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Attenuation Losses Due to Changes in Curvature, Temperature, and Pressure in Optical Fiber Cables

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Abstract

In this paper, the attenuation losses due to changes in curvature, temperature, and pressure in optical fiber cables are investigated. A single mode optical fiber cable was subjected to curvature of radii 5mm, 10mm, 20mm, 30mm, 40mm and 50mm. 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 using an Optical Spectrum Analyzer and graphs plotted corresponding to each curvature radius. The single mode optical fiber cable was placed on thermal chamber where temperature was regulated .The range of temperatures considered corresponded to the ones of Nakuru area with changes in the order of 13°C, 20°C, 25°C, 30°C, 35°C and 40°C. Optical signal from CW laser emitting wavelength radiation in the range 800-880nm was transmitted over the optical fiber. Various transmission graphs were plotted for each temperature change. Similarly, the single mode optical fiber cable was subjected to pressure using various masses in the range of 1kg, 2kg, 3kg, 4kg, 5kg and 6kg. The masses exerted 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 was found to be proportional to the size of the curvature. It was observed that as the curvature reduces there is a reduction in transmission percentage definitely attenuation loss. Transmission percentage and the nature of peaks were noted for each temperature. Transmission percentage and the nature of peaks changed according to the weight applied. This study showed that increased pressure resulted to increased attenuation which resulted to minimal or no signal transmission

Keywords : *Attenuation losses, Curvature, temperature variation, CW laser, Optical fiber cable*

1. Introduction

Attenuation is the loss of optical power as light travels along the fiber. Signal attenuation is defined as the ratio of optical input power (P_i) to the optical output power (P_o). Optical input power is the power injected into the fiber from an optical source. Optical output power is the power received at the fiber end or optical detector. 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 subject to curvature or 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 attenuation 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[1)].

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[2)].

There are two types of curvatures that cause attenuation losses. 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. Microbends can be caused by imperfection in the cladding, ripples in the core cladding interface, tiny clacks 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[3)].

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[4)].

Temperature is another major factor which influences other factors such as polarization mode dispersion, chromatic dispersion, Microbending loss and refractive index changes chich contribute to optical fiber attenuations[5,6)].

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[7].

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[8] .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.

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[9].

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[10]. The effective pressure on the fiber was calculated using the relation:

$$Effective - pressure = \frac{F}{A} \quad (1)$$

Where: F ≡ force applied by weight 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[11].The change in the refractive index will result to the change on the signal transmission.

2. Materials and Methods.

2.1 Experimental set up 1: Investigation of the attenuation losses due to curvature

To investigate the attenuation losses due to curvature was implemented according to the scheme in figure.1

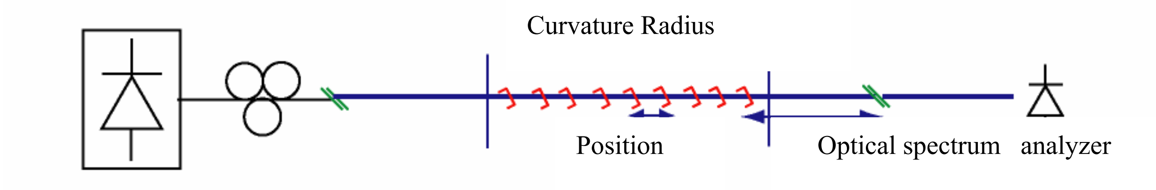

Figure 1. Experimental set up for investigation of the effects of curvature

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 curvature radii in the order of 5mm, 10mm, 20mm, 30mm, 40mm and 50mm. The attenuation at the receiver was measured for different values of SMF curvatures through the optical spectrum analyzer. Transmission graphs were plotted for various curvature radii.

2.2 Experimental set up 2: Investigations of the attenuation losses due to temperature variation.

To investigate the temperature effects on attenuation losses 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 2.

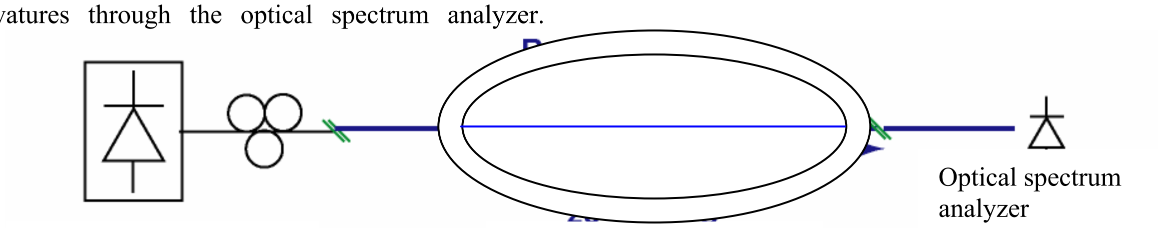

Figure 2. Experimental set up for investigation of the effects of

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 path. The temperature was regulated at 13°C, 20°C, 25°C, 30°C, 35°C and 40°C. The signal attenuation at the receiver was measured for different values of SMF temperature, through the optical spectrum analyzer.

