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An Effect Of Pressure Bending In Single Mode Optic Fiber On Light Intensity Attenuation

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ABSTRACT
Single-mode optical fibers are widely used in modern communication systems due to their high data transmission capacity and low signal attenuation. However, the physical condition of the optical fiber, such as bending caused by mechanical pressure, can affect transmission performance. This research aims to analyze the effect of pressurized bending on single-mode optical fibers and its impact on the attenuation of transmitted light intensity. Experiments were conducted by varying the bending radius and pressure applied to the optical fiber to measure changes in the received light intensity. The results show that as the bending radius decreases and the applied pressure increases, the attenuation of light intensity increases significantly. The reduction in light intensity occurs due to the leakage of light modes from the fiber core as a result of physical deformation in the fiber structure. These findings are important for designing more efficient and resilient optical fiber installations, especially in environments prone to physical pressure and bending.

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INTRODUCTION

Optical fiber has become a key component in modern communication technology due to its ability to transmit data at high speeds and over long distances. In fiber optic communication systems, single-mode optical fiber is used to transmit light through a single propagation mode, which allows for more stable data transmission and lower signal attenuation compared to multimode optical fiber. However, despite its many advantages, its performance can be affected by various external factors, one of which is physical bending of the fiber.

Bending of optical fiber is often unavoidable in real-world applications, such as installations in confined spaces, pulling fibers on network infrastructure, or due to mechanical stress applied during installation or use. When an optical fiber bends, the light propagation path changes, which can cause attenuation or even significant signal loss. Bends with a small radius, especially when accompanied by high stress, can result in leakage of light energy from the fiber core, thereby reducing transmission quality.

The increasing density of cable tunnels (subducts) today to reduce congestion requires smaller cables, namely by using fiber optics. Fiber optic technology is a media construction network that provides large bandwidth that is not affected by electromagnetic wave interference, is free of corrosion and minimal losses for data transportation. Because fiber optics are able to transmit signals far away, fiber optic installations require several coils to maintain the fiber when it expands due to heat. From these coils, losses will occur which are called macrobend losses. This thesis will analyze the calculation of losses that occur due to the influence of the bend of the optical fiber.

This study aims to analyze the effect of pressure bends on single-mode optical fibers, and expected to provide new insights into the bend tolerance limits of single-mode optical fibers and offer solutions to minimize the impact of light attenuation caused by mechanical factors with a focus on how the bends affect the attenuation of the transmitted light intensity. Understanding the relationship between physical bends and signal quality degradation is essential in designing reliable and efficient optical communication systems, especially in environments that are vulnerable to mechanical stress or installations that require fiber flexibility.

Literature Review

Previous Research

In today's communication systems, fiber optic communication is increasingly used. Not only as a replacement for previous types of transmission systems, but because this fiber optic system provides much more effective and efficient advantages than others. This type of fiber optic communication is also non-conductive, so it can be used in electrically isolated areas. Because it has a high information capacity, the channel lines can be condensed into much smaller cables, thereby reducing traffic flow on very dense cable lines. In this fiber optic communication system, the initial signal in the form of an electrical signal on the transmitter will be converted by the transducer into light waves which are then transmitted through the fiber optic cable to the receiver located at the other end of the cable. At the receiver, this optical signal will be converted back by the transducer into an electrical signal.

Singlemode-Multimode-Singlemode Fiber Optic Sensor Research

The development of fiber optics as sensors has been widely developed and progressed. Fiber optic sensors are divided into two, namely extrinsic and intrinsic fiber optic sensors. Currently, the development of fiber optics as intrinsic sensors. Fiber optics as intrinsic sensors function as light guides and play a role in the sensing process. In the light guidance process, external interference such as mechanical and temperature interference will occur, so fiber optics can be applied as a sensor. Various fiber optic structures that can be used as sensors are singlemode fiber, multimode fiber, plastic fiber optics, singlemode-multimode-singlemode (SMS) structures and multimode-singlemode-multimode (MSM) structures. One example of an intrinsic optical sensor is the singlemode-multimode-singlemode (SMS) structure. Research into various types of fiber optic sensors with SMS structures has been widely developed, including temperature, strain, load, refractive index, pressure, humidity, current, voltage, gas sensors, chemical sensors, etc. The SMS fiber structure is by connecting two singlemode fibers with multimode fibers at each end (A. Kumar et al., 2003). A. Kumar et al. explained that the SMS structure is used as a sensor by utilizing the multimode interference (MMI) phenomenon that occurs due to the difference in

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diameter of the singlemode fiber and multimode fiber when at the connection point.

