THE EFFECTS OF TEMPERATURE VARIATION, PRESSURE, AND BENDS ON THE QUALITY OF THE OUTPUT SIGNAL GENERATED BY CONTINUOUS WAVE (CW) LASER IN SINGLE MODE OPTICAL FIBER

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DECLARATION AND RECOMMENDATION

Declaration

I solemnly declare that my thesis work is original and has not been presented before in any institution for any award.

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SM 13/1870/07

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Recommendation

This thesis has been submitted for examination with our approval as the candidates' supervisors.

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ABSTRACT

Information signals need to be transmitted fast, efficiently and accurately. Optical fiber cables are the transmission medium used in optical fiber communications. Optical fiber communication has exhibited many advantages over other means of communication. However, natural and physical environment within the vicinity where the cable is installed poses a great challenge to signal transmission. The effect of bends on the quality of the output signal generated by a continuous wave (CW) laser on a single mode optical fiber was investigated. A single mode optical fiber cable was subjected to Macrobends in the range of 5mm-50mm bend radius. An optical signal from a CW laser emitting beams in the range of 800nm-880nm was transmitted through the cable. Transmission percentage and variation in peaks were noted and graphs plotted corresponding to each bend radius. Transmission percentage was found to be proportional to the size of the bend radius. Similarly, the single mode optical fiber cable was subjected to pressure using various weights in the range of 1-6kg. The weights develop stress on the cable. The optical signal from the CW laser was transmitted and its transmission quality analyzed. Various transmission graphs were plotted for each pressure exerted. Transmission percentage and the nature of peaks changed according to the weight applied. This study showed that increased pressure resulted in increased attenuation which resulted in minimal or no signal transmission. The single mode optical fiber cable was placed in thermal chamber where temperature was regulated. The range of temperatures considered corresponded to the ones of Nakuru area with changes in the range of 13^{0}C to 40^{0}C. An Optical signal was transmitted and various transmission graphs were plotted for each temperature change. Transmission percentage and the nature of peaks were noted for each temperature. The temperatures under study had no effect on the quality of the output signal since transmission graph appeared similar.

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LIST OF ABBREVIATIONS

CW laser- Continuous Wave Laser
dB/km- decibels per kilometer
FDM-Frequency Division Multiplexing.
Gbps-transmission bite rate
LED- Light Emitting Diodes.
LD- Laser Diodes
MMF-Multi-Mode Fiber
OSA-Optical Spectrum Analyzer.
TDM-Time Division Multiplexing.
SMF-Single Mode Fiber
WDM-Wavelength Division Multiplexing.

CHAPTER ONE

INTRODUCTION

1.1 Background information

An optical fiber is a dielectric waveguide through which information is propagated inform of electromagnetic energy at optical frequency. It primarily consists of a core at the center, followed by cladding layers and a protective coating on the outside. The light wave is confined within the core layer and propagates through the core. The core can be made of thin flexible threads of transparent glass or plastic on which the visible light carrying information propagates. The cladding surrounds the core. The cladding is made of a material with a slightly lower refractive index than the core. This difference in the refractive indices causes total internal reflection to occur at the core-cladding boundary along the length of the fiber. In the process light is transmitted down the fiber and does not escape through the sides of the fiber (Mukherje, 1997).

Optical fibers are classified as multimode fiber (MMF) and single mode fibers (SMF) determined by core diameter. Fibers with many propagation paths or transverse modes are called multimode fibers (MMF). Multimode fibers generally have a large core diameter, and are used for short-distance communication links or for applications where high power must be transmitted (Wikipedia, 2008). Their attenuation is approximately 2.6 to 50dBkm^{-1} at a wavelength of 0.85µm, limited by absorption or scattering. Fibers with only a single mode are called single mode fibers (SMF) and have a smaller core diameter than the multimode (Senior, 1992). The small core and single light-wave virtually eliminate any distortion that could result from overlapping light pulses, providing the least signal attenuation and the highest transmission speeds of any fiber cable type. Their attenuation is approximately 2 to 5 dBkm^{-1} with a scattering limit of around 1 dBkm^{-1} at wavelength of 0.85 µm (Senior, 1992). It carries higher bandwidth than multimode fiber, but requires a light source with a narrow spectral width and is used for most communication links longer than 200 meters.

Optical fiber cable is the transmission medium used in optical communication. Compared with other transmission media such as copper cable and free space, optical fibers provide extremely wide bandwidth for high data transmission, lack of crosstalk between parallel fibers is another added advantage. Low signal attenuation, electrical isolation and strong immunity to electromagnetic interference provided by glass also makes optical fibers preferred as they can be passed near microwaves, television set, electrical appliances and densely populated centers but still exhibits high quality transmission (Max , 1996). High degree of secrecy is achieved by use of optical fiber and hence they have replaced copper cables for high bandwidth link (Wood, 1994). The copper cables employ frequency division multiplexing (FDM) which involves the transfer of multiple channels of information within a single transmission channel by assigning each channel a different carrier frequency .The use of waveguides in frequency division multiplexing (FDM) occupies an extra space hence limiting the bandwidth in copper cable transmissions (Adar et al, 1999) . The bandwidth in fiber optics is in excess of 10GHZ. An extremely wide bandwidth means that a greater volume of information or messages or conversions can be carried over a particular circuit. Whether the information is voice, data, or video or a combination of these, it can be transmitted easily over optical fiber in large channel groups (Max, 1996). As a result, transmission capacity in optical communication is not limited by optical channel but by the electronic speed. This limitation motivates the use of parallel transmission such as wavelength division multiplexing (WDM), which involves the transmissions of several optical signals each at its center wavelength in single fiber (Baker and Ali, 2006). WDM enables the full use of the bandwidth of the single fiber hence leading to wide band transmissions.

The optical fiber cable is installed underground, passed under the ocean or sea, encased in concrete, run through walls or floor in buildings, pulled through underground ducts or hung on telephone poles. In this physical environment or natural environment the optical fiber is likely to receive much stress and strains during its life time from external conditions such as temperature variations, bends, moisture content and effects of pressure (Hoss and Edward, 1993). The aim of transmission is to transfer information of high quality, confidential/secure, efficient and up to form i.e. which does not get lost on the way. While being installed, an optical fiber may be stepped on and banged about, trucks and drums may roll over it. As it is being pulled through ducts it may be stressed beyond expectations. Once in place it may be subjected to very cold winter or hot summer i.e. extreme temperatures changes. In ice clogged ducts, technicians may heat it with steam as they clear the ducts. It may be submerged in water in flooded manholes (Hoss and Edward, 1993). All these are challenges to signal transmission through the fiber cable either during installation, repair and maintenance or servicing.

The wavelength depends on the refractive index of the material. The refractive index of a material is the ratio of velocity of light in vacuum to the velocity of light in a particular material medium. This refractive index depends upon environmental factors such as temperature, mechanical stress, or electrical and magnetic fields (Billings, 1993). These conditions bring a change in the refractive index and definitely will have an influence on the quality of the output signal with time.

1.2 Statement of the problem

An enormous amount of data is transferred to every place of the world, having deep impact to the economy and political situations, by optical fiber cables hence the need to transfer information with minimal losses and interference. Fibers buried in the ground are subjected to thermally and mechanically induced changes in birefringence which leads to their aging. Temperature variations, pressure and bends account for these changes. Even though during manufacturing this parameters (Temperature variations, pressure and bends) are taken into account by cable jacketing, there is need to find how this parameters affects the quality of output signal in the actual field for improving the quality of outer covering during manufacturing. This motivated this study to find out how temperature variations, pressure and bends affect the quality of the output signal hence the data or information coded.

1.3 Objectives

1.3.1 General Objective

To investigate the effect of temperature variations, pressure changes and bends on the quality of the output signal transmissions through the single mode optical fiber cables.

1.3.2 Specific objectives

i. To transmit an optical signals operating in the wavelength range of 800-880nm through a single mode optical fiber.
ii. To analyze the signal obtained at the output of the single mode optical fiber in terms of its transmission properties using optical spectrum analyzer.
iii. To analyze the effect of temperature variations, pressure and bends on the quality of the output signal.

1.4 Justification

Protecting the integrity and quality of critical data is of vital importance since information has become the field of enterprises**.** The research findings, will help us better understand the various stress phenomena occurring in single-mode optical fiber and can lead to a significant improvement of the parameters and characteristics of optical fibers required for underground transmission system. It will also help us in determining the extent of signal interception along the optical fiber link through variations in transmission properties. The study will provide manufactures with useful insights for further development of different fiber optics for a wide range of applications in different environmental set up. The optical signals employed in this study operates in the wavelength range of 800-880nm so any effects in the quality of the output signal can give predictions on the effects which will occur as a result of transmitting many optical signals over a single mode optical fiber cable by WDM. The results will allow us to offer expert advice on the installation of optical fiber.