2.3 Experimental set up 3: investigations of the attenuation losses due to pressure

The attenuation losses due to the pressure effects were implemented according to the scheme in figure 3. Were a CW laser was transmitted over a standard single mode optical fiber (SMF).

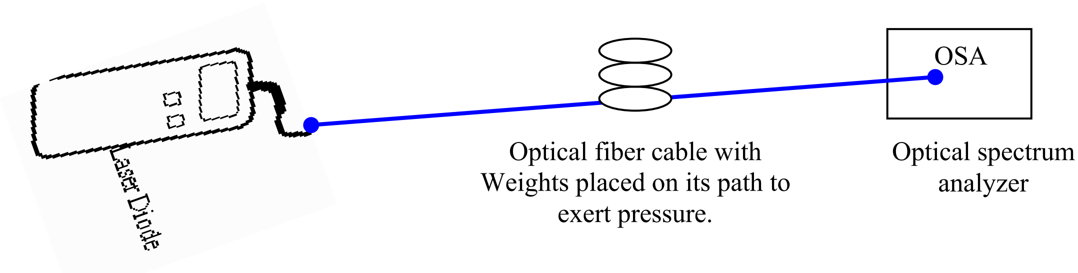

Figure 3. Experimental set up for investigation of the effects of pressure

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 blocks with diameter 8cm were inserted in the path of the fiber to exert pressure on the fiber. The blocks masses were in the order of 0kg, 1kg, 2kg 3kg, 4kg, 5kg and 6kg .The attenuation of the laser output was detected for each load magnitude from the transmission graphs plotted.

3. Results and Discussions

3.1 Transmission graph for different curvature radius

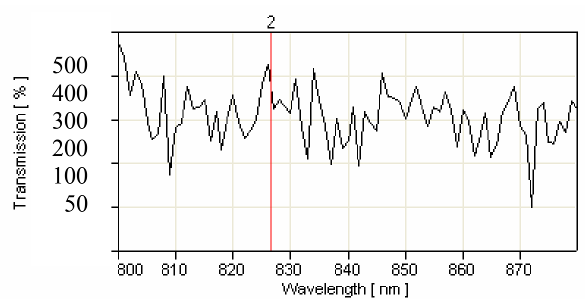

Figure 4. Transmission graphs for a straight cable.

Figure 4 shows the transmission graphs 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.

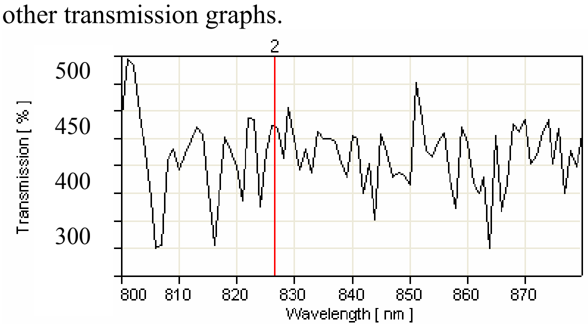

Figure 5. Transmission graph for curvature radius of 50mm.

Figure 5 demonstrates the transmission graph for curvature 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.

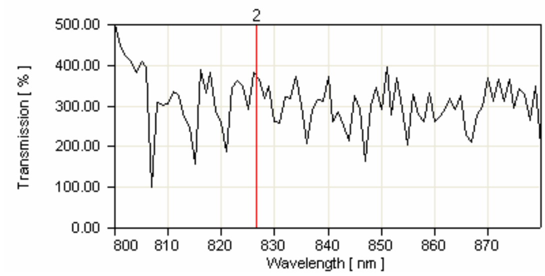

Figure 6. Transmission graph for curvature radius of 40mm.

Figure 6 shows the transmission graph for curvature radius of 40mm. The transmission percentage lies between 200-400% indicating a shift in percentage. The bandwidth reduction is 50% of 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.