Research conducted by R.X. Gao et al. on the use of SMS fiber structures for liquid refractometers. SMS fiber structures are fabricated by connecting singlemode fibers and multimode fibers with a length of 6.05 mm. The diameter of the multimode fiber is ~82 μm and the diameter will be controlled by monitoring the output power during the etching technique using a hydrofluoric acid (HF) solution. The length parameter of the multimode fiber will not change while the fiber diameter will change during the immersion process in the HF solution. The results of this study are that the SMS sensor has a sensitivity of ~4.6 x 10-6. This SMS fiber-based refractometer sensor shows that it can be used to monitor the refractive index accurately in the fields of chemistry and biomedicine (Gao et al., 2012). SMS fiber sensor as a liquid level sensor has been conducted by Yu Zhao et al in 2013. In this study, to increase sensitivity, the cladding of the multimode fiber was dipped in a hydrofluoric (HF) solution for 12 minutes and the length of the multimode fiber was 3.2 cm with a core diameter of 100 μm. The liquid sample used for level measurement is water. The multimode fiber in the SMS structure acts as a sensor probe. The results of this study are that the sensitivity produced is 1.02 nm/mm and 1 dBm/mm (Yu Zhao et al., 2013). Research on temperature sensors using SMS fibers that have high sensitivity. In this study, there are two types of materials used as a substitute for multimode fiber cladding, namely fluoroacrylate and silicone elastomer.

The two types of materials are compared to determine better sensor performance. The light source produced from Amplified Spontaneous Emission (ASE) is transmitted into the singlemode fiber then passes through the multimode fiber and the MMI phenomenon occurs. The output of the multimode fiber is recombined into a singlemode fiber to be detected by the Optical Spectrum Analyzer (OSA). The SMS fiber sensor is placed on a hotplate with a temperature variation of 30 - 80oC. The resolution of the temperature sensor is 5.5 x 10-3 oC with a sensitivity of 0.1 nm / oC. This study is useful in making the right choice of multimode fiber type depending on the application whether it requires high temperature sensitivity or low temperature sensitivity (Kushida, Fukano, & Taue, 2013). Research conducted by Manoj Kumar et al. in 2014 regarding the comparison of temperature sensors using SMS fiber graded index and step index multimode fiber types.

Temperature changes will affect the refractive index, length and core radius of the fiber. The calculation of sensitivity is known by the presence of a peak spectral shift that changes with increasing temperature. The sensitivity of the SMS fiber sensor using the step index multimode fiber type is smaller than the graded index. This is because the peak spectral shift in the step index type SMS sensor is very small so that the spectrum at two temperatures almost overlaps (M. Kumar, Kumar, & Mani, 2014).

Principle of Light Guidance in Optical Fiber

Light guidance in optical fiber is based on the principle of total internal reflection (TIR). Total Internal Reflection is the principle of light guidance. Light can be guided through optical fiber because the light beam comes from a medium with a larger refractive index (n1) to a medium with a smaller refractive index (n2). The angle of the incident light beam is smaller than the critical angle (ϴcr), then the light will be refracted out of the optical fiber.

The angle of the incident light beam is greater than the critical angle, then the light will be reflected back into the optical fiber. The critical angle is the magnitude of the incident angle that produces a refractive angle of 90° (Ghatak & Thyagarajan, 1997).