CHAPTER TWO

LITERATURE REVIEW

2.1 Theory of optical fiber communication

Optical fiber communication is the transfer of information from one point to another by the use of light as the carrier wave. When the information is conveyed over any distance, a communication system is usually required. Within a communication system the information transfer is frequently achieved by superimposing or modulating the information on to an electromagnetic wave, which acts as a carrier for the information signal (Max, 1992). This modulated carrier is then transmitted to the required destination where it is then received and the original information signal is obtained by demodulation. Sophisticated techniques have been developed for this process using electromagnetic carrier waves operating at radio frequencies as well as micro wave and millimeter wave frequencies (Hoss and Edward, 1993). However communication can be achieved by using an electromagnetic carrier which is selected from the optical range of frequencies.

In order to transmit information via an optical fiber it is necessary to modulate characteristics of the light bearing the information signal. These characteristics are intensity, frequency, phase and polarization (Senior, 1992). For example in direct intensity modulation, no electrical modulation or demodulation is required. The transmitted optical power waveform as a function of time $P_{opt}(t)$ may be written as:

$$P_{opt}(t) = P_i(1 + m(t)) \tag{2.0}$$

Where P_i is the average transmitted optical power (i.e. the unmodulated carrier power) and $m(t)$ is the intensity modulating signal which is proportional to the source message $a(t)$.For a sinusoidal modulating signal,

$$m(t) = m_a \cos \omega_m t \tag{2.1}$$

Where m_a is the modulation index or the ratio of the peak excursion from the average power, and ω_m is the angular frequency of the modulating signal. Combining the above two equations (2.0) and (2.1) we obtain.

$$P_{opt}(t) = P_i(1 + m_a \cos \omega_m t) \tag{2.2}$$

which is the resultant wave to be transmitted.

2.1.1 Optical communication system

The fiber optics system is a communication system (a point –to – point transmission link) that uses optical waves as the carrier for transmission. The transmission link consists of a transmitter, a channel and a receiver. In optical fiber communication, the key components are a light source, the channel is an optical fiber and the receiver consists of a photo–diode and a detection circuit (Hoss and Edward, 1993).

2.1.2 Light sources

The light source can be a light emitting diode (LED) or a laser diode (LD). The light source is a transducer used to convert an electrical signal to an optical signal, which can propagate inside the fiber (Wilson and Hawkers, 1987). Light emitting devices used in optical transmission must be compact, monochromatic, stable, and long-lasting. LEDs are relatively slow devices, suitable for use at speeds of less than 1 Gbps, they exhibit a relatively wide spectrum width, and they transmit light in a relatively wide cone. These inexpensive devices are often used in multimode fiber communications. Semiconductor lasers have emitting areas which can be the order of a few microns across and are ideal for use with small core diameter fibers especially single –mode fibers (Adar et al, 1999). Semiconductor lasers generally emit their radiation within a narrower core than the LEDS and this leads to higher coupling efficiencies (Viswanathan, 1992). Using lasers and simple joining technique one can couple a milli watt of optical power into a single –mode fibers. It is possible to improve the coupling efficiencies of both LEDS and lasers by incorporating some kind of optical coupling elements such as a micro sphere lens or making the end of the fiber hemispherical (Wilson and Hawkers, 1998).

2.1.2 Optical Waveguide

An optical wave guide is a structure that "guides" a light wave by constraining it to travel along a certain desired path**.** The optical waveguide is primarily an optical fiber cable, which consists of a core and cladding layers with refractive indices n_1 and n_2 ($n_1 › n_2$) respectively and a protective coating for strength and mechanical isolation (Billings, 1993). Light is kept in the core of the optical fiber by total internal reflection. Fibers are divided into Single–mode fibers which are fibers which allow propagation of only one transverse mode and Multi-mode fiber which allows propagation of multiple transverse modes or supports more than one propagating modes.

Fiber are also further classified into step–index which is fiber that has refractive index which is constant throughout the core diameter and graded–index which contains a core in which the refractive index diminishes gradually (smoothly) from the center axis out toward the cladding (Smith, 1995).

The figure 2.1 shows the structure of an optical fiber cables.

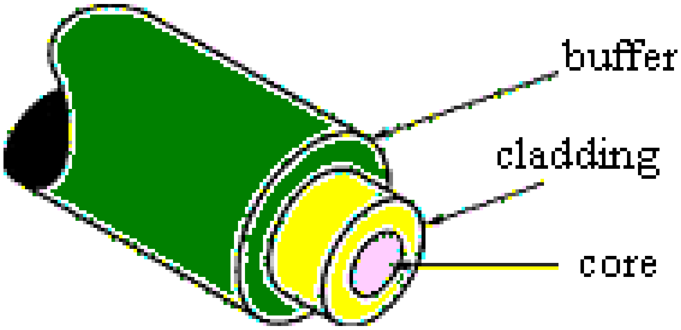

Figure 2.1 Optical fiber cable.

2.1.3 Transmission in the optical fiber

A typical fiber consists of two concentric dielectric cylinders or layers. The inner layer called the core, has a refractive index n_1, the outer cylinder called the cladding has a refractive index n_2 which is less than n_1. If a ray is incident on the boundary between two media of refractive indices n_1 and n_2 ($n_1 > n_2$). Part of the ray is reflected back into the first medium, the remainder is refracted as it enters the second medium (see figure2.2). From Snell's law we have

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \tag{2.3}$$

And since $n_1 > n_2$ then $\theta_2 > \theta_1$. When the $\theta_2 = 90^0$ the refracted ray travels along the boundary. The corresponding value of θ_1 is known as the critical angle θ_c and is given by

$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right) \tag{2.4}$$

When θ_1 is greater than θ_c, all of the incident ray is totally internally reflected back into the first medium as shown in figure 2.2.

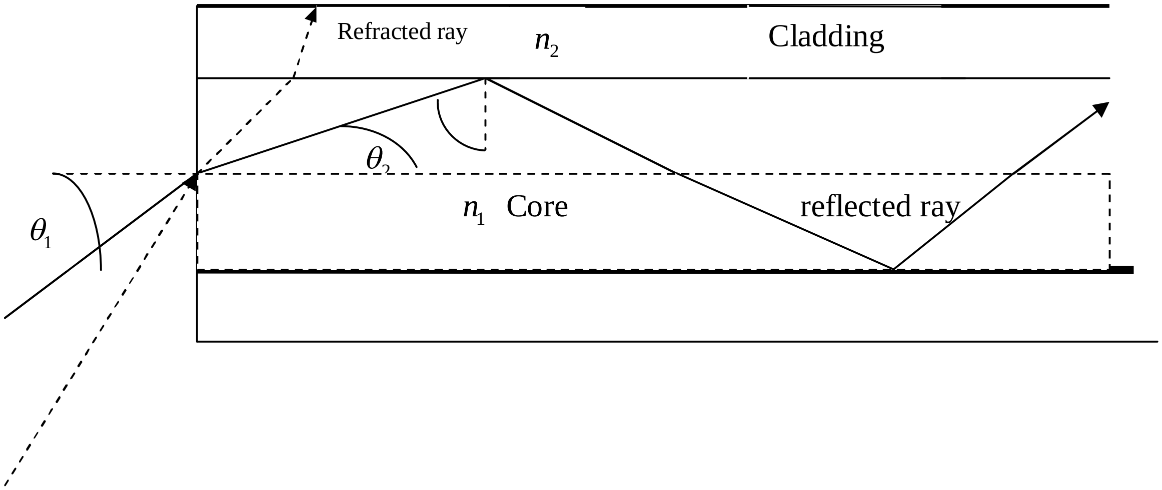

Figure 2.2 Total internal reflections in a fiber

The figure 2.3 below shows the Propagation of light down the cable by total internal reflections