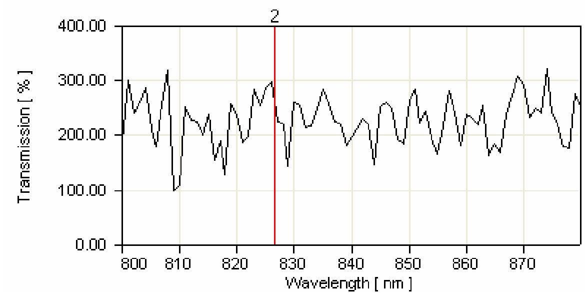

Figure 7. Transmission graph for curvature radius of 30mm.

Figure 7 indicates the transmission graph for curvature 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. The is a reduction in bandwidth due to reduction in percentage transmission indicator of change in the quality of output signal

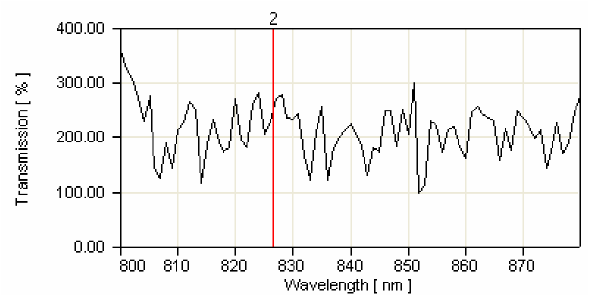

Figure 8. Transmission graph for curvature radius of 20mm.

Figure 8 shows the transmission graph for curvature 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.

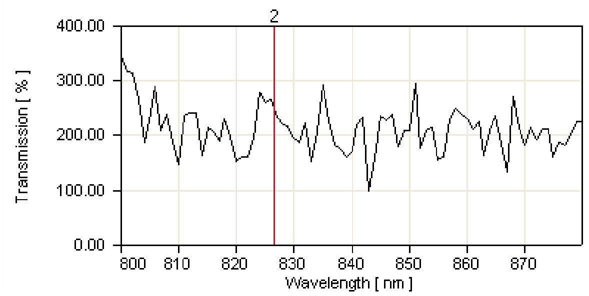

Figure 9. Transmission graph for curvature radius of 10mm.

Figure 9 shows the transmission graph for curvature 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.

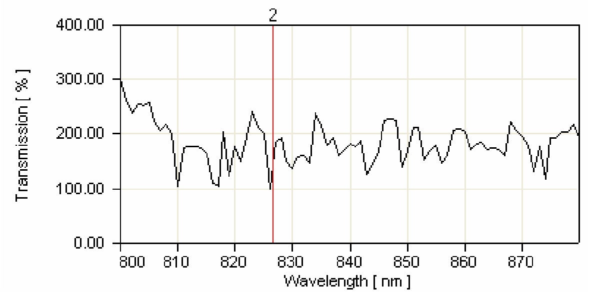

Figure 10. Transmission graph for curvature radius of 5mm.

Figure 10 is the transmission graph for curvature 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 curvatur radius the cable was almost breaking and this could lead to loss or no transmission at all.

3.2 Transmission graphs due to temperature variations on the cable

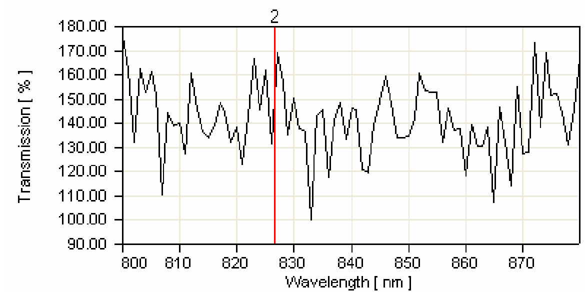

Figure 11. Transmission graphs due to temperature at 13 ^{o}C

Figure 11 shows the transmission graphs due to temperature at 13 ^{o}C. At 13^{o} 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.

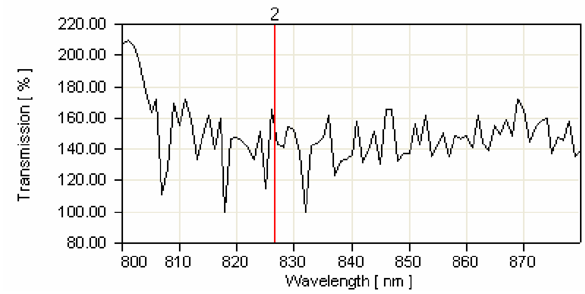

Figure 12. Transmission graphs due to temperature at 20 ^{o}C

Figure 12 shows the transmission graphs due to temperature at 20 ^{o}C. When the temperature rises to 20^{o}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^{o} C.

