CHAPTER - 2

MICROBEND WEIGHING ( MBW ) SENSOR
Introduction

As indicated in the article 1.7.1 present microbend weighing (MBW) sensor is aimed at the single pan balance using optical fiber. The choice of optical fiber, amongst the available fibers, governs the specifications of the balance. The obvious choice is Plastic Optical Fiber because of its elastic properties and ruggedness. These fibers are detailed in article 2.1 where as 2.2 focuses on the details about available optical fiber sensors in general. The design, fabrication and study of the present MBW sensor cum balance are elaborated in the remaining chapter.

2.1 Plastic Optical Fiber

Plastic Optical Fiber, abbreviated as POF, typically uses Polymethyl-Methaacrylate Resin PMMA (acrylic), (a general-purpose resin) as the core material, with fluorinated polymers as a clad material.

In large-diameter fibers, 96% of the cross section is a core that allows transmission of light. Although quartz fiber is widely used, POF has been called the "consumer" optical fiber. Due to the fact that costs of POF associated optical links, connectors, and installation costs are low. A POF has much larger diameter than HPOF, and Glass Optical Fiber (GOF) as shown in figure 2.1. Most POF's being used have a fiber diameter of 1000μm, with a core diameter of 980μm. Due to this large diameter, transmission is possible even if the ends of the fiber are slightly damaged, or if the light axis is slightly off centered. Therefore, parts such as optical connectors can be made inexpensively and installation work is simplified. The sizewise comparison

![Fig. 2.1 Diameters of Optical fibers in micrometer for POF – Plastic Optical Fiber, HPCF – Hard Polymer Clad Fiber, GOF – Glass Optical Fiber](image)

Figures are elaborated in figure 2.1. Normally, a 650nm LED is used as the light source for POF optical transceiver modules because of low transmission loss. Since this is within
the visible light spectrum, it acts as an eye safety feature because the user can easily experience when he/she is in danger of directly viewing the light beam. Compared with other fibers, there is a large transmission loss as shown in figure 2.2. Some applications do not require transmission over long distances, having a need for ease-of-use, low cost, and stability. POF is best suited for use in these environments.

POF is strong against vibration and bending.

![Fig. 2.2 Transmission loss in POF at 650 nm](image)

The comparison of optical fibers is briefed in table 2.1.

**Table 2.1: Comparison between All-glass fiber, H-PCF and Plastic Fiber**

<table>
<thead>
<tr>
<th>Type of optical fiber</th>
<th>All-glass fiber (AGF or GOF)</th>
<th>Hard polymer-clad fiber (H-PCF)</th>
<th>Plastic fiber (APF or POF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component</td>
<td>Core</td>
<td>Cladding</td>
<td>Simplicity of assembly with an optical connector</td>
</tr>
<tr>
<td></td>
<td>Silica glass (50 µm, 62.5 µm)</td>
<td>Silica glass (20 µm)</td>
<td>Fairly easy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hard plastic (230 µm, 250 µm)</td>
<td>Very easy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Plastic (1000 µm)</td>
<td>Very easy</td>
</tr>
<tr>
<td>Attenuation</td>
<td>1-3 dB/km</td>
<td>Min. 6 dB/km</td>
<td>200-400 dB/km</td>
</tr>
</tbody>
</table>
2.1.1 Optical Fibers verses Plastic Optical Fiber:

Optical fibers are developed mainly for communication purpose. In the olden days metallic reflecting pipes were used for short distances. At present optical guides working on total internal reflection with coaxial core and clad of high & low refractive indices respectively. (Above it there can be some co-axial protective cover). The material needed to be optically transparent which can be quartz, or glass. The last one (GOF) is most common for long distances, as loses are low. The cheaper one using plastic core (POF) is popular because of low cost for short distances. One of the parameter to govern the performance of the fiber is the uniformity of the refractive index of the core and its gradient may be used to classify the fibers as elaborated in the next subarticle.