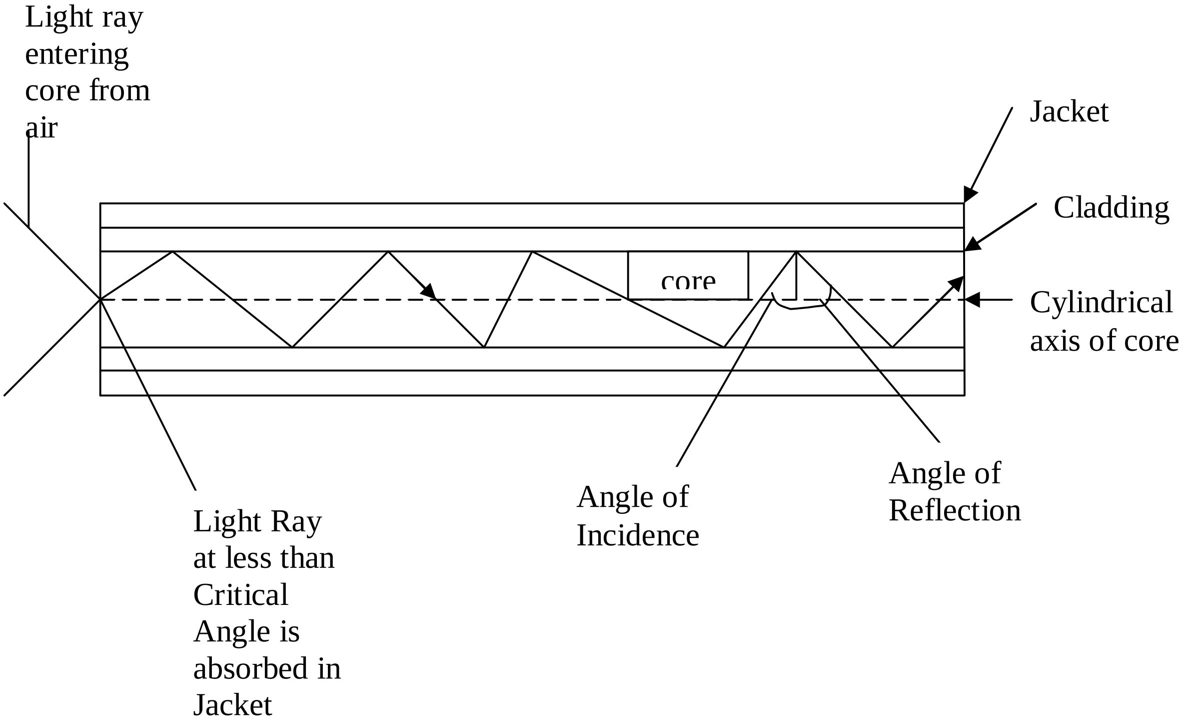

Figure 2.3 Propagation of light down cable by total internal reflections

2.2 Multiplexing

Multiplexing is the means by which two or more information signals are transmitted simultaneously over a common link (Baker and Ali, 2006).

Multiplexing of several optical signals on a single fiber is used to maximize the information transfer over an optical fiber communication link (Max, 1996). In fiber optics, three types of multiplexing are common: Time-Division Multiplexing (TDM), Frequency-Division Multiplexing (FDM), and Wavelength -Division Multiplexing (WDM).

2.3 Wavelength -Division Multiplexing (WDM)

Wavelength-Division Multiplexing (WDM) is a new option for adding applications or expanding existing applications over currently available fiber links. It introduces the transmission of a number of different peak wavelength optical signals in parallel on a single fiber. WDM works on the same principles as FDM and TDM, except the channel discriminator is the wavelengths instead of the frequency or time (Baker and Ali, 2006). Since optical waves of different lengths do not interfere with each other, multiple wavelength signals can be transmitted through the same optical fiber without error. By allowing multiple high-speed communications applications to share the same fiber simultaneously, WDM unlocks optical fiber's tremendous bandwidth capability more than one terabit per second. New optical multiplexers employ WDM to increase existing fiber capacity for data communications environments (Adar et al, 1999).

WDM equipment converts each input data stream into separate wavelengths (colors) and simultaneously transmits these channels through the same optical fiber. Since each wavelength is completely isolated from the others, creating a discrete channel, and since the WDM unit never processes the data, protocols can be mixed within the same link (Mukherje, 1997). Essentially the unit creates "virtual fibers" from one fiber. As a result, existing fiber can be leveraged to add new applications within a metropolitan area.

The research study on optical fiber duplexer investigated the effect of interband and intraband on how it influenced the received signal. The analysis found out that the intraband crosstalk did not affect the received signal as long as it is below 25dB but on increasing this value the power penalty increased. On finding this, further investigation on the power penalty when the spontaneous beat noise of the received signal dominated was carried out and compared with the thermal noise dominated case. Findings showed that the case worsened for the thermal noise dominated case (Baker and Ali, 2006).

2.4 Effects of External Conditions on Fiber Optics transmissions

Optical fiber cables are installed in the natural environment where external conditions such as temperature, pressure, electric or magnetic fields and bends will introduce stress and strains on the optical fiber cable during its life time (Hoss and Edward, 1993). After the cable has been installed, with time, it is subject to these external conditions. Fiber cable is a linear transmission system (Senior, 1992). Waveguide perturbations such as deviations of the axis from straightness, variations in the core diameter, irregularities at the core-cladding interface and refractive index variation may change the propagation characteristics of the fiber (Billings, 1993). Since the signal will propagate in this perturbed waveguide there exist signal variations of what is being transmitted.

The effects of temperature rise and hydrostatic pressure on microbending loss and refractive index change in a double–coated optical fiber have been investigated and findings showed that, when temperature rises, the microbending loss and refractive index changes would decrease with increase of thickness of primary coating layer and will increase after passing through minima. Increase of thickness of secondary coating layer causes the microbending loss and refractive index changes to decrease (Faramarz and Golnoosh, 2006). Effects of temperature on performance of chromatic dispersion compensated 160 Gbps optical fiber network as also been looked into. Based on temperature dependence models and measurements, simulation studies have been carried out and the obtained results showed the expected quantitative compensation requirements for seasonal thermal effects (Hadj, 2007). A similar research entitled transmission fiber chromatic dispersion dependence on temperature; implication on 40 GB/s performance was done and finding showed that temperature had an influence in chromatic dispersion. Further study indicated that even buried optical cables are subject to temperature variations larger than 40^0C, which combined with the long link extensions is responsible for a high value of the fluctuation of residual chromatic dispersion (Paulo et al, 2006).

A research on temperature dependence of polarization mode dispersion (PMD) in tight-buffered standard single mode fiber looked on effects of temperature and pressure on PMD. Polarization mode dispersion is a form of modal dispersion where two different polarization of light in a waveguide, which normally travel at the same speed, travel at different speeds due to random imperfections and asymmetries, causing random spreading of optical pulses. Findings indicated that PMD depended on temperature and pressure. The tight-buffered accounted for 50-70% of total modulus and generated considerable mechanical forces (pressure) which acted on the fiber when its dimensions changed due to high thermal expansion coefficient of plastics (Krzysztof and Marek, 2006). All these researches have looked at temperature and pressure influence on mode dispersion, refractive index changes and micro bend loss.

Optical fibers suffer radiation losses at bends or curves on their paths (Senior, 1994). When a fiber is bent, the inner part is compressed and the outer part rarefied. Assuming that at the mean radius of bend $\bar{R}$ (along the axis of bent fiber) the density of the fiber material is unchanged, and that the density of the fiber is inversely proportional to R, the radius of bend. To calculate the variation of refractive index due to a variation in fiber material density, we use the clausius-mosotti relation for the refractive index of dense material given by (Lau, 1981)

$$n^2 = 1 + \frac{N\alpha}{1 - \left(\frac{N\alpha}{3}\right)} \tag{2.5}$$

Where n is refractive index, N is the number of atoms/unit volume of the medium (number density) and α is the atomic polarizability which is approximately $10^{-24} cm^3$ for glass. N is inversely proportional to the radius of curvature R:

$$N = \frac{\bar{R}}{R} N_o \tag{2.6}$$

Where N_o is the number density of the fiber without bending, which corresponds to a refractive index n_o of about 1.5. The refractive index at a point in the fiber where the radius of bending is R is given by substituting eq. (2.6) to eq. (2.5) to obtain:

$$n^2 = 1 + \frac{\frac{\bar{R}}{R} N_o \alpha}{1 - \frac{\bar{R}}{3R} N_0 \alpha} \tag{2.7}$$

Research on bend Loss in Single-Mode Fibers, shows measurements for two different fibers over wide ranges of wavelength (800–1600 nm) and curvature radius (13.5–27.5 mm). Some different approaches have been proposed for the evaluation of bend loss in single-cladding and multiple-cladding fibers. The instrument used in for this research was a 0.01 dB resolution spectrophotometer. Allowing loss measurement up to 45 dB on single-mode fiber (Luca and Giuseppe, 1997).

Research done on mode scalability in bent optical fibers shows compressive study on modes of the bent step-index fiber. A mode here is simply the various propagation paths light can take in a fiber. This analysis was based on the introduction of a scaling parameter, analogous to the V-number for straight step-index fibers and the bend radius. When this parameter remained constant, waveguides of different bend radii, numerical apertures and wavelengths propagated identical mode field distributions, except that they were scaled in size (Ross, 2007). Here researchers have looked at the power losses due to bends and how bends changes the mode of propagation.

