Research of the Additional Losses Occurring in Optical Fiber at its Multiple Bends in the Range Waves 1310nm, 1550nm and 1625nm Long

A V Yurchenko [1], N I Gorlov [2], A D Alkina [3], A D Mekhtiev [3], A A Kovtun [4]

[1] Professor, Tomsk Polytechnic University, Tomsk, Russia
[2] Professor, Head of "Communication lines" Department in Siberian state university of telecommunications and information sciences, Novosibirsk, Russia
[3] TPU graduate student, master's degree in "Information Technologies and communication systems"
[4] Head of "The technology and communication systems" Department in Karaganda State Technical University, Karaganda, Kazakhstan
[5] Undergraduate in Siberian state university of telecommunications and information sciences, Novosibirsk, Russia
E-mail: barton.kz@mail.ru

Abstract. Article is devoted to research of the additional losses occurring in the optical fiber at its multiple bends in the range waves of 1310 nanometers, 1550 nanometers and 1625 nanometers long. Article is directed on creation of the external factors methods which allow to estimate and eliminate negative influence. The automated way of calculation of losses at a bend is developed. Results of scientific researches are used by engineers of “Kazaktelekom” AS for practical definition of losses service conditions. For modeling the Wolfram|Alpha environment — the knowledge base and a set of computing algorithms was chosen. The greatest losses are noted on wavelength 1310nm and 1625nm. All dependences are nonlinear. Losses with each following excess are multiplicative.

1. Introduction

Further development of communication and telecommunication is already impossible without digital fiber-optical systems using, in view of their indisputable advantages before the directing systems with copper conductors. Despite of positive results and the moments of using fiber – optical transmission lines (FOTL) there are shortcomings connected with the feature of information signal distribution in the optical fiber, its design connected with its criticality to different external influences and loadings. Distinctive feature of the optical cable (OC) in comparison with electrical cabels is availability of quartz fiber instead of copper, which is subject to aging, degradation and can be the reason of the cable exit out of the operation. Therefore it is necessary to consider separately the optical fiber (OF) and the optical cable OC in general.

The introduction features of optical technologies in Kazakhstan are the considerable extent of highways, because of the huge territory taking the 9th place in the world on the area of the terrestrial land with rather low population density falling on one inhabitant. It is necessary to create extended main and intra-zone lines with large volume OC various types and other technical equipment.

Economic consequences of that are relative expenses 2,3 times more in comparison with the average world expenses. It must be kept in mind feature that Kazakhstan in considerable part is in a zone of a severe temperate climate with sharp temperature differences. An important point in ensuring standard reliability and efficiency of the optical directing systems operation throughout the long term of OC operation is the question of elimination of factors of negative external mechanical loads influence of the OF and a cable and also on the transfer system of transfer in general [1]. The creation of methods which allows us to estimate and eliminate negative influence, in particular a bend which reduce reliability of FOTL and serve as the reason of increase in losses service conditions of "Kazaktelekom" AS based on the hierarchical approach, is a novelty and solves an actual problem of the applied direction. FOTL is one of conservative telecommunication parts, which has to be operated based on considerable capital and labor OC expenditure [2].

While laying of the fiber-optical communication lines there are questions of external impacts influence on the optical cable characteristics of an optical cable. The most important is the influence of optical fibers bends on additional losses of radiation power in an optical cable. In case of deformation, namely a bend of optical fiber there are additional losses of energy. The size of these losses depends on many reasons, but the main can be at achievement of a certain critical bend radius. In case when the bend radius makes only some millimeters at fibers with a high numerical aperture and when radius about tens centimeters for fibers in the single-mode mode with a big cross mode area [2].