2.1.1.1 Types of Optical Fiber

The waveguides are classified, by the profile of the refractive index of the core material, and by the propagating modes viz. single mode and multimode fibers. In classifying with the profile of the refractive index, differentiation is made between step index, gradient index and spatial profile fibers. Step index fibers have a constant index profile over the whole cross section. Graded index fibers have a non-linear, rotationally symmetric index profile, which falls off from the center of the fiber outwards as shown in figure 2.3. In the case of step index, multimode fibers the index of refraction is constant. For graded index fibers, the index of refraction is reduced from the middle.
outward. As opposed to traveling in a straight line, the rays travel in a spiral form around the optical axis of the fiber.

The material used for POF is typically PMMA. However, there are many other types of optical fiber. The individual characteristics of these fibers are applied to variety of fields. Typical optical fibers which are mass-produced today are Quartz Optical Fiber, Single Mode Fiber (SMF), Multi Mode Fiber (MMF), Plastic Optical Fiber, and Polymer Clad Fiber.

In addition to this material dependence, the optical fibers also are classified as single and multi mode fibers. The single mode fiber has its core diameter of the order of $\lambda/2$. Though it has its own applications, the multimode fibers are more used because of ease of operation. When the electromagnetic wave travels through the fiber, various losses occur. These are summarized in following sub article.

2.1.2 Loss Mechanisms in Fibers

The losses in electromagnetic energy propagating in fibers are due to material absorption, material scattering, waveguide scattering due to in-homogeneities cladding losses and losses are due to fiber bending.

2.1.2.1 Material Absorption

Absorption losses are largely due to the impurities in glass material from residual foreign atomic substances and hydrogen/oxygen molecules. There are attenuation maxima in small band wavelength regions.

2.1.2.2. Material Scattering

One of the crucial scattering mechanisms is Raleigh Scattering. Spatially there are high-density gradients (short compared to the wavelength) which alter the index of refraction and cause scattering. The intensity of the scattered light is proportional to $\frac{1}{\lambda^4}$ the effect evidences itself in, among others things, strong reverse scattering.

Another scattering mechanism is Mie Scattering, which mainly results in forward scattering due to material in-homogeneities in larger wavelength spectrums. Stimulated Raman Scattering and Stimulated Brillouin Scattering are non-linear radiation induced effects, which exceed intensity thresholds. Transmitting laser light alone can exceed these threshold values.
2.1.2.3. Light Guide Specific Scattering Mechanisms

Intrinsic fiber characteristics can cause loss of energy. These are changes (errors) in core diameter, difference in refractive indices, index profile effects, mode coupling (double mechanisms) and scattered radiation in the cladding glass. Radiation losses can exist due to the conversion of core modes to non-propagating modes (cladding modes). This results in a reduction in the carrying modes.

Extrinsic causes for loss mechanisms come from such things as mechanical influences, such as micro and macrobending.

2.1.2.4 Fiber Coupling Losses

Cleaved single fibers may be spliced. The splicing region can exhibit intrinsic (purely optical), there can be extrinsic (mechanical alignment) losses.

2.1.2.5 Radiation Losses due to Macro bending

Macro bends are caused by bending the cable beyond a specified bend radius. Light escaping at the bends increases attenuation.

2.1.2.6 Losses due to Micro bending

The mechanical perturbation of a multimode fiber waveguide causes a redistribution of light power among many modes in the fiber is known as micro-bending. The more severe the mechanical perturbation or bending, the more light is coupled to radiation modes and is lost. Thus, the important characteristics of microbend sensors (microbender) are that it uses a multimode optical fiber, it is a light intensity sensor and the light intensity decreases with mechanical bending. To enhance the microbending effect by squeezing the fiber between a set of corrugated plates, called the 'deformer plates' or 'tooth blocks'. Their configuration is shown in figure.2.4. It was found that by tuning the mechanical bend frequency, the microbending loss could be increased by orders of magnitude. A microbender is called an intrinsic sensor because light is not permitted to exit the fiber into free space. The microbender is basically a displacement sensor. When the separation between the teeth blocks changes, the

![Original diagram of microbend sensor.](image-url)
sinusoidal amplitude of the clamped fiber changes accordingly. The light transmission
through the clamped region is a sensitive function of the sinusoidal amplitude of the bent
fiber.