In this research we have looked on how the bends ,pressure effects and temperature variations influences the quality of the output signal i.e. how the information signal is influenced in terms of the changes in signal amplitude, spread of peaks, nature of the curve, and peak wavelength changes.

CHAPTER THREE

The effect of bends on the quality of the output signal generated by CW laser on single mode optical fiber

3.1 Introduction

The transmission of an optical signal over an optical fiber is by the theory of total internal reflections. The optical path should be linear for optimum transmission. However; optical fiber cable may be bent during installation, servicing or maintenance. The radius of the bend may cause the light ray to be incident at an angle less than the critical angle, thus incurring losses. This could be from a ray that is directly incident onto the bend at less than critical angle or from a ray that is reflected off a bend and then into the cladding at an angle less than the critical angle. Since the normal is always at right angles to the surface of the core, if the core bends, then the normal will follow it and the ray will find itself on the wrong side of the critical angle and will escape (Crisp, 2001).

A small amount of light will escape into the cladding at the point of bend. This light entering the cladding will be very small in amplitude and will readily leak off the cladding with slight bends in the fiber (Bailey and Wright, 2003).

There are two types of bends that causes loss. The first is referred to as a macrobend, this is where a cable is installed with a bend in it that has a radius less than the minimum bend radius. Light will strike the core/cladding interface at an angle less than the critical angle and will be absorbed by the cladding hence lost. The second type of bending loss is referred to as Microbending which takes the form of a very sharp bend (a kink) in the cable. Microbend can be caused by imperfection in the cladding, ripples in the core cladding interface, tiny cracks in the fiber and external forces. The external forces may be from a heavy sharp object being laid across the cable or from the cable being pinched as it is pulled through a tight conduit (Agrawal, 2001).

Optical fiber cable can be installed aerially or underneath the earth or sea. The simplest installation method is direct burial, in which a trench is dug, the cable or duct laid, and the trench backfilled. If ducts are not used, the cable may be indirect contact with any rocks, roots, or other underground hazards, which, if not severing the fiber can often produce unacceptably tight bend radii (Green, 2006).

Finally, all brands and types of optical fiber cable despite of the outer coating physical protection are subject to outside forces that can damage or break optical fibers. The ability to bend around corners does not alleviate physical limitations of rough handling or damage from nails, screws, staples or external pressures. Even reduced bend radius fibers have limitations to excessive bending, pinching or binding.

3.2 Method

To investigate the bend effects on transmission performance we implemented a CW laser transmission system over a standard single mode optical fiber (SMF) according to the scheme in figure. 3.1

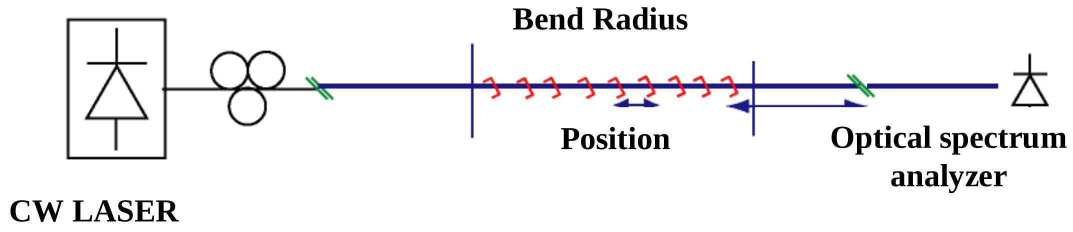

Figure 3.1: Experimental set up for investigation of the effects of bends.

The optical signal from a CW laser emitting wavelength radiations in the range 800nm-880nm was transmitted over a single mode optical fiber cable. The average output power was 1mW, which was sufficiently low to avoid the excitation of nonlinear effects on the transmission fiber which was a two meter of SMF. The cable was subjected to various bend radii in the order of 5mm, 10mm, 20mm, 30mm, 40mm and 50mm. The signal quality at the receiver was measured for different values of SMF bends through the optical spectrum analyzer. Transmission graphs were plotted for various bend radii.

3.3 Results and Discussions

There has been considerable progress in the telecommunications technology based on the transmission of light waves through optical fibers. However bends are a challenge to obtaining the good quality of the transmitted signal. In this study, the transmission graphs for the straight cable was treated as a reference for comparing the output signal obtained when propagated through a cable subjected to various bend radius. The Optical spectrum analyzer calibrations were in such a way that the transmission percentages appeared over 100%. The changes in amplitudes, peak wavelengths and spread of peaks depicted the changes in the quality of the output signal.

3.3.1 Transmission graph for different bend radius

The various transmissions graphs where generated for each bend radius. The range of percentages e.g. from 200% to 500% will show the available bandwidth of the fiber. Information will be propagated within such a range and any changes will denote changes in quality.

3.3.2 Transmission graphs for a straight cable

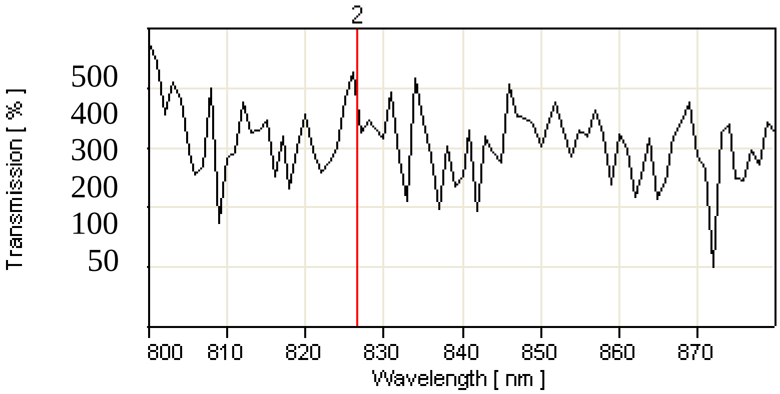

Figure 3.2: The graph of transmission percentages versus wavelength for a straight cable.

From the graph, it is evident that the transmission percentage lies between 200 -500%. This implies that in this case all the vital information is passed without interference within a given bandwidth. The 828nm wavelength corresponds to the amplitude 450%. This can be used in observing the trend of increase or decrease in amplitude for comparison to other transmission graphs.

3.3.3 Transmission graph for bend radius of 50mm

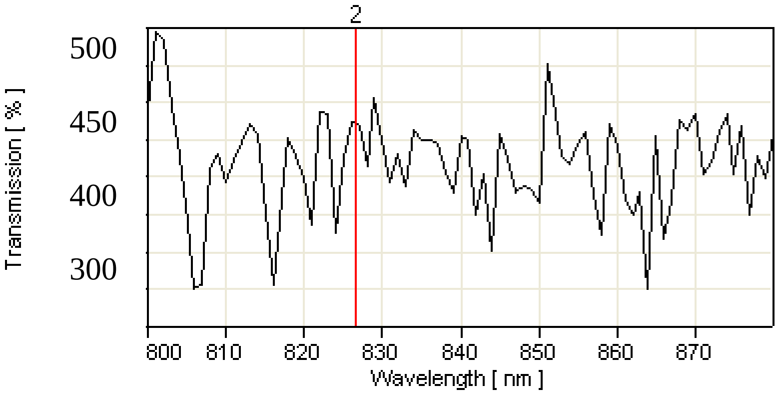

Figure 3.3: The graph of transmission percentages versus wavelength for a bend radius of 50mm.

In this graph transmission percentage lies between 250-450% indicating a transmissions loss of around 50% when comparing to the case with no bend. The wavelength of 828nm corresponds to the amplitude of 440% this indicates a loss of 10%. This drop of transmission can be linked to introduction of the bend on the cable.

3.3.4 Transmission graph for bend radius of 40mm

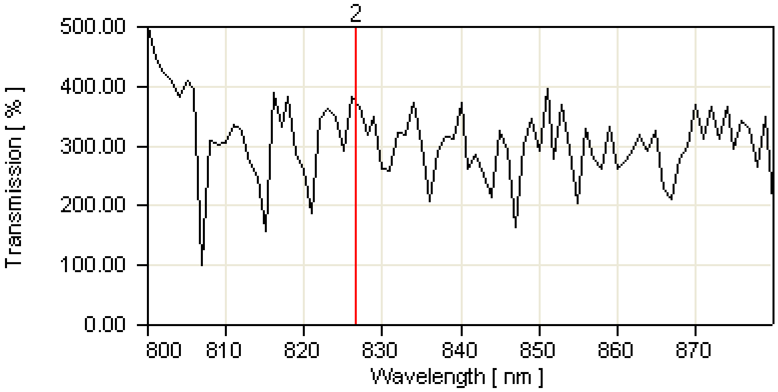

Figure 3.4: The graph of transmission percentages versus wavelength for a bend radius of 40mm.

