OF used in optical cables (OC) are constantly exposed to certain mechanical tension, and this is one of the reasons for its faults during service. Tension degree can be determined by the OC structure and OF placement as a structure element. Fault properties of glass OF, which is exposed to tension, can be found out, by establishing a relation between imposed load in time and OF fault probability. Moreover, the following parameters should be considered like characteristics of crack growth n, and ultimate load factor. Then integrated fault probability F of L length optical fibre exposed to σ tension can expressed as:

$$F = 1 - exp[-LN(\sigma)], \quad (1)$$

where $N(\sigma)$ is an integrated number of cracks per OF length unit, provided that breakage strength is no fewer than tension.

Given that initial strength S_i conforms to Weibull distribution, we get:

$$N(S_i) = \left(\frac{S_i}{S_0}\right)^m, \quad (2)$$

where S_0 and m are constants referred to initial strength distribution. Value m displays slope of curve in Weibull distribution.

Based on (1) and (2), the correlations were received in the paper [3], which allows us to assess the time of OF service.

Forecasting of OF fault probability usually is based on the results of its strength testing. To assess initial strength distribution, the OF long length tension determination test is carried out. In addition to this, the OF fault probability is determined during strength test N_p, by calculating of number of breakouts while testing.

The result was the following correlation for calculation of permissible tensions:

$$\frac{\sigma_s}{\sigma_p} = \left(\frac{n-2}{m} \cdot \frac{F_s}{LN_p} \cdot \frac{t_p}{t_s}\right)^{\frac{1}{n}}, \qquad (3)$$

where σ_p is tension the OF is exposed to during the strength test (%); σ_s is static tension, the OF is exposed to beyond strength test; t_p– duration strength test; t_s – static tension time; F_s – OF fault probability.

Value n can be assessed with the help of this dynamic ageing test [5, 6]. Value m is much harder to determine, especially for long length fibres. To do this, e. g., repeated strength test can be carried out.

If σ_{p1}, t_{p1} и σ_{p2}, t_{p2}, is tension and time of test one and test two, the following correlation will be fair for determination of $(n-2)/m$ [3], respectively:

$$\frac{n-2}{m} = \frac{\lg\left(1+\sigma_{p2}^{n} t_{p2}/\sigma_{p1}^{n} t_{p1}\right)}{\lg\left(1+N_{p2}/N_{p1}\right)}. \qquad (4)$$

Thus, the OF reliability can be calculated only by the number of faults occurred during strength test.

It should be noted that formula (1) allows us to assess permissible OF tension in the cable in the context of its lifetime.

Fig. 1 shows the graph forecasting permissible tension after strength test to secure durable OF service.

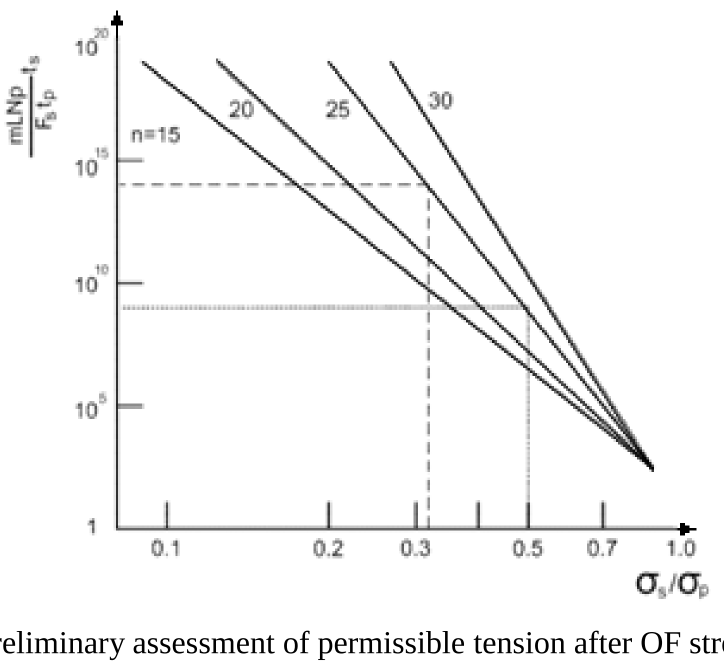

Fig. 1. Preliminary assessment of permissible tension after OF strength test

It can be seen from Fig.1 that relation σ_s/σ_p is approximately equal to 0,3 for fibre service time $t_s = 25$ years (shown with dash lines). Moreover, values of other parameters are: L = 1000 km, n = 25, m = 10, F_s = 0,01, t_p = 2 c, N_p = 0,1 fault/km. It can also be seen that relation σ_s/σ_p is reduced if value n is reduced, what happens in case of high ambient humidity.

The described method can be used to forecast faults of long length OFs without measuring of initial strength distribution.

Fig. 2 shows graphs for assessment of permissible tension after strength test to secure durable OF service and with parameters: σ_s = 0,2%; n = 23; m = 3; σ_p = 1,1%; t_p = 0,5 c; N_p = 0,0067 (1/km) (or 1 fault per 150 km).