2.2 Optical Fiber Sensors (A General Review)

Telecommunication has been revolutionized by fiber optic technology. A third
revolution is emerging as designers' combine the product growths of fiber optic
telecommunications with opto electronic devices to create fiber optic sensors. The basic
suggestion that optical fiber technology could be useful in sensors dates back well over
30 years.

The past two decades have seen a rapidly growing interest in the field of fiber­
optic sensors. Some of the principal reasons for the popularity of optical fiber based
sensors systems are 7 small sizes, light weight, immunity to electromagnetic interference
(EMI), high temperature performance, large bandwidth, higher sensitivity as compared to
existing techniques, and multiplexing capabilities. Moreover, the widespread use of
optical fiber communication devices in the telecommunication industry has resulted in a
substantial reduction in cost of optical fiber sensor. As a result, optical fiber sensors have
been developed for verity of applications in industry, medicine, defense, and research.

2.2.1 Classification of Optical Fiber Sensors

Optical fiber sensors are classified by types, and operating principle. These are
described in next article in brief.

2.2.1.1 Classification by type

A typical fiber sensor is illustrated diagrammatically in Fig.2.5. Light is taken to
a modulation region using an optical fiber and modulated there in by physical, chemical
or biological phenomena, and the modulated light is transmitted back to a receiver,
detected and demodulated.

There are two substantial issues in realizing a viable optical fiber sensor
technology.

1) To ensure the one to one relationship between the parameter to be measured and the
demodulated signal.

2) To match the technology to the application in terms of both performance and cost.
The first of these is the similar one despite the fact that the impact of the fibers to and from the modulation region, variations in source and detector characteristic with temperature and time and the influence of temperature on the modulation process are all important.

The second of these must recognize the presence of established techniques and in particular must identify otherwise insoluble problems which are important but for technical reasons have not been satisfactorily resolved.

Optical fiber sensors can be broadly classified as either I) intrinsic or extrinsic, and more specifically classified II) by their operating principles. Information in each type of sensor can be conveyed by polarization, phase, frequency, wavelength, and intensity modulation, or a combination of the above.

If all sensing mechanisms take place within the fiber itself, the sensor is classified as intrinsic. In this type of sensor, the fiber functions as both a transmission medium and sensing element. An external parameter induces a change in the light guiding properties of the fiber, which is detected and demodulated to produce information of the measurands. Microbend, distributed, blackbody and interferometric are the types of intrinsic fiber optic sensor. In intrinsic, distributed sensors are further classified in Raleigh, Raman, Mode coupling and Quasi-distributed. In extrinsic sensors, the fiber plays no role in the sensing mechanism and only serves as a transmitting medium for the light intensity i.e. to bring the light to and from an external medium where it is modulated. The external medium can range from special optical crystals to air. Extrinsic sensors are further classified as, encoder plates/disks, total internal reflection, fluorescence, laser Doppler velocimetry, photo-elastic effects, reflection and transmission, gratings, evanescent, absorption band edge and pyrometers.
2.2.1.2 Classification by Operating Principle

Optical fiber sensors can also be further classified by their operating principle. If the sensor is based on the interference between light waves, it is referred to as interferometric. Interferometric sensors are classified by their geometry: Fabry-Perot, Mach-Zehnder, Michelson etc. Other sensors are based on the loss of light from the fiber or coupled to the fiber and are referred to as intensity based sensors. The optical fiber sensors are summarized in the next sub article 2.2.1.3.