The transmission percentage lies between 200-400% indicating a shift in percentage. The bandwidth as a reduction of 50% from the previous bend. The wavelength 828nm corresponds to the amplitude having 330%.this is an indication of reduction in % in terms of transmission and information is lost at the point of bend.

3.3.5 Transmission graph for bend radius of 30mm

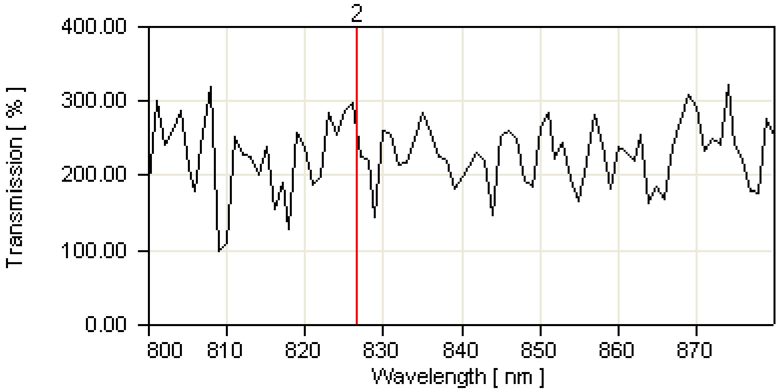

Figure 3.5: The graph of transmission percentages versus wavelength for a bend radius of 30mm.

In graph above the transmission percentage further shifts down and lies between 150-300%. The wavelengths of 828nm correspond to 300% amplitude. There is a reduction in bandwidth due to reduction in percentage transmission indicator of change in the quality of output signal.

3.3.6 Transmission graph for bend radius of 20mm

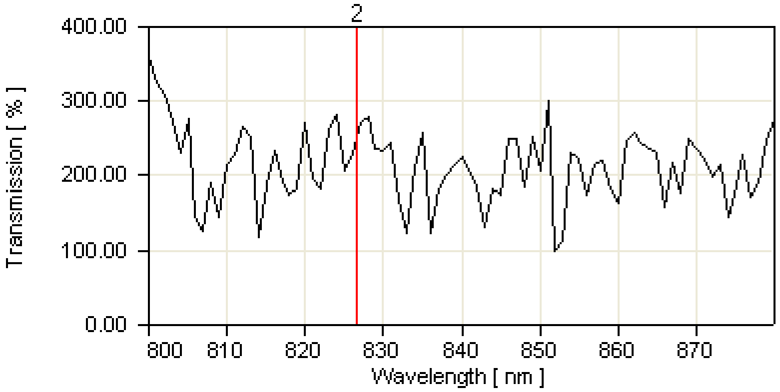

Figure 3.6: The graph of transmission percentages versus wavelength for a bend radius of 20mm.

Here the transmission percentage further shifts to between 110-280%.there is a reduction in bandwidth hence a reduction on the information to be transmitted. The wavelength 828nm corresponds to amplitude of around 280% indicating a further drift down in comparison to the case with no bend. Most information will not be detected at the receiver hence decrease in transmission percentage.

3.3.7 Transmission graph for bend radius of 10mm

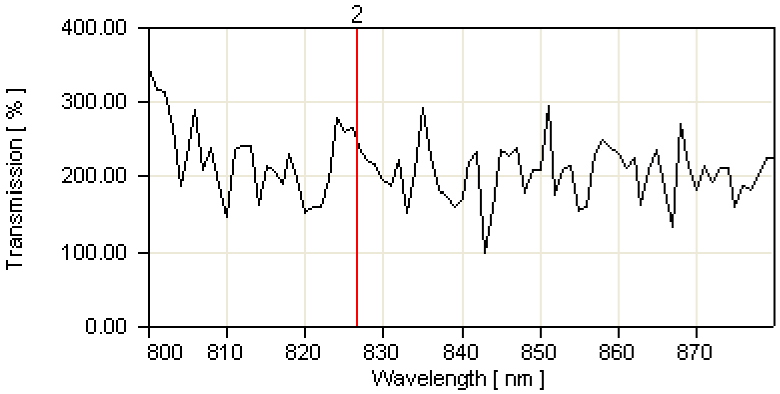

Figure 3.7: The graph of transmission percentages versus wavelength for a bend radius of 10mm.

In the above graph there is further indication of the drift has the bend radius becomes smaller. The transmission lies between 100-280% and the 828nm wavelength corresponds to 270% amplitude. The graph has started spreading the peaks and reducing the number of transmission peaks. The transmission waves have reduced in size.

3.3.8 Transmission graph for bend radius of 5mm

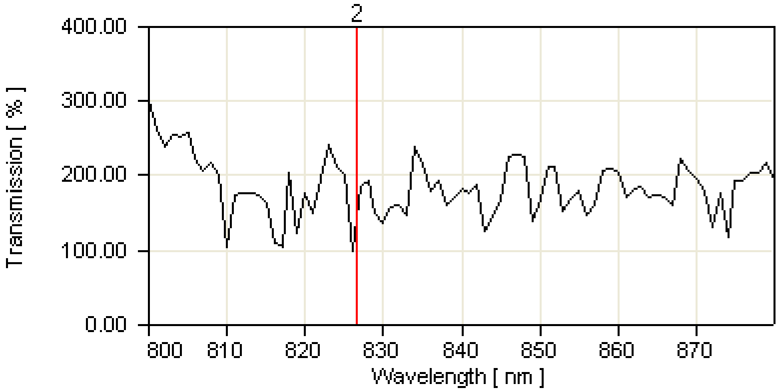

Figure 3.8: The graph of transmission percentages versus wavelength for a bend radius of 5mm.

From the graph above the transmission percentage lies between 100-230% and the amplitude of peaks as reduced and they have spread. The 828nm wavelength corresponds to the amplitude of 180% indicating a greater reduction. It will be very difficult for all the information to be detected at the receiver. Beyond this bend radius the cable was almost breaking and this could lead to loss or no transmission at all.

3.4 Conclusion

There is percentage shift as the bend radius reduces and the nature of curve and amplitude changes has the bend becomes small. There is a decrease in the amplitude of the transmission graph for example for the 828nm wavelength from 500% for the straight cable to almost 180% for a bend radius of 5mm.The decrease in percentages of transmission is proportion to the size of the bend radius. At the point of bend, vital information is lost before it reaches the detector or receiver. Hence the reduction in transmission percentage indicating a loss input power at bend hence output signal power is less compared to the input power. The shift in transmission percentage for certain wavelengths is a clear indicator of the effects of bends on the quality of the signal. A bend in the cable is risk as the information to transmitted will be distorted hence it will be difficult to be decoded. The quality of the output signal is affected by the size of the bend. This study is important in sending a message to optical technician and installers to observe technicians' best practices.

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CHAPTER FOUR

The effect of pressure on the quality of the output signal generated by CW laser on single mode optical fiber

4.1 Introduction

Optical fiber cables are the transmission medium for transfer of information whether it is Television, radio, video, audio, data or any other information in form of light. Optical fibers with low transmission loss and wide bandwidth have been widely used in many practical transmission systems. Long-term stability is a common requirement for optical transmission, so optical fibers must maintain stable performance in the most severe conditions. However, the optical fibers are sensitive to external pressure (Chang et al, 2000).

Pressure on the cable introduces a bend at the point where it’s applied which lead to signal degradation as a result of loosing some power. Also external pressures push core and the cladding together, creating tiny bending in the fiber whereby bending the fiber causes attenuation (Ahmed et al, 2008). The effective pressure on the fiber was calculated using the relation:

$$Effective - pressure = \frac{F}{A}$$

Where: F ≡ force applied on the cable, A ≡ block area in direct contact with the optical fiber cable.

In the presence of hydrostatic pressure acting on the outside of the fiber, an anisotropic stress is induced in its core due to the fiber geometry. Resulting to a change in the refractive index in each axis is produced through the photo elastic effect (Clowes et al, 1998). The change in the refractive index will result in the change of the signal transmission.

4.2 Method

The pressure effects on transmission performance on the quality of the output signal were implemented according to the scheme in figure.4.1. Were a CW laser was transmitted over a standard single mode optical fiber (SMF).