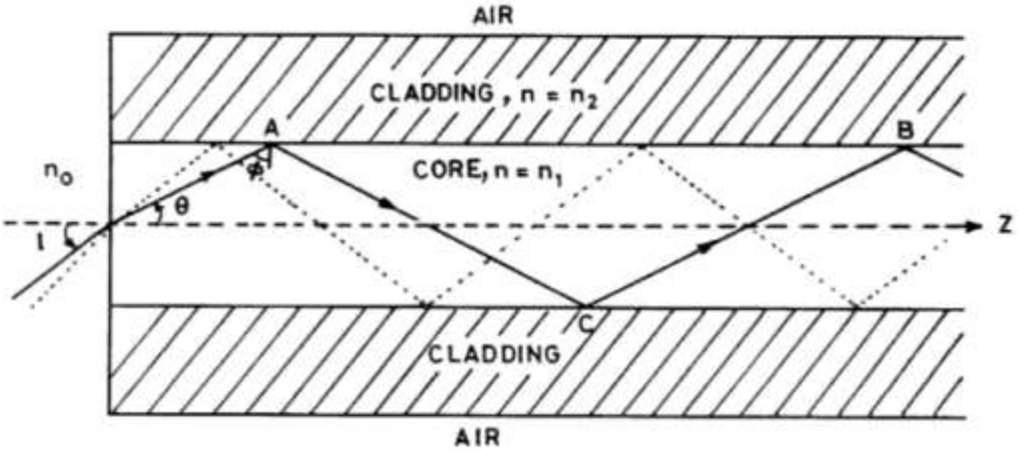

Figure 1. Light Bending In Optical Fiber

Light propagating from singlemode optical fiber to multimode optical fiber in SMS optical fiber will experience a multimode interference (MMI) phenomenon. MMI occurs due to differences in the input profile of light in the optical fiber. The MMI event is a phenomenon that occurs due to repeated reflection of light in the arrangement of the core and cladding of the optical fiber. The repeated reflection event causes interference between modes. The interference that occurs can be constructive or destructive. The reflection of light with many modes that occurs repeatedly at a periodic time span along the guide is called a self-imaging event. Self-imaging that occurs in multimode optical fiber is one type of constructive interference.

Sensor Characteristics

Sensors are often defined as devices that receive stimuli and respond with electrical signals. Stimulus is a certain condition in an environment that will be detected or captured by the sensor (Fraden, 2016). The definition of a sensor in a measurement system is the first element that provides an output signal as a function of a certain physical quantity input (Bentley, 2005). Sensor characteristics are the performance of a sensor. Sensor characterization is carried out to determine the performance of a sensor that has been designed. One of the characteristics of a sensor is a static characteristic which includes span, range, linearity, sensitivity, resolution and hysteresis (Fraden, 2016).

Span is the measurement range where the sensor can still respond to the stimulus given. The sensor measurement range lies at the input and output of the sensor. The measurement range must be calculated from the difference between the maximum input and the minimum input, while the output measurement range is also calculated from the difference between the maximum output and the minimum output.

The input measurement range is the minimum input value to the minimum input. The output range is the minimum output value to the maximum output. Linearity is an ideal characteristic of a measurement system. Sensitivity will show how far the sensitivity of a sensor is. The sensitivity of a sensor can be known from the comparison of output changes to input changes. Resolution is the presence of the largest change in the sensor input value will not cause a change in the sensor output value. Hyteresis is the difference in the sensor output value that can be obtained from the up measurement and down measurement of the same input value.

METHOD

The research method used is qualitative-quantitative, namely research that tends to be descriptive-analytical, and prioritizes processes and meanings based on calculations. The theoretical basis is a very crucial guide so that the research results are expected to be close to the facts in the field. And the simulations carried out are based on mathematical formulas (models) that have been derived.

Therefore, this study uses instruments in the form of literature studies and Matlab programming simulations. Literature studies are a series of activities related to library data collection methods, reading and recording, and processing research materials. This research method is needed to strengthen the research foundation by tracing various references related to the intended research topic. The results of the literature study are then applied to the mathematical model by determining several parameters that are conditioned for two simulations: macrobending and microbending.

This experiment was designed to test various bending and pressure conditions on single-mode optical fibers and measure their effect on the intensity of transmitted light. Some of the parameters tested include:

a. Bend radius variations, Bends on optical fibers are carried out with various radii, ranging from large to small, to simulate fiber installation conditions that are common in the field.
b. Applied pressure, Various levels of mechanical pressure are applied to the optical fiber to assess its impact on light attenuation.

where the material used

a. Single Mode Optical Fiber, Single mode optical fiber is used in this test because its sensitivity to bending is higher compared to multimode fiber.
b. Light Source, A laser light source with a wavelength that matches the characteristics of the single mode optical fiber is used as the input light transmitted through the fiber.
c. Optical Power Meter, Used to measure the light intensity before and after the optical fiber is subjected to pressure bending.
d. Bend and Pressure Tester, This tool is used to provide controlled bending to the optical fiber and provide proper mechanical stress during the test.