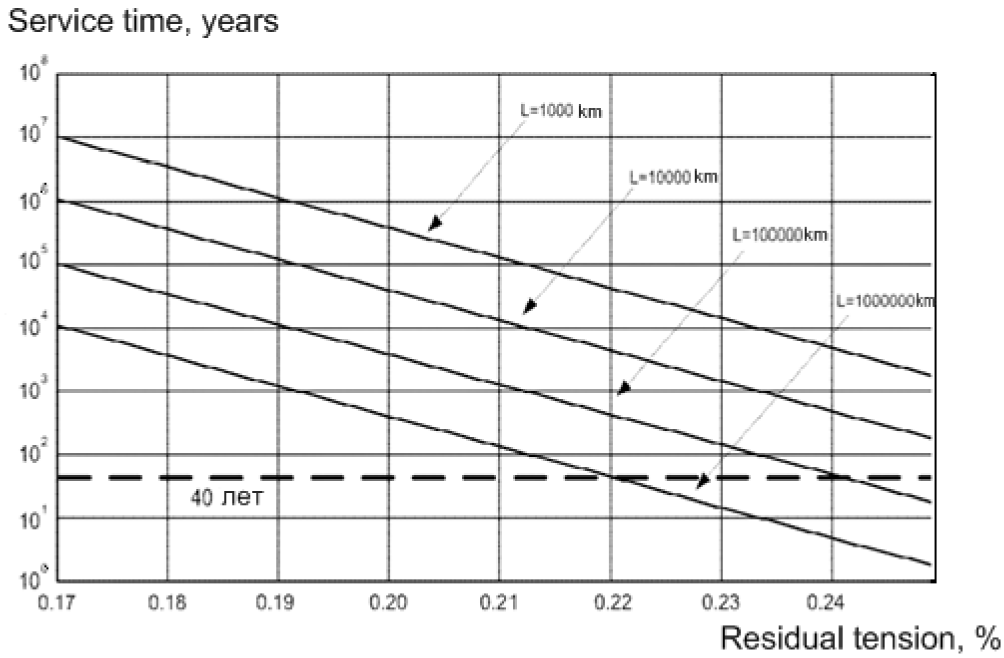

Fig. 2. Dependence of OF service time on residual tension

As it can be seen from graphs, residual tension plays important role for increase of optical fibre line reliability. This should be considered when choosing the technology for optical cable installation.

Account of residual tension is needed during optical cable installation in the premises, during optical cable mounting in optical closures, distribution cabinets and boxes where OC and OF with it is considerable bent. In such case optical fibre may not only be exposed to residual tension, but to residual stress predefined by optical fibre bends (Fig.3).

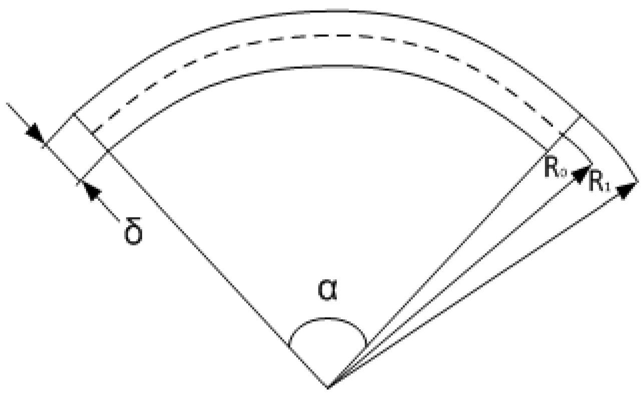

Fig. 3. Occurrence of tension deformation on OF external surface when bent

As it can be seen from Fig. 3, external surface of optical fibre is stretched out when bent and internal surface is compressed. Relative elongation of fibre external part makes$\delta/2R_0$, where δ is fibre diameter, R_0 is bending radius.

It is easy to assess relative deformation of OF external part depending on bending radius. If we take standard OF with 125 µm, we will get the results shown in Fig. 4.