2.2.1.3 Summary of Fiber Optic Sensors

<table>
<thead>
<tr>
<th>TYPE OF SENSOR</th>
<th>APPLICATION</th>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extrinsic Fabry-Perot Fiber Etalon Sensors</td>
<td>Measure longitudinal component of strain, pressure or temperature through two mirrored surfaces: single point static strain measurements in experiments and manufacturing processes for structures and bridges, pressure measurements</td>
<td>Gauge lengths similar to conventional strain gauges; immunity to electromagnetic interference; high temperature, shock &amp; vibration resistant</td>
<td>Difficulties associated with measuring temperature and strain simultaneously, which may be important for internal measurements in inaccessible areas</td>
</tr>
<tr>
<td>Intrinsic Fabry-Perot Fiber Etalon Sensors</td>
<td>Measure longitudinal component of strain, pressure or temperature through two mirrored surfaces: time varying strain measurement applications, including strain on cylinder heads operating at elevated temperatures, vibrating machinery and dynamic loads on railway</td>
<td>Gauge lengths similar to conventional strain gauges; immunity to electromagnetic interference; high temperature, shock &amp; vibration resistant</td>
<td>Difficulties associated with measuring temperature and strain simultaneously, which may be important for internal measurements in inaccessible areas</td>
</tr>
<tr>
<td>Mach Zehnder and Michelson Interferometric Sensors</td>
<td>Measure acoustic waves and vibration, both the time varying and static quantities, since strain, temperature and pressure all affect their response: Undersea surveillance and geophysical Seismic exploration.</td>
<td>Extremely flexible geometry and high sensitivity, wide area distribution</td>
<td>High cost; the long coherence length lasing light sources required are not as reliable and cannot handle as high of temperatures as the light source for the Sagnac sensor.</td>
</tr>
</tbody>
</table>

The advantages of optical fiber sensors are dealt with in the next sub article.
2.2.2 Advantages of Fiber Optic Sensors

Some of the fiber optic sensor advantages are as follows.

1. Due to light weight and small size these sensors can be placed in structural materials without degrading structural integrity, which also makes the fiber sensors a much less obvious target for vandals and thieves.

2. These sensors have immunity to electromagnetic interference. Shielding requirements and problems associated with ground loops, lightning strikes and electrical hazards are eliminated.

3. Optical fiber gives the bandwidth needed for optical communication.

4. Fiber sensors can operate at high and low temperatures.

5. They can be embedded in composite materials.

6. The change in the $5^{th}$ decimal position in refractive index because of pressure, absorption of gas in the clad affects the transmission characteristics, hence sensitivity is high.

7. These sensors with large dynamic ranges and high frequency responses are located along a single fiber line, since the bandwidth of the connecting optical fiber is extremely large.

8. A high degree of synergy with the telecommunication and opto-electronic markets make the prospect of low cost, high performance devices very likely in the future.

9. A series of parameters can be sensed along the same fiber line simultaneously, such as multi-axis strain, pressure, corrosion, temperature, and, the location and measurement of an acoustic signal.

10. Even though fiber optic sensors possess a wide range of gauge lengths, ranging from less than one mm to many kilometers, and have the ability to use fiber optic demodulators many kilometers from the sensors themselves, this does not significantly affect the signal to noise ratio.

These features allow the designer of fiber optic sensor systems for infrastructure to have a range of options that are unavailable using conventional sensor based technology.
2.2.3 Intrinsic Fiber Optic Sensors

Several methods have been demonstrated for the measurement of physical phenomena using optical fiber sensors. In general, some parameter of the light wave guided by the optical fiber is modified by the measurand, and the magnitude of the measurand is inferred from the amount of change of the light wave parameter. Some of the changes in the light wave that can be related to applied external effects include changes in intensity (optical power), wavelength, phase, and polarization. Sensors that are employing either change in light wave intensity or phase have been the most widely researched.

Intensity based sensors are relatively simple to implement. Low cost light sources such as light emitting diodes (LEDs) can be used and simple photodetectors may be employed to determine the intensity of the optical power in the sensor output along with the appropriate signal conditioning.

2.2.3.1 Review of Microbend Sensor

Sensors based on microbend loss in optical fiber were first proposed and demonstrated in 1980. Since this early work, much has been done to understand microbend sensors and to investigate how to increase dynamic range and improve sensitivity to the measurement parameter of interest while reducing sensitivity to unwanted variables.

The early interest in microbend sensors was for hydrophone applications. Since that time several different studies on microbend sensors have appeared in the literature and the sensor have been adapted to many different measurement applications.