Losses are observed at macroscopic bends of fiber, which arise at operation owing to emergence of roughnesses (violations of structure) in fiber, which are explained by imperfection of manufacturing techniques or installation. The bends arising in fiber can be divided into two types [2] conditionally. Microbends are the small local violations of fiber straightforwardness caused by constructive and technological discontinuity, which can arise at a fiber production, and also laying and production of a cable [2]. Fiber macrobends appear as a result of their twist on the cable length and winding on a drum. Losses are caused by an effluence or radiation of the directed modes and become inadmissibly big at the radius reduction of the bend curvature to critical values. Critical radius of a fiber bend approximately pays off on a formula (1):

$$R_{cr} \approx \frac{3n_1^2\lambda}{4\pi\left(n_1^2-n_2^2\right)^{3/2}} \qquad (1)$$

where n_1, n_2– refraction indicators of a core and cover; λ – the wavelength of the applied radiation.

We executed the influence researches on external impacts on OC in particular at a bend leading to growth of additional losses dB on which results basis the radius calculation method the optical cable (OC) at mechanical influence is developed. The obtained data will allow to create automated calculation method for the solution of an actual problem of the "Kazakhtelekom" AS FOTL operation efficiency. In particular the task of additional losses definition in dB at various bend angles of a cable in 45, 90, 135 degrees was set, depending on wavelength 1310nm, 1550nm and 1625nm, the quantity of fiber bends is also considered. As object of research single-mode G-652 fiber 10 meters long was used. The dead zone of the reflectometer makes 0.75 meters (according to the passport).

At the decision of the theory of the directing systems, theories of transfers lines, calculus mathematics, computer processing of experiment tabular data, programming in the environment of DBMS, methods of computer and imitating modeling with the using of Wolfram|Alpha were used. The approximations executed by us will allow to receive value of additional losses in dB at various combinations of bend angles and their quantities.

During the first experiment 70 measurements were taken. On ten measurements for one, two, three, four, five, six and seven excesses, with a radius of curve not less than 5 mm, at an angle in 45 degrees for one site of FOTL. Also the other experiments are similarly made. For researches the special stand representing the panel with a grid at a slow pace in 1sm with fixing bolts on each centimeter, for giving it any form to a fiber-optical cable without possibility of its mechanical damage was manufactured (figure 1).

During research nine groups of experiments will be carried out. On three types of a corner for each frequency separately. All experiments are made by means of the high-precision reflectometer of

Yokogawa AQ1200E firm. A series of optical Yokogawa AQ1200E reflectometers are developed especially for work on city or local networks when it isn't necessary to measure long distances, and compactness when moving is necessary on foot between objects. Yokogawa AQ1200E is a multipurpose tester, it can be completed with the certain port of the measuring instrument of power for measurement of losses, a source of visible radiation for search of damages, the video probe for optical sockets check.

For losses definition on fiber at bends the stand of five probe zones in size 0.5m×0.5m for a cable laying was made. Each probe zone represents an array 11×11 with a step in 1sm. While laying a cable various variations – with a corner 45, 90,135 degrees are possible. Radius of a cable excess makes 1.5–1.7sm that corresponds to critical angles of a bend which most often turn out at the wrong cable laying or at other situations when the cable is bent under critical angles.

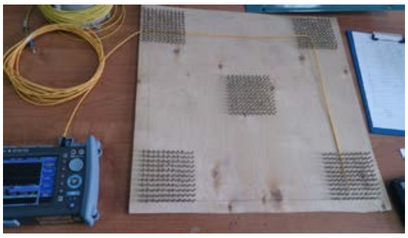

Figure 1. Laboratory stand.

The important point is that the automated method development capable to give out values of losses, when using various lengths of waves and at various laying of a cable, for further planning of laying FOTL within laboratories, buildings, server rooms, offices, etc. PO has to apply various dependences of losses calculation, to obtaining the most exact data on short sites of a fiber-optical cable or to definition of losses on a long site of FOTL at a smaller quantity of excesses.

During the first experiment the fiber-optical cable was fixed at the stand at an angle in 45 degrees in quantity from one to seven. For more exact statistical data it was removed on 10 indications for each corner.