The test is carried out with the following steps Optical Fiber Preparation: The single mode optical fiber is prepared with a certain length, and both ends are connected to the light source and optical power meter. then the optical fiber is bent with different bending radii, ranging from large to small radii, according to the experimental design. After the fiber is bent, mechanical stress is applied at the bending point to simulate the physical stress that

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may occur in real installation conditions.

After each change in the bend radius and pressure, the transmitted light intensity was measured using an optical power meter. This data was compared with the light intensity measured before the fiber was bent or stressed.

The light intensity data obtained from each experiment were analyzed to determine the relationship between the variation in the bend radius and pressure and the degree of light intensity attenuation. An equation or mathematical model describing this phenomenon was developed based on the measurement results.

The test was repeated several times to ensure the consistency and validity of the results. Experimental variations were carried out to ensure that the measured attenuation was truly caused by the bend and pressure, not other factors such as defects in the fiber or light source. With this method, it is expected to obtain comprehensive results regarding the effect of pressure bending on the transmission performance of single-mode optical fibers, which can later be used to improve the reliability of optical communication systems.

RESULT

Configuration of multimode coreless fiber sensor as a probe

Testing of SMS fiber optic sensor for magnesium ion detection is done by placing the sensor in a container filled with magnesium ion liquid. The input sample variation tested is magnesium ion with a concentration of 0% -5%. The SMS fiber optic sensor is first characterized at a wavelength of 1550 nm with an input power of -6 dBm. Determination of the quality of the SMS fiber optic sensor before use is by determining the output power after splicing with a splicer. The light source used is an optical light source (OLS) and will be detected as the output power of the optical fiber by an optical power meter (OPM) which in this study uses THORLABS PM100USB.

The principle of light transmission in SMS fiber optic is that the light produced by the OLS will be transmitted from single-mode optical fiber to multimode optical fiber. In multimode fiber, a multimode interference (MMI) phenomenon will occur which occurs due to differences in the light input profile in the optical fiber, where single-mode fiber has a smaller diameter compared to multimode fiber. So that the MMI phenomenon occurs due to repeated reflection of light in the core and cladding arrangement of the optical fiber. The repeated reflection events cause interference between modes. The interference that occurs can be constructive or destructive. Multimode fiber acts as a sensor probe. Light that has passed through the multimode fiber will be transmitted to the single-mode fiber and will be received by the OPM as output power.

Analysis of Sensor Characteristics and Stability of Straight Configuration SMS Fiber Optic Sensor

The performance testing of SMS fiber optic sensor was conducted to determine the characteristics of the fiber after splicing. The test was conducted by connecting a 1550 nm laser light source with an input power of -6 dBm and received by the OPM as output power so that the power loss due to splicing was known. The multimode optical fiber used as a sensor probe is a coreless multimode fiber. Coreless multimode fiber does not have a core so that the cladding on the fiber acts as the fiber core. In this test, air acts as the cladding of the coreless multimode fiber. The core refractive index of 1.44 is greater than the air refractive index of 1 so that light will continue to propagate along the fiber according to the principle of Total Internal Reflection (TIR). Based on this, there should be no power loss due to differences in refractive index, but power loss can be caused by splicing at both points on the SMS optical fiber. The initial step before measuring the output power of the optical fiber, a light source stability test is carried out first. This is done to find out how long it takes for the light source to be used to measure the output power of the fiber.