Microbend sensors have been demonstrated to have their own unique sets of advantages. These advantages are mechanical and optical efficiency that leads to low parts counts and low cost. Due to easy mechanical assembly that does not require fiber bonding to other components. This avoids differential thermal expansion problems. In addition, microbend sensors have been used in hostile environment applications such as in high temperature zones and explosion hazard areas.

Fields, Asawa, Ramer, and Barnoski came up with a way to enhance the microbending effect by squeezing the fiber between a set of corrugated plates called deformer plates or tooth blocks. Their configuration is shown in figure 2.6.
The length of optical fiber connecting a source and detector is sandwiched between two plates in which ridges have been machined. When a pressure is applied to one of the plates, the resulting force deforms the fiber in a quasi-sinusoidal pattern. From the telecommunication theory it is known that, the periodic deformations of an optical fiber can generate sizable optical losses, even if the amplitude of the deformation is only a small fraction of the fiber diameter. Therefore, the force/pressure applied to the plate can be correlated to the reduction in optical power transmitted through theoretical analysis or by experimental calibration.

A proposal for a novel microbend sensor structure for use in distributed and quasi-distributed microbend sensors is presented by Denis Dolagic. The used sensor element is graded index multimode fiber coupled to the measurand field through the microbend inducing structure. In this, the feed to the sensing section is through a single-mode fiber spliced to the multimode fiber to ensure that only the lowest order spatial mode is launched.

Similarly the receiver also coupled to the sensing element through a single mode fiber. This is called SMS structure. He has also shown that the single mode within multimode fiber prorogates with minimal mode coupling with source to receiver losses of typically 0.7dB for short sensors ranging to approximately 0.3dB per each additional kilometer of sensing fiber. The optical power loss for a given microbend structure and force is about three to six times higher in this architecture than for conventional fully mode filled microbend sensor.

Arun Kumar et al. have proposed the transmission characteristics of a SMS fiber structure assuming that the single and multimode fibers are axially aligned at each
splice but have different spot sizes for the fundamental modes. In such cases, the transmitted power is extremely sensitive to the length of the multimode fiber section and wavelength of operation.

Takao Kobayashi et al. tried for strain measurement of geo-textile applications. The new fiber strain distribution sensor has been developed using microbend scattering of silica and plastic fibers. This technique has unique feature that strain distribution can be measured with high spatial resolution, wide range of strain measurement of 0.01-1.5% shot detection time of 0.1 to 10ms, maximum fiber length up to 200m.

Spiral fiber microbend sensor was developed by T. Yoshino et al., which can be used for an analogue sensor having simple and definite sensing characteristics. The sensor is in spiral- form of single mode fiber. In the sensor, an application of an arbitrary amount of deformation in the spiral axis leads to a uniform change in the radius of the circularity bent fiber. Sensing characteristic affects by the effect of spiral coil radius, pitch and gauge length.

A practical tactile sensor using micro-machined techniques is implemented and evaluated by Chao.

Grossman et al. have designed, tested and developed a compact microbend FOS using a modified polymer bead and its swelling effects for in situ concentration measurements of the surface of the ocean. This microbend NaCl sensor showed feasibility as a practical sensor since it had most of the desirable FOS properties and reversibility through the use of modified polymer beads. A key advantage of this sensor is that the salt water is not in contact with optical fiber, nor other optical components. As seen from above review, there is no report on microbend being used for force sensor and more specifically gravity force based balance. Here an attempt is made to use optical fiber using microbend as a force sensor for use as a single pan balance.

The following article discusses the design of Micro Bend Weighing (MBW) sensor.
2.3 Microbend Weighing (MBW) Sensor: Design considerations

The MBW sensor assembly is as shown in figure 2.7 mainly consists of plastic optical fiber, optical transmitter-receiver, pan and related structure & a pair of fiber deforming plates.

2.3.1 Balance Structure:

To reduce the weight of the weighing balance, the body of the balance stand structure is made from aluminum. Proper bearing is used in the vertical direction to achieve minimum friction between the shaft and the body of the structure. As the weighing pan, rod and top deforming plate (all of stain less steel) are coupled together with fixed (screwed) joints; the weight of the object to be weighed is the only force on POF. A POF is clamped between & compressed by a pair corrugated deforming plates. Force on the top deformer plate causes compression microbending in POF, the bottom deformer plate is being fixed on the aluminum stand.