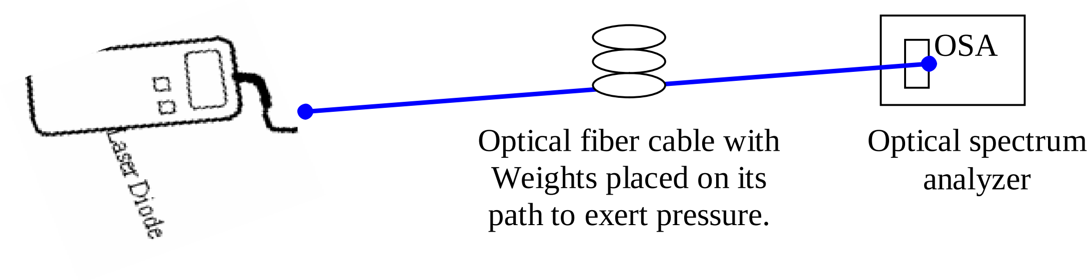

Figure 4.1: Experimental set up for investigation of the effects of pressure.

Its output transmission, after its propagation through the fiber was measured without any load (no pressure exerted) for the first test using the optical spectrum analyzer. There after various steel weights were placed on the fiber cable at a point. The blocks weights ranged from 1-6kg. The attenuation of the laser output was detected for each load magnitude from the transmission.

4.3 Results and Discussion

Investigation of the effects of pressure on the quality of the output signal, results obtained indicate that pressures due to 3kg and above contributes to signal degradation hence the transmission percentage drops below 0%. Information is blocked at the point where the forces exert pressure resulting to the changes in the transmission graphs generated by the optical spectrum analyzer.

4.3.1 Transmission graphs due to pressures exerted by various weights

Presented are the transmission graphs due to pressure for the pressures applied on the optical fiber cable. Transmission percentages shifts and changes according to the size of force exerted thus showing the effect of pressure on the quality of the output signal.

4.3.2Transmission graph due to no Pressure exerted

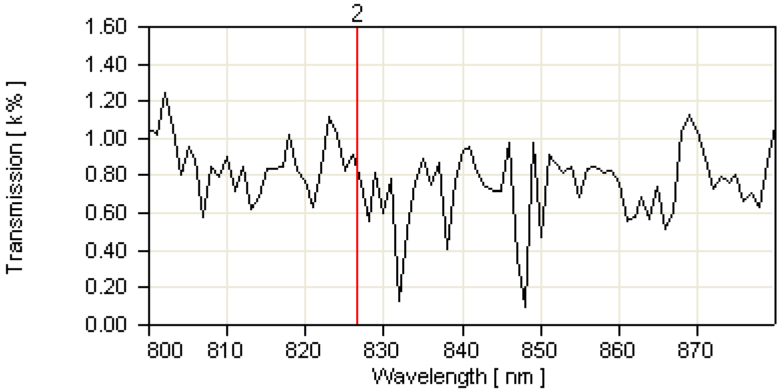

Figure 4.2: The graph of transmission percentages versus wavelength due to no Pressure exerted.

From the transmission graph, transmission percentage lies between 20%-120%. This implies that the signal can transmit information without interferences and all the information will be received at receiver or detector.

4.3.2 Transmission graph due to Pressure exerted by 1kg weight

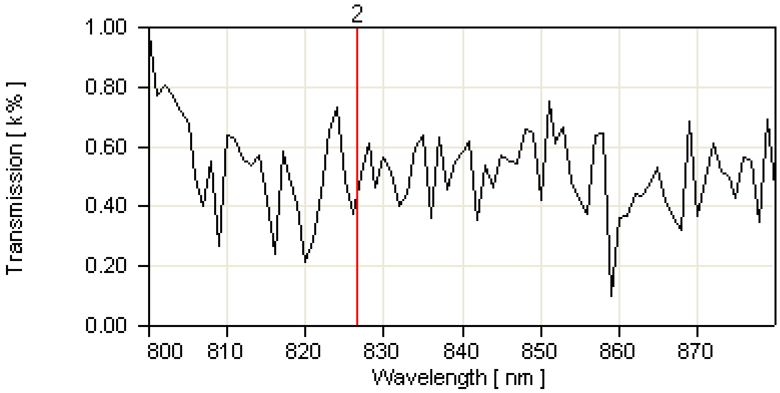

Figure4.3: The graph of transmission percentages versus wavelength due to Pressure exerted by 1kg weight.

The transmission percentage has shifted to below 80% meaning pressure exerted caused interference which resulted to some losses. This implies not all transmitted information will be received at the receiver. The signal power has decreased by around 40% indicating signal degradation due to the pressure exerted.

4.3.3 Transmission graph due to Pressure exerted by 2kg weight

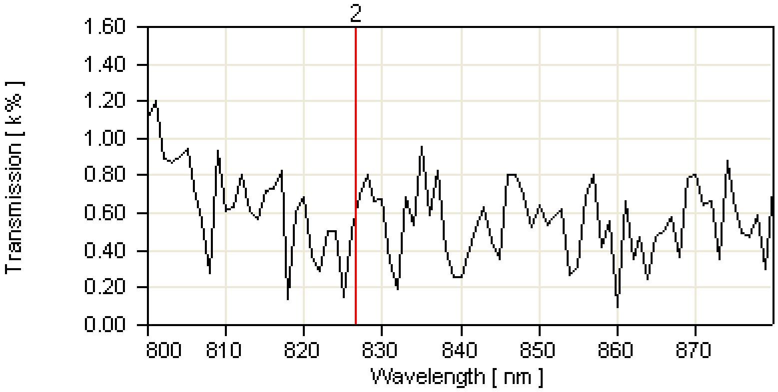

Figure 4.4: The graph of transmission percentages versus wavelength due to Pressure exerted by 2kg weight.

There is further shift in percentage in transmission to between 80% and 20%. The shift in percentage has affected the shape of the transmission peaks has they have reduced downwards as compared to transmission graph due to no pressure. Information to be transmitted down the cable will loose some characters.

4.3.4 Transmission graph due to Pressure exerted by 3kg weight

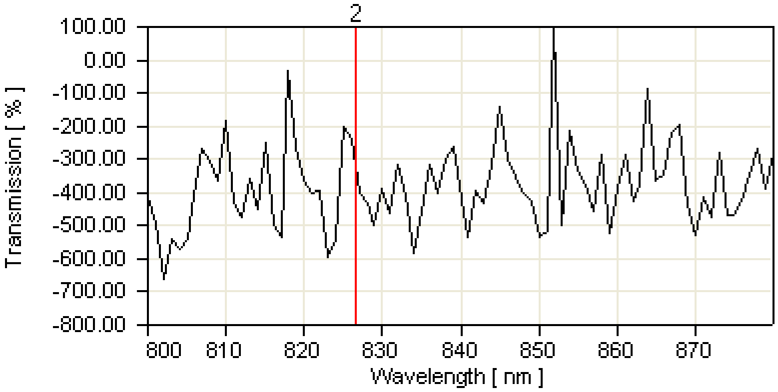

Figure 4.5: The graph of transmission percentages versus wavelength due to Pressure exerted by 3kg weight.

Transmission percentage is below 0% indicating no transmission of signal occurs as the exerted pressure makes the signal to be lost at the point where the pressure is exerted.

Much attenuation of the signal as occurred hence most of signal power is lost by scattering or absorption leading to no transmissions.

4.3.5 Transmission graph due to Pressure exerted by 4kg weight

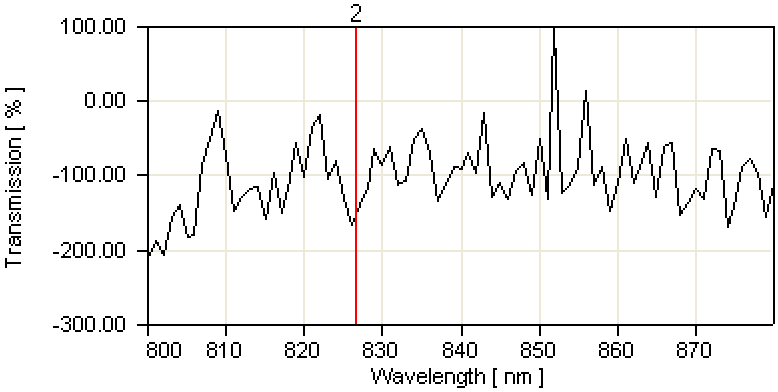

Figure 4.6: The graph of transmission percentages versus wavelength due to Pressure exerted by 4kg weight.

No transmission occurs as the pressure blocks the transmission hence transmission is below 0% transmission mark. All the input power of the signal is lost at the point where the weight was exerted. Information will not be detected at the receiver.