The schedule have a nonlinear dependence, about increase in quantity of bends losses increase. During the following experiments made similarly dependences for all other cases were revealed. Schedules are compared and revealed the main regularities. Nonlinearity of growth of losses. Multiplication of losses for each corner.

For modeling the Wolfram|Alpha environment was chosen the knowledge base and a set of computing algorithms [3]. Wolfram Alpha is the system intended for storage, processing and delivery to users of the structured data on inquiries in natural English. Wolfram Alpha isn't a search engine. It is caused by that it isn't intended for automatic processing of unstructured texts. For its work it is necessary to enter manually previously factual information into a database, and also to develop and realize algorithms of its processing. These procedures are carried out manually by community of developers and experts of Wolfram Alpha.

The Wolfram|Alpha project is created by the well-known mathematician Stephen Volfram on the basis of the theory about a computability. Actually, its sphere all is built on IT. Stephen devoted to idea of calculations more than thirty years and created two significant projects: Mathematica and Wolfram Alpha. The first represents system of computer algebra, and the second — the knowledge base and a set of computing algorithms on the basis of the first

Wolfram Mathematica (WM) is a package of symbolical mathematics. The huge number of the functions put by developers, and also the open environment allowing to supplement a package with own expansions makes its opportunitues truly boundless. Mathematica has high speed and almost not limited accuracy of calculations that allows it to work as at very powerful computers, and not really strong personal computers. On the basis of a kernel of a package there is a Web server which allows to use its opportunities to unlimited number of people.

General competitors of a package are called Maple, MathCAD and MatLab. If with the first it is difficult to argue, about MathCAD and MatLab it is possible. The matter is that these two packages occupy absolutely other niche, than Mathematica. Both use numerical algorithms at calculation but not symbolical. Symbolical calculations are poorly developed (in comparison with packages of symbolical calculations) additions. Much more similar product is free of charge extended Maxima package.

Results of experiments were processed with use of Wolphram Alpha, the most plausible models of approximation are: polinomal approximation of the fourth degree, cubic approximation, square approximation.

For wavelength 1310nm, for corners 45 °.

Experiment studying results are presented on the figure 2.

According to the handler: polinomal approximation (2) of the fourth degree (quartic):

$$-0.0000751894\,x^4 + 0.0011976\,x^3 - 0.00660133\,x^2 + 0.0168207x \quad + 0.0363341 \tag{2}$$

cubic approximation (cubic) (3):

$$-0.000144949\,x^3 - 0.00203626\,x^2 + 0.0106552\,x + 0.0372364 \tag{3}$$

square approximation (quadratic) (4):

$$-0.000514286\,x^2 + 0.00666905\,x + 0.0387583 \tag{4}$$

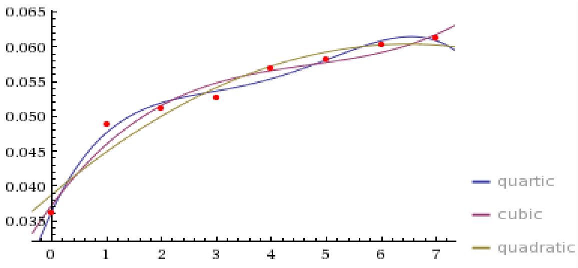

Figure 2. Schedules of accuracy comparison.

Here it is well noticeable that the most satisfying result is yielded by polinomal approximation of the 4th degree and a cubic approximation.

For wavelength 1550nm for corners 45 °.

Experiment studying results are presented on the figure 3.