The 10mm diameter stainless steel rod is connected between weighing pan and top deformer plate through linear ball bearing of 20-mm length. The POF gets clamped and
compressed between the top and bottom segments of the deforming plates. The POF is finally clamped at the two ends, through optical transmitter and receiver to the aluminum base stand. The front and side view of the constructed balance using MBW sensor is shown in figure 2.8.

(a) Front view of balance structure

(b) Side view of balance structure

Fig. 2.8 (a) Front view of balance structure with POF clamped between 10mm pitch deforming plate (b) Side view of balance structure. (With level adjustment screws at bottom)
2.3.2 Pair of Deforming Plates

The geometry of the deforming plates (table 2.3) is the most critical part in this weighing balance. Stainless steel square deformer plates of thickness 4 mm were used for study the microbending effects on the POF are listed in table. The width of the deforming plates is selected so as just to cover the POF.

Table 2.3 Details of the Deformer plate with number of teeth of top deformer plate

<table>
<thead>
<tr>
<th>Plate length</th>
<th>Pitch</th>
<th>No. of Teeth</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 mm</td>
<td>2.5</td>
<td>12</td>
</tr>
<tr>
<td>30 mm</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>30 mm</td>
<td>10</td>
<td>3</td>
</tr>
</tbody>
</table>

The basic shape of the top deforming plate is shown in figure 2.9.

![Fig. 2.9 Basic shape of deforming plate for 10mm pitch and 30mm length](image)

Fig. 2.10 Photograph of deformer plates (top/bottom) used 30mm length, 2.5, 5 and 10 pitches.
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The photographs of the various deforming plates used in the present work and an assembly of one of them (pitch 10 mm) are in figures 2.10 and 2.11 respectively.

![Photograph of Assembly of deforming plates with POF](image)

**Fig. 2.11 Photograph of Assembly of deforming plates with POF Clamped between two supports**

### 2.3.3 Plastic Optical Fiber

A Plastic optical fiber (POF) has several advantages over a glass fiber as far as sensing applications are concerned. The numbers of technologies have made it significantly possible and easily to enhance the performance of POF for sensors, using simple and inexpensive techniques and equipment, compared with those required for glass.

A plastic optical fiber (POF) consists of a polymethylmethacrylate (PMMA) core approximately 980μm thick with 20μm thick cladding made of fluoride- containing carbon polymer. The refractive indices of the core and cladding are 1.492 and 1.417 respectively. With PVC protecting sheath the POF has a total diameter of 2.2mm. The length of the optical fiber is 150mm. Care was taken while cutting the POF. To maximise the bend sensitivity of the POF, wet polishing of the fiber end with 600-grain sandpaper is done for pre defined time. The plastic optical fiber is clamped between transmitter and receiver module through deforming plates. Total length of POF used is 60mm for all (30 mm) deformer plate length. The plastic optical fiber properties are as given below in table 2.4,
<table>
<thead>
<tr>
<th>Material</th>
<th>Core</th>
<th>Cladding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter (Typical)</td>
<td>980 micro meter</td>
<td>20 micro meter</td>
</tr>
<tr>
<td>Young’s Modulus</td>
<td>3.09 GPa</td>
<td>0.68 GPa</td>
</tr>
<tr>
<td>Poisson’s Ratio</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Refractive Index</td>
<td>1.492</td>
<td>1.405</td>
</tr>
<tr>
<td>Yield Strength</td>
<td>82 MPa</td>
<td></td>
</tr>
<tr>
<td>Transmission loss</td>
<td>200 db km⁻¹</td>
<td></td>
</tr>
<tr>
<td>Maximum operating</td>
<td>70 °C</td>
<td></td>
</tr>
<tr>
<td>Approximate weight</td>
<td>1 gm⁻³</td>
<td></td>
</tr>
<tr>
<td>Density</td>
<td>20.69 gm/cc</td>
<td></td>
</tr>
<tr>
<td>Total diameter</td>
<td>2.00 mm</td>
<td></td>
</tr>
</tbody>
</table>