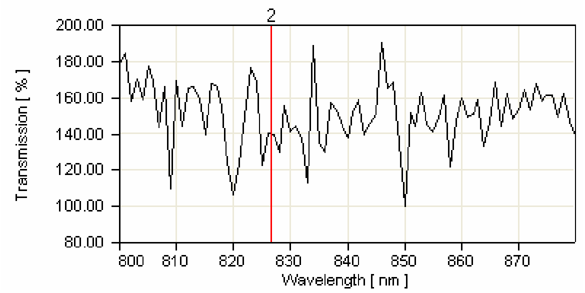

Figure 13. Transmission graphs at 25 °C

Figure 13 shows transmission graphs at 25 °C. Here the transmission lies between 100-180% and the transmission peaks at wavelengths 855nm-880nm have reduced amplitudes.

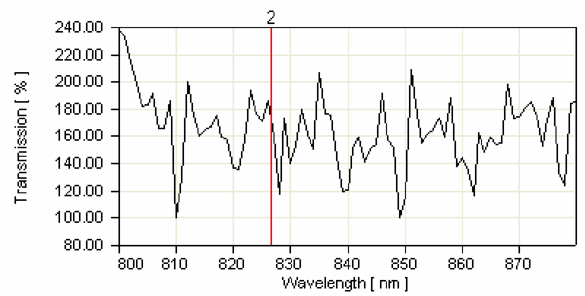

Figure 14. Transmission graphs at 30 °C

Figure 14 shows transmission graphs at 30 °C. In this case the transmission peaks have spread although transmission percentage lies between 100-200%transmissions.

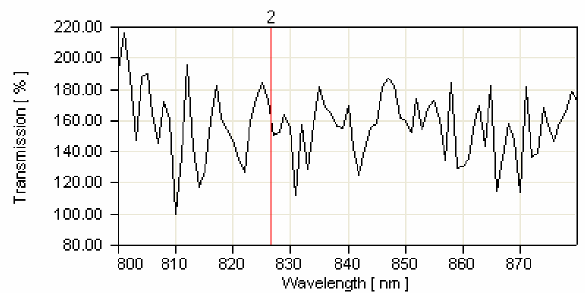

Figure 15. Transmission graphs at 35 °C

Figure 15 shows transmission graphs at 35 °C. The transmission lies between100-190% and the waves are not close as compared to transmission graphs due to temperatures of 13° C.

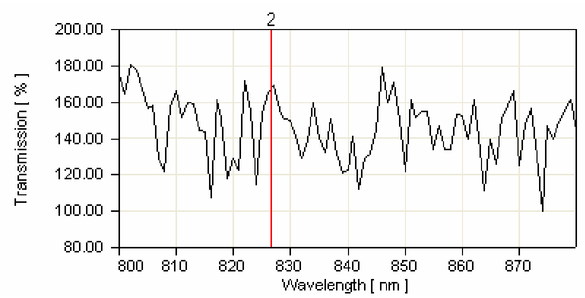

Figure 16. Transmission graphs at 40 °C

Figure 16 shows transmission graphs at 40 °C. From the above transmission graphs it can be noted clearly that the transmission peaks in each case lies between 100% for troughs and 200% for peaks. The transmission waves have spread in comparison to transmission graphs due to temperatures of 13° C.

3.3 Transmission graphs due to pressures exerted by various weights

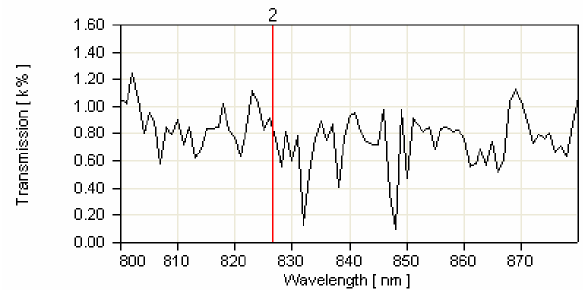

Figure 17. Transmission graph due to no Pressure exerted -0 kg weight

Figure 17 is transmission graph due to no Pressure exerted -0 kg weight. 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.