Polinomal approximation (5) of the fourth degree (quartic):

$$0.0000105114\,x^4 + 0.000213068\,x^3 - 0.000987973\,x^2 + 0.00292265\,x \quad + 0.048486 \tag{5}$$

Cubic approximation (6):

$$0.0000659091\,x^3 - 0.000349784\,x^2 + 0.00206071\,x \quad + 0.0486121 \tag{6}$$

Square approximation (quadratic) (7):

$$0.000342262\,x^2 + 0.000248214x \quad + 0.0493042 \tag{7}$$

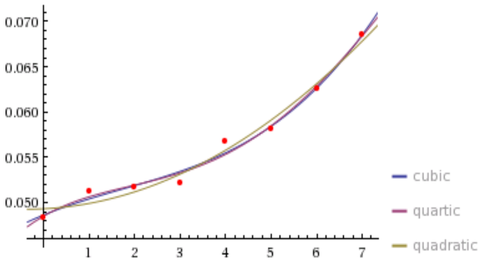

Figure 3. Schedules of accuracy comparison.

Here it is well noticeable that the most satisfying result is yielded by polinomal approximation of the 4th degree and cubic approximation.

For wavelength 1625nm for corners 45 °.

Experiment studying results are presented on the figure 4.

Polinomal approximation of the fourth degree (quartic) (8):

$$0.000104072\,x^4 + 0.00167948\ \ x^3 - 0.00868381\,x^2 + 0.019243\,x \quad + 0.0362693 \tag{8}$$

cubic approximation (cubic) (9):

$$-0.000222475\,x^3 - 0.00236515\,x^2 + 0.0107091\,x \quad + 0.03751820 \tag{9}$$

square approximation (quadratic) (10):

$$-0.000514286\, x^2 + 0.00666905\, x + 0.0387583 \quad (10)$$

Schedules of accuracy comparison:

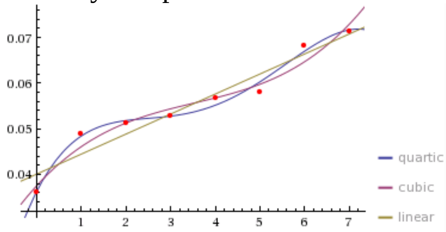

Figure 4. Schedules of accuracy comparison.

Experiment general results are presented on the figure 5.

Here it is well noticeable that the most satisfying result is yielded by polinomal approximation of the 4th degree and cubic approximation.

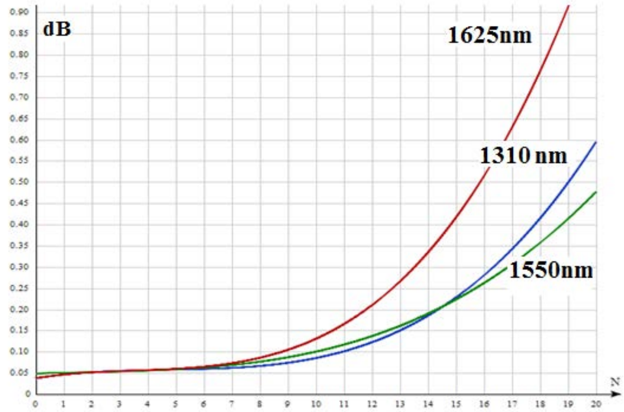

Figure 5. Schedules of comparison of losses for the wavelength of 1310 nanometers, 1550 nanometers, 1625 nanometers, with a bend angle 45 °.

We made experiments of measurement of additional losses in wavelengths 1310nm, 1550nm, 1625nm for corners 90 ° on the figure 6. Results of experiments are processed by means of the Wolphram Alpha program. We made experiments of measurement of additional losses in wavelengths 1310nm, 1550nm, 1625nm for corners 135 ° on the figure 7.

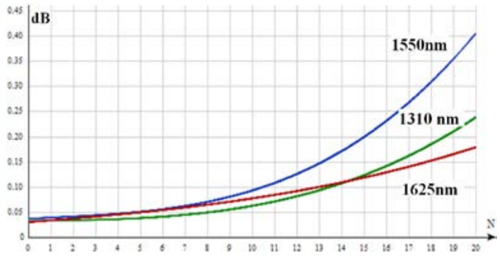

Figure 6. Schedules of comparison of losses for the wavelength of 1310 nanometers, 1550 nanometers, 1625 nanometers, with a bend angle 90 °.