4.3.6 Transmission graph due to Pressure exerted by 5kg weight

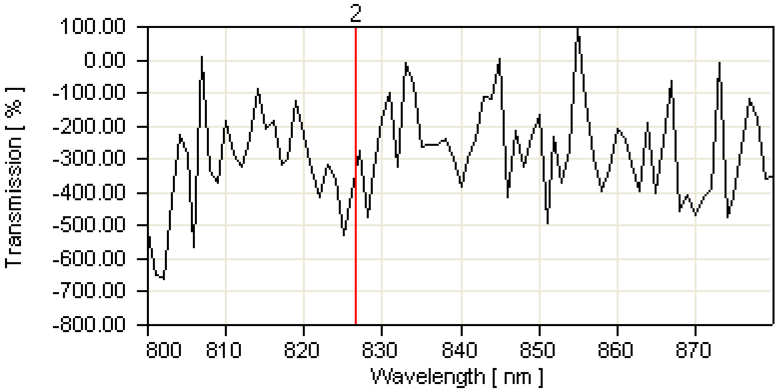

Figure 4.7: The graph of transmission percentages versus wavelength due to Pressure exerted by 5kg weight.

No transmission occurs as the pressure blocks the transmission hence transmission is below 0% transmission mark. The signal lost power at the exerted pressure. No signal will be detected at the receiver. Information is lost before it reaches its destination.

4.3.7 Transmission graph due to Pressure exerted by 6kg weight

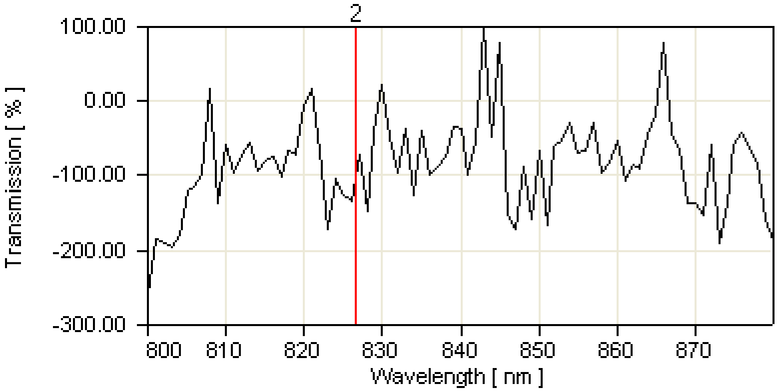

Figure 4.8: The graph of transmission percentages versus wavelength due to Pressure exerted by 6kg weight.

No transmission occurs as the pressure blocks the transmission hence transmission is below 0% transmission mark.

4.4 Conclusion

It is clear that the attenuation of the laser output signal increases with the increase in weight exerted. Transmission % decreases until no signal is transmitted for weights greater than 3kg. Pressure has an effect on the quality of the output signal which indicates a linear proportionality to attenuations. During and after installation it's important to avoid various weights along the path of the cable to avoid signal degradation.

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CHAPTER FIVE

The effect of temperature variation on the quality of the output signal generated by CW laser on single mode optical fiber

5.1 Introduction

Optical transmission system technologies are being extensively studied to increase the transmission capacity. Factors affecting optical fiber transmission quality are a concerned to many researchers. Temperature is the major factor which influences other factors such as polarization mode dispersion, chromatic dispersion, Microbending loss and refractive index changes (Hadj, 2007; Sait and Gunes, 2007).

Chromatic dispersion in standard optical fibers (SMF) is temperature dependent, which results in a dependence of residual dispersion for fully compensated link as the temperature of the transport fiber changes (Andre et al,2006).

The temperature rise affecting the fiber makes the Microbending loss and refractive index decrease, linearly. at a particular temperature, the microbend loss takes negative values, due to tensile pressure applied on the fiber (Faramarz and Golnoosh,2006) .If the temperature changes affects the transmission path by either introducing micro bends or changing the refractive index then the signal quality may be influenced.

5.2 Method

To investigate the temperature effects on transmission performance a CW laser transmission system was implemented over a standard single mode optical fiber (SMF) which was placed on a thermal chamber to ensure temperature stabilization on the fiber according to the scheme in figure 5.1.

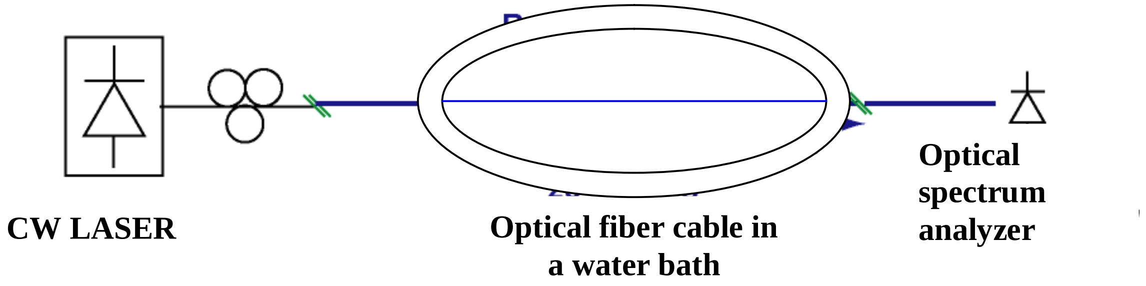

Figure 5.1: Experimental set up for investigation of the effects of temperature variation.

The optical signal from a CW laser emitting in the range 800nm-880nm was transmitted over a single mode optical fiber cable placed in a water bath. The temperature was regulated at 13°C, 20°C, 25°C, 30°C, 35°C and 40°C. The signal quality at the receiver was measured for different values of SMF temperature, through the optical spectrum analyzer.

5.3 Results and Discussions

The results obtained in case of the temperature in study shows limited effects on the quality of the output signal. Transmission parameters are not much influenced since the shift of peak and amplitude is almost similar. This may be contrary to the discussion in section 6.1 due to the lower temperatures considered in this study.

5.3.1 Transmission graphs due to temperature variations on the cable

Various transmission graphs are generated for each temperature and comparison was based on the 13 ^{0}C for the cable installed underground.

5.3.2Transmission graphs due to temperature at 13 ^{0}C

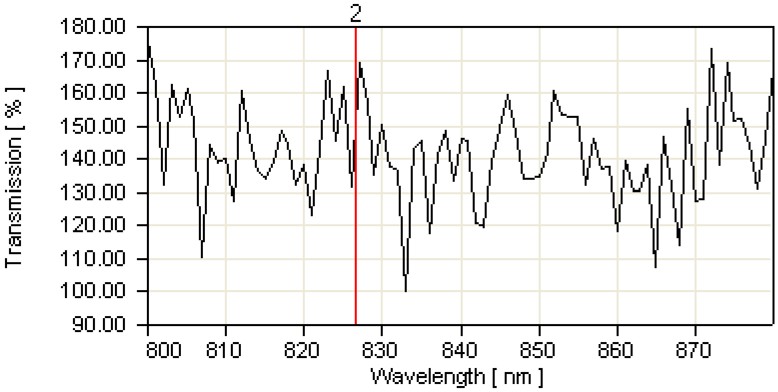

Figure 5.2: The graph of transmission percentages versus wavelength due to temperature at 13 ^{0}C.

At 13° C the transmission peaks are in the range of 100%-170% transmission window which implies transmission of any signal in the range will reach the receiver or detector with minimal or no interferences.

5.3.3 Transmission graphs due to temperature at 20 ^{0}C

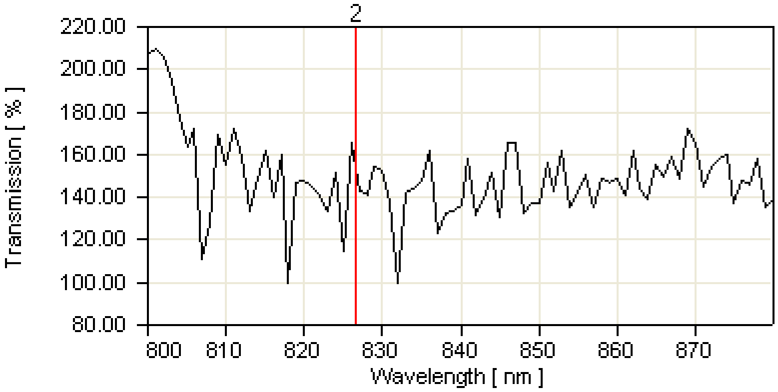

Figure 5.3: The graph of transmission percentages versus wavelength due to temperature at 20^{0}C.