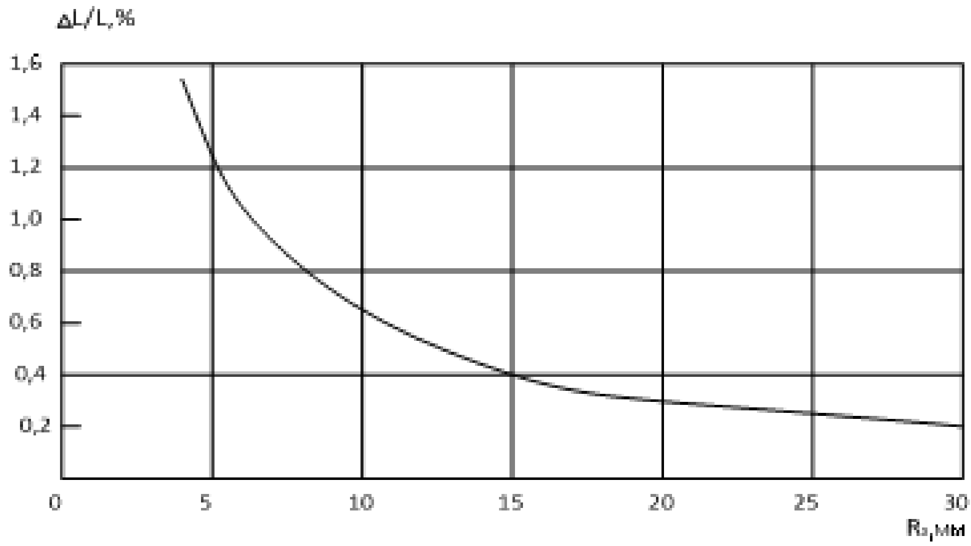

Fig. 4. Dependence of relative deformation of OF external surface when bent on bending radius

Considering the values of OF lifetime dependence on relative elongation mentioned in the paper [6], OF lifetime can be determined depending on bending radius. For instance, to achieve the value for fibre services for 25 years, its relative elongation must not exceed 0.3%. In compliance with Fig. 4, this meets to bending radius approximately equal to 20 mm.

Use of smaller bending radius during optical equipment mounting visibly reduces OF lifetime, though it is quite permissible under ITU-T recommendations. With the value of relative elongation at 0.33%, the OF lifetime is reduced up to 5 years already. Thus, during design and installation of optical networks, optical cable bending radius should chosen based not only on their permissible bending radius but lifetime either. In this case special focus should be on OF, which meet ITU-T G.657 recommendations, because their permissible bending radius does not secure practically needed OF lifetime.

Considering that relative deformation of tension according to the Hooke's law is associated with the OF stress as follows:

$$\frac{\Delta L}{L} = \frac{\sigma}{E}, \tag{5}$$

where ΔL is OF absolute elongation, L – OF length, σ – stress tension in OF, E – Young's modulus of OF material, then based on relative elongation value stress tension in OF can be determined:

$$\sigma = \frac{\Delta L}{L} E\,, \tag{6}$$

which also uniquely determinates OF lifetime.

Fig. 5 shows the results of experimental research carried out by Fujikura company, which make it possible to assess the OF lifetime in case of known tension stress values in it [7].

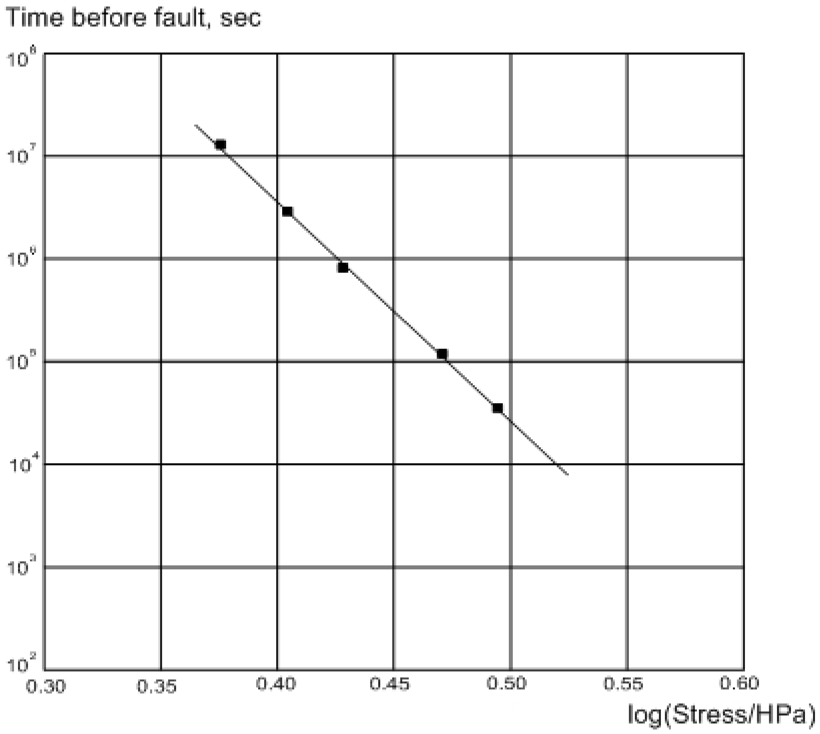

Fig. 5. Dependence of time before fault on tension stress level in OF during static fatigue tests

Thus, during design of optical cable networks for internal installations optical cable bending and OF, respectively, radius in stationary service conditions should be considered. Special focus should be on new type fibres, for which in line with ITU-T standards permissible bending radius is essentially lowered. Furthermore, conformity of project bending radius to optical network lifetime must be mandatory checked, and its value must be adjusted, if appropriate.

III. CONCLUSION

The analysis conducted in the paper makes it possible to design optical networks with regard to their lifetime and especially those areas, where optical cables are bent. Furthermore, special focus should be on optical lines built with the use of new type OF, for instance, those in line with ITU-T G.657 recommendations. Such OF have reduced permissible bending radius, which results in considerable reduction of optical network lifetime, i.e., its reliability reduction.

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