### 2.3.4 Optical Transmitter-Receiver

Siemens Plastic Fiber Components (PFC) emitters and detectors are used as shown in figure 2.12. These low cost components permit the use of plastic fibers even in most cost sensitive applications. SFH 450 emitter diode is used as a transmitter. A phototransistor SFH 350 is used as a receiver. The advantage of the Siemens PFCs is the housing aperture into which a standard POF is introduced without having to remove the cladding. This has additional benefit of automatically centering the fiber on chip. The transmitter and receiver are connected to the POF ends and clamped to aluminum structure. Some of the major features of used transmitter and receiver are as designed for data rates from 10 kbit/s up to 100 Mbit/s, Suitable for transmission distances up to 50 m, has extended temperature range from -40°C to 85°C with high-reliability 650 nm LED and Si detectors, transmitter forward voltage lower than 3 V, 2 mm aperture holds standard 1000 micron plastic fiber, Molded micro lens for efficient coupling. Excellent
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linearity, Plastic connector packaging, Mounting screw at the connector to attach the fiber. Interference-free transmission from light-tight housing. Compact packaging allows flexible positioning.

2.3.4.1 Plastic Fiber Optic Transmitter Diode SFH 450

Some of the features SFH 450 are, 2.2 mm Aperture holds Standard 1000 Micron Plastic Fiber, no Fiber Stripping Required, Good Linearity, Molded Micro lens for Efficient Coupling.

The body of the transmitter is Plastic has, Mounting Screw Attached to the Connector. Interference Free Transmission from light-Tight Housing, Transmitter and Receiver can be flexibly positioned and no Cross Talk. The absolute maximum data is listed in following table.

Table 2.5 Transmitter characteristics for SFH450

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Limit values</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating temperature range</td>
<td>TOP</td>
<td>-40</td>
<td>+85</td>
</tr>
<tr>
<td>Storage temperature range</td>
<td>TSTG</td>
<td>-40</td>
<td>+100</td>
</tr>
<tr>
<td>Junction temperature</td>
<td>TJ</td>
<td>100</td>
<td>°C</td>
</tr>
<tr>
<td>Soldering temperature</td>
<td>TS</td>
<td>260</td>
<td>°C</td>
</tr>
<tr>
<td>Reverse voltage</td>
<td>VR</td>
<td>5</td>
<td>V</td>
</tr>
<tr>
<td>Forward current</td>
<td>IF</td>
<td>130</td>
<td>mA</td>
</tr>
<tr>
<td>Surge current</td>
<td>IFSM</td>
<td>3.5</td>
<td>A</td>
</tr>
<tr>
<td>Power dissipation</td>
<td>PTOT</td>
<td>200</td>
<td>mW</td>
</tr>
<tr>
<td>Thermal resistance</td>
<td>RINJA</td>
<td>375</td>
<td>K/W</td>
</tr>
</tbody>
</table>

Transmitter characteristics at 25 °C are as follows

Circuit consideration for LED Driver is briefly explained below.

Figure 2.13 Transmitter SFH450 LED driver options
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The emitter is stimulated into emission by current flowing in the forward direction. There are several possibilities for the design of the driver circuit, which has the task of adjusting and stabilizing the current flow. In Figure 2.13 the basic types of driver circuits are given. In the simplest example (Figure 2.13a) the emitter diode is connected in series with a resistance $R_s$ to the supply voltage $V_s$. The current $I_f$ is dependent of the forward voltage $V_f$ of the diode:

$$I_f = \frac{(V_s - V_f)}{R_s} \quad (2.1)$$

The diode may also be driven using the output transistor of a TTL gate or a separate driver transistor (Figure 2.13b), in which case the collector-emitter voltage should be taken into account. In this configuration the current let through by the transistor is given as:

$$I_f = \frac{(V_s - V_f - V_{ce})}{R_s} \quad (2.2)$$

In order to keep the current and thus the optical power constant, it is preferable to control the current flow (Figure 2.13c). It is necessary to ensure than sufficient voltage is provided.