When the temperature rises to 20°C there is a shift in the transmission slightly to between 100%-160% and decrease in transmission peaks. The transmission peaks for the wavelengths 840nm -880nm have reduced in amplitudes in comparisons to the transmission graphs at 13°C.

5.3.4 Transmission graphs at 25 ^{0}C

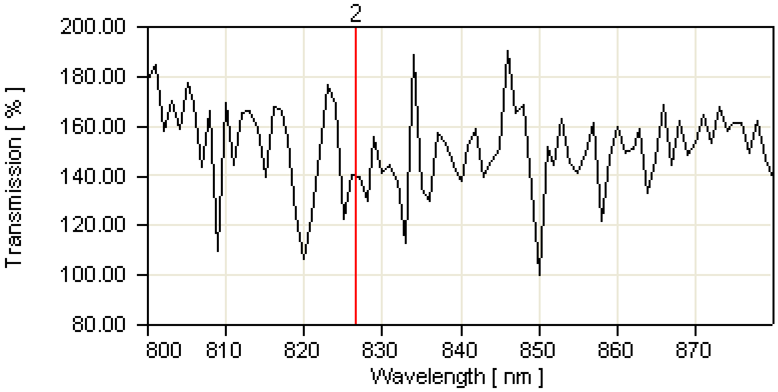

Figure 5.4: The graph of transmission percentages versus wavelength due to temperature at 25^{0}C.

Here the transmission lie between 100-180% and the transmission peaks at wavelengths 855-880nm have reduced amplitude.

5.3.5 Transmission graphs at 30 ^0C

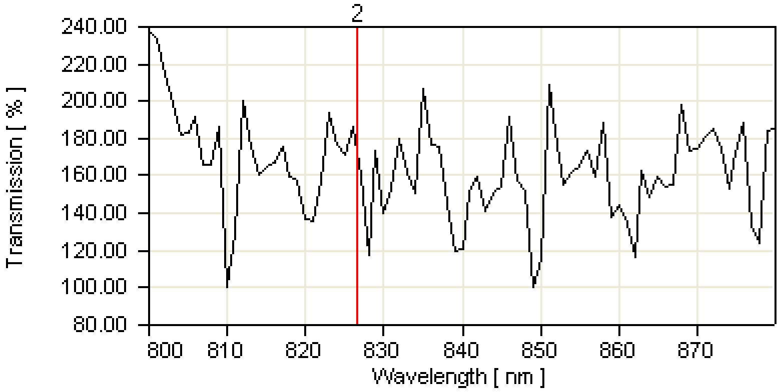

Figure 5.5: The graph of transmission percentages versus wavelength due to temperature at 30 ^0C.

In this case the transmission peaks have spread although transmission percentage lies between 100-200% transmissions.

5.3.6 Transmission graphs at 35 ^0C

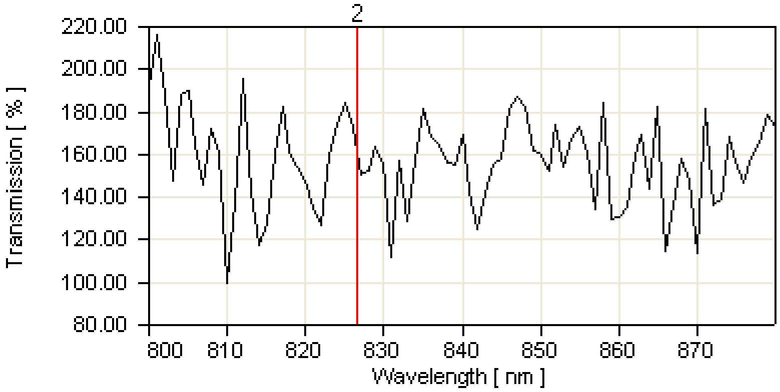

Figure 5.6: The graph of transmission percentages versus wavelength due to temperature at 35 ^0C.

The transmission lies between 100-190% and the waves are not close as compared to transmission graph due to 13^{o}C.

5.3.7 Transmission graphs at 40 ^0C

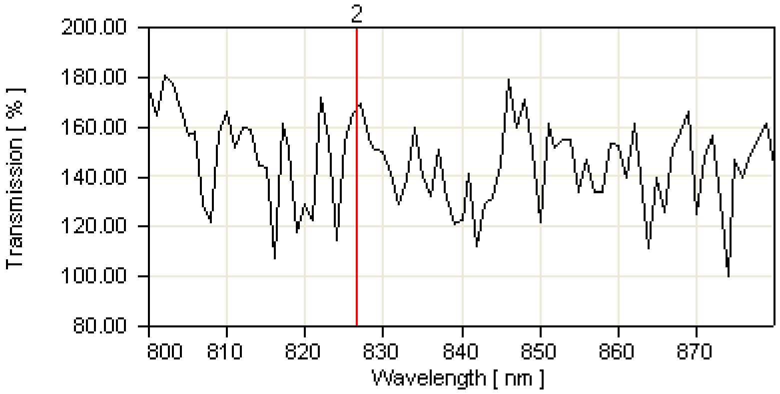

Figure 5.7: The graph of transmission percentages versus wavelength due to temperature at 40 ^0C.

From the above transmission graphs it can be noted clearly that the transmission peak lies between 100% for troughs and 180% for peaks. The transmission waves are not close as compared to transmission graph due to 13^{o}C.

5.4 Conclusions

The signal after each temperature rise is observed to be shifting in 100%-180% transmissions windows hence temperature variation in Nakuru area have very little effect on the quality of the output signal in SMF. Most of the characters transmitted will be received at the receiver since transmission percentage is almost similar. Transmission over these temperatures is quit good hence most of the information sent will be received at the receiver.

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CHAPTER SIX

GENERAL DISCUSSIONS, CONCLUSIONS AND RECOMMENDATIONS

6.1 DISCUSSIONS

6.1.1 Effects of bends on the quality of the output signal

As the bend radius becomes smaller there is a reduction in amplitude of the optical signal, spread of peaks and wave. This indicates a reduction of output power hence loss at the point of bend. The propagation of the optical signal is by the theory of total internals reflections; hence the optical signal at the point of bend instead of being reflected some of it leaks into the cladding hence lost. This gives rise to a reduction in transmission percentage of the wave.

6.1.2 Effects of pressure on the quality of the output signal

The pressure exerted on the cable leads to transmission dropping below 0% indicating blockage of signal hence information to be transferred will not reach the receiver. Input signal power is reduced at the point were pressure is exerted. Loss occurs resulting to transmission percentage dropping below 0% signal transmission.

6.1.3 Effects of temperature variations on the quality of the output signal

Upon exposure of the cable to various temperature variations transmission percentage in each temperature change is observed to oscillate between 100-180 %. It can be observed that quality of the output signal is not much affected by the temperatures changes in study since the wave amplitudes are almost the similar.

6.2 CONCLUSIONS

- Bends have an effect in the quality of the output signal by changing the amplitude of the waves, nature of peak and nature of transmission graph.
- Pressure affects transmission by changing the propagation path resulting to signal degradation indicated by transmission percentage dropping to below 0%.
- For the case of temperatures in study, Most of the characters transmitted will be received at the receiver since transmission percentage is almost similar. Transmission over these temperatures is quit good hence most of the information sent will be received at the receiver.

6.3 RECOMMENDATIONS

From the research findings bends, pressure and temperature variations have an effect in the quality of the output signal. These effects may interfere with vital information to be transmitted which my result to loss or distortions hence we have recommended the following:

- The design of an automated system for monitoring any fault along the optical fiber communication system. The system should be in such way that it will be just sending an optical signal without any transmission signal to determine any fault along the optical fiber system. The automated system upon detecting the degradation of the signal it should be able to determine the distance of the fault and the cause of the degradation whether its temperature variation, bend or pressure effects. Upon degradation of the signal the technicians should increase the power input of the optical signal and go to the location of the fault to do maintainace and servicing. Also technicians should be trained to follow technician’s practices to the later and try to avoid at all cost any errors during installation, cabling, servicing and maintenances.
- Manufacturers to improve cabling of the optical fiber cable to the standards of avoiding bends, pressures and temperature variation over a wide time period.
- Future work which will involve investigation in detail smallest bend radii possible with different structures, including determination of their specific breaking point compared to various fiber types.
- There is need to design good cabling at corners to avoid bends for we are heading to fiber Connectivity to the home, desk, and premises.
- The effect of pressure on the quality of the output signal is observed to start at 3kg, hence we recommend further work to investigate in detail minimal interval tests between 2kg and 3kg masses to determine the optimum mass point at which the effect starts for this will be of value to installation technicians when installing the cables at the field.

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