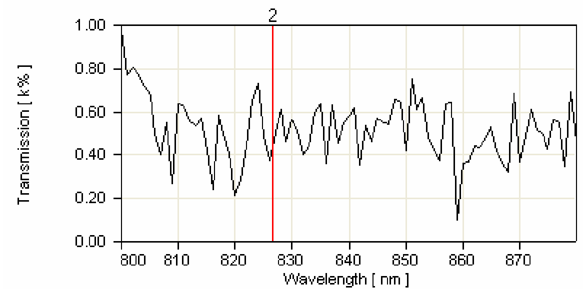

Figure 18. Transmission graph due to Pressure exerted by 1kg weight

Figure 18 shows transmission graph 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.

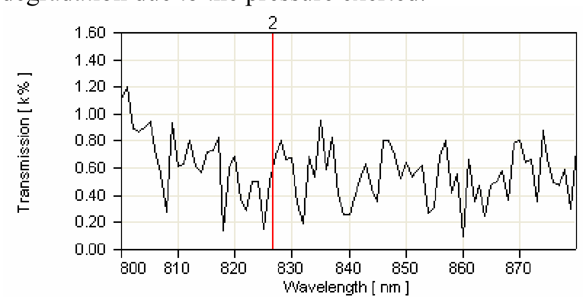

Figure 19. Transmission graph due to Pressure exerted by 2kg weight

Figure 19 is transmission graph 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.

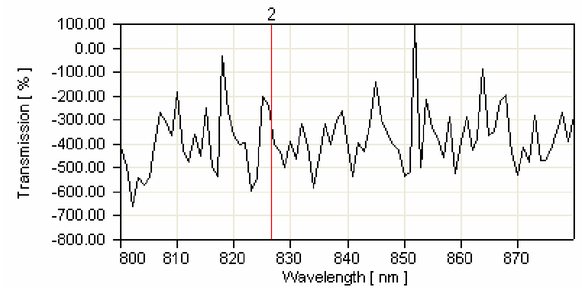

Figure 20. Transmission graph due to Pressure exerted by 3kg weight

Figure 20 demonstrates transmission graph 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.

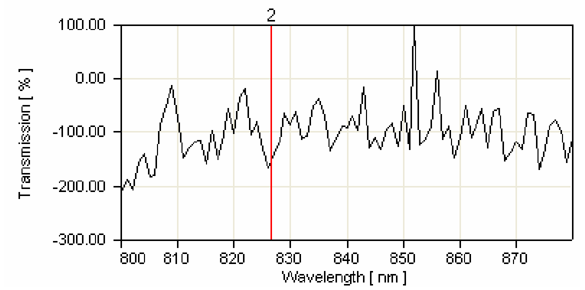

Figure 21. Transmission graph due to Pressure exerted by 4kg weight

Figure 21 illustrates transmission graph 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.

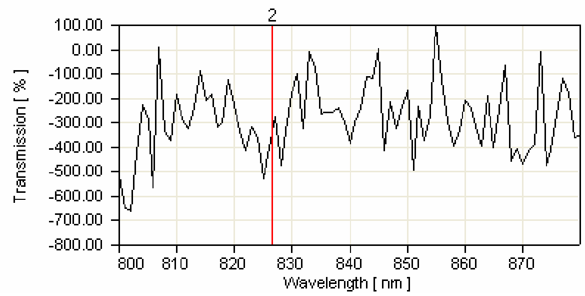

Figure 22. Transmission graph due to Pressure exerted by 5kg weight

Figure 22 shows transmission graph 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.

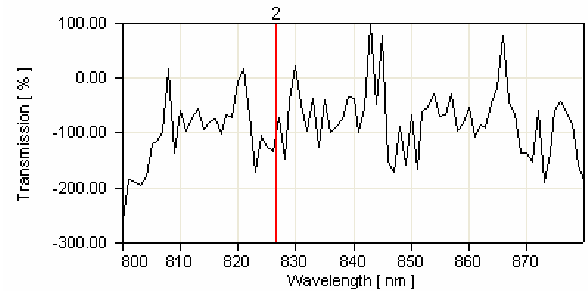

Figure 23. Transmission graph due to Pressure exerted by 6kg weight

Figure 23 is transmission graph due to Pressure exerted by 6kg weight. No transmission occurs as the pressure blocks the transmission hence transmission is below 0% transmission mark.

4. Conclusion

There is percentage shift as the curvature 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.

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. Transmission over these temperatures is quit good hence most of the information sent will be received at the receiver.

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 large weights. Pressure has an effect on the quality of the output signal which indicates a linear proportionality to attenuations losses. 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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