One of the diagrams in the emitter data sheet shows the dependency of the forward voltage $V_f$ on the current. Since $V_f$ may reach 3 V for currents of 300 mA for example, therefore the supply voltage may limit the maximum duty cycle.

Another important parameter when dimensioning the driver is the permissible pulse load. It is clear from the relevant diagram in the data sheet, that in regard to power loss, peak currents up to 1 A are possible for short duty cycles. Whether this peak current can be used, depends on the available supply voltage.

2.3.4.2 Plastic Fiber Optic Phototransistor Detector SFH 350

At the other end of the POF is the detector, which serves to convert the optical signal back to an electrical signal. The detector accepts highly attenuated power down in the nano watt levels. Subsequent stages of the receiver amplify and reshape the electrical signal back into its original shape. (Some detector packages have a preamplifier built in to boost the signal immediately). Detectors operate over a wide range of wavelengths and at speeds that are usually faster than the LEDs. The most important figure of merit for a detector is its sensitivity (it is the weakest optical power it can convert without error). The signal received must be greater than the noise level of the detector. Any detector has a small bit of fluctuating current running through it; this minuscule current is noise spurious, unwanted current. The minimum power received by the detector must still be enough to ensure that the detector can clearly distinguish between the signal and
the underlying noise. This is expressed as a signal-to-noise ratio or a bit error rate. SNR is a straightforward comparison of the signal level and the noise level, while the bit error rate is a more statistical approach for determining the probability of noise causing a bit to be lost or misinterpreted. Some of the brief characteristics of the detector used are tabulated in table 2.6.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Limit values</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating temperature range</td>
<td>$T_{\text{OP}}$</td>
<td>-40 to +85</td>
<td>°C</td>
</tr>
<tr>
<td>Storage temperature range</td>
<td>$T_{\text{STG}}$</td>
<td>-40 to +100</td>
<td>°C</td>
</tr>
<tr>
<td>Soldering temperature</td>
<td>$T_{s}$</td>
<td>260</td>
<td>°C</td>
</tr>
<tr>
<td>Collector Emitter voltage</td>
<td>$V_{\text{CE}}$</td>
<td>50</td>
<td>V</td>
</tr>
<tr>
<td>Collector current</td>
<td>$I_{c}$</td>
<td>50</td>
<td>mA</td>
</tr>
<tr>
<td>Collector peak current</td>
<td>$I_{\text{CP}}$</td>
<td>100</td>
<td>mA</td>
</tr>
<tr>
<td>Emitter bias voltage</td>
<td>$V_{\text{EB}}$</td>
<td>7</td>
<td>V</td>
</tr>
<tr>
<td>Reverse voltage</td>
<td>$V_{r}$</td>
<td>30</td>
<td>V</td>
</tr>
<tr>
<td>Power dissipation</td>
<td>$P_{\text{TOT}}$</td>
<td>200</td>
<td>mW</td>
</tr>
<tr>
<td>Thermal resistance</td>
<td>$R_{\text{f}}$</td>
<td>375</td>
<td>K/W</td>
</tr>
</tbody>
</table>

### 2.3.5 Electronics for MBW Balance

The optical detector (SFH350) output is given to a signal conditioner to give suitable corresponding output to a microcontroller based circuit to display weight of the object. The block diagram is as shown in figure 2.14. Block wise description is as follows.

![Block diagram MBW sensor Weighing Balance](image)
2.3.5.1 Fiber optic Transmitter and Detector circuit

The circuit of the transmitter and receiver (described in 2.3.4.1 and 2.3.4.2) used in MBW sensor is as shown in figure 2.15. The only care to be taken is not to exceed the specifications of the transmitter and detector. The output of the detector (Vc) is given to signal conditioning circuit.

![Image of Transmitter and Detector circuit using SFH 450 and SFH 350]

Fig. 2.15 Transmitter and Detector circuit using SFH 450 and SFH 350

2.3.5.2 Signal conditioning

Signal conditioning involves the modification of the signal and often includes