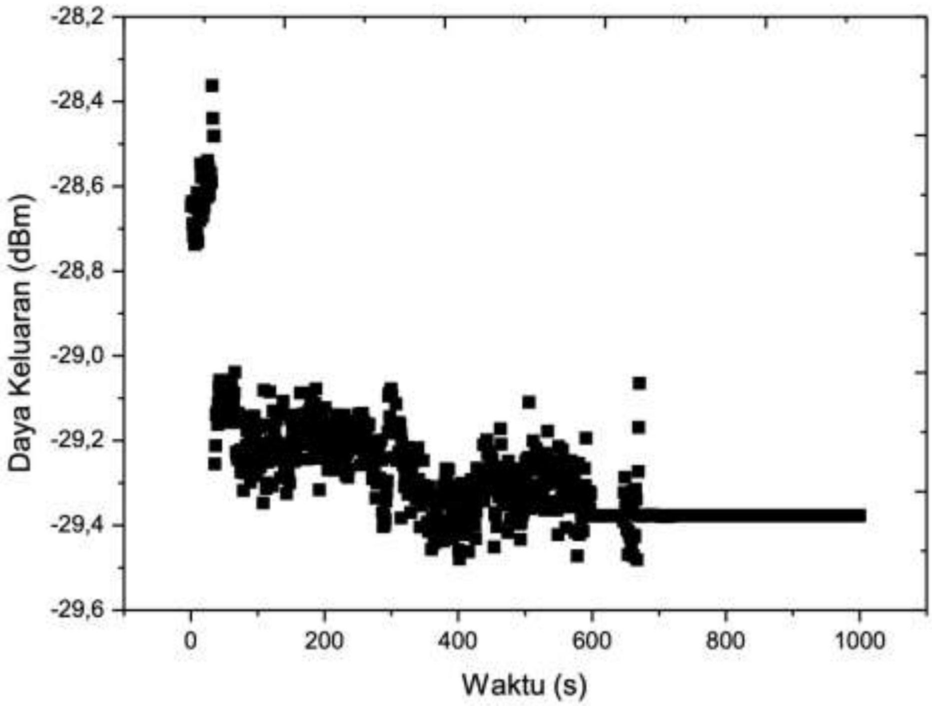

Figure 2. Stability of light source with wavelength 1550 nm

Figure 2 is the result of the output power to determine the stability of the light source. The light source stability test was carried out for 1000 seconds by connecting the light source to the optical fiber, then the output power was detected by an optical power meter. Based on the figure, it was found that the light source took approximately 11 minutes to reach stability. The length of time for the light source to reach stability was used as a reference before the light source was used. The following are the results of the SMS fiber output power test with various variations in the length of the multimode fiber after the connection was made.

Table 1. SMS fiber optic output power results after splicing

Multimode Fiber Length (mm)	Input Power (dBm)	Output Power (dBm)	Power Loss (dB)
10	-6	-13,91	7,91
20	-6	-13,71	7,71

Multimode Fiber Length (mm)	Input Power (dBm)	Output Power (dBm)	Power Loss (dB)
30	-6	-11,47	5,47
40	-6	-15,36	9,36
50	-6	-13,06	7,06
60	-6	-14,01	8,01
70	-6	-13,62	7,62

The next step after characterizing the SMS sensor is testing the sensor with a magnesium ion test sample. SMS optical fiber is made by connecting a coreless multimode fiber and two singlemode fibers. Coreless multimode fiber is used because the cladding of the fiber will be replaced by the solution to be tested so that there is a difference in the refractive index of the core and cladding. The difference in the refractive index of the core and cladding will affect the output power of the SMS fiber. The refractive index of magnesium ions is measured using an ABE refractometer and the refractive index is shown in Figure 4.3. The refractive index of magnesium ions changes with changes in the concentration of magnesium ions. Sensor testing was carried out on 7 lengths of multimode fiber that had been made to be used for magnesium testing at concentrations of 0% and 5%. This was done to determine the most optimal length as a magnesium ion sensor.

CONCLUSION

From the analysis results, the following conclusions were obtained: 1. Attenuation has a major effect on fiber optic bending losses. The smaller the attenuation that occurs in the optical fiber, the smaller the macrobend losses that occur in the optical fiber. 2. The bending radius of the optical fiber greatly affects the losses that occur in fiber optic transmission. The larger the bend radius of the optical fiber, the smaller the bending losses that occur. This very significant change in value shows that the optical fiber is quite responsive to external stimulation in simulation, both on a macro and micro scale. And based on its quite responsive nature, it can be assumed that optical fiber is very likely to be used in the design of sensor systems. However, there are several factors that should be considered in the simulation in this study, including several parameters that are randomly selected, dimensional analysis and also the capacity of Matlab itself. Therefore, it is hoped that the results of this research will have a comparison in the form of research through practical experiments to evaluate or strengthen the results of the research that has been carried out, or by changing several independent variables and dependent variables contained in this research with other variables.

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