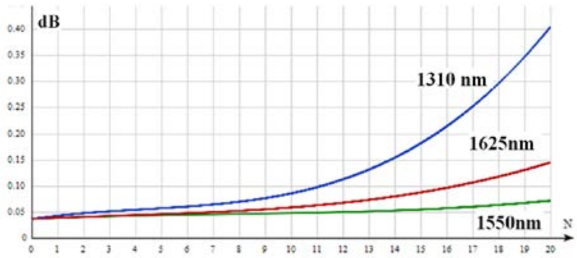

Figure 7. Schedules of comparison of losses for the wavelength of 1310 nanometers, 1550 nanometers, 1625 nanometers with a bend angle 135 °.

Drawing up the program for calculations of losses on different lengths of waves at different corners. In the environment of Delphi 7 development of the program with which it is possible to estimate losses in optical fiber at multiple bends of critical radius was developed. A window of the program for the automated calculation of additional losses of OV with its multiple bends in the range waves 1310nm, 1550nm and 1625nm long is shown on the figure 8.

The program has intuitively cleared interface and allowed to carry out visualization of bends losses. For creation of the schedule the program uses a method of cubic approximation which showed on the highest precision.

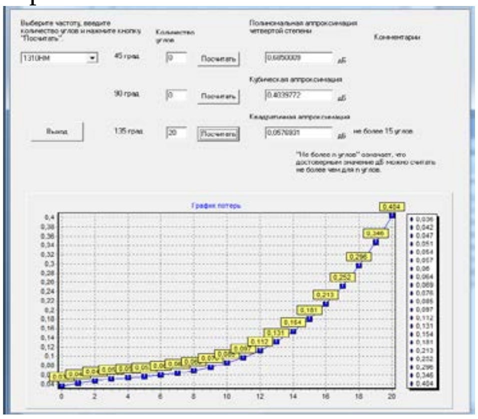

Figure 8. A window of the program for the automated calculation of additional losses of OV with its multiple bends in the range waves 1310nm, 1550nm and 1625nm long.

4. Conclusion

During research work experiments with various corners of optical fiber excesses and also loss of FOTL were made for each of standards of work: 1310nm, 1550nm, 1625nm. The greatest losses are noted for waves 1310nm and 1625nm long. All dependences are nonlinear. Losses with each following excess are multiplicative.

In most cases losses at a bend strongly increase with a length of waves 1625nm because they are strongly defined by existence of an interference of light reflected from cover/border of a covering and/or from an external surface of a covering. The increase in losses at a fiber bend on big lengths of waves limits ranges a transmission of single-mode fibers. The greatest losses are caused by an excess in 45 degrees. It is possible to see that with increase in a corner of loss fall as well as with increase in wavelength.

During research data according to which mathematical models of dependences of losses on quantity a catch, types of corners and wavelength were multiply obtained. The software prepared by them allowing to calculate automatically losses of OC service conditions of “Kazaktelekom” AS at various quantities of bends in the waves range 1310nm, 1550nm and 1625nm long.

References

[1] Gorlov N, Mekhtiyev A, Airikh V, Aldoshina O, Kshalova A 2014 *Methods and gages of optical fiber communication lines parameters* (Karaganda: Publishing house of KSTU)
[2] Gambling W (2000) *The Rise and Rise of Optical Fiber* IEEE Journal on Selected Topics in Quantum Electronics **6** (6) 1084–1093 doi: 10.1109/2944.902157
[3] Mitschke F 2009 *Fiber Optics – Physics and Technology* (Berlin; Heidelberg: Springer)
[4] Ramaswami R, Sivarajan K, Sasaki G 2009 *Optical Networks: A Practical Perspective.*(Morgan Kaufmann; 3rd edition)
[5] http://www.wolframalpha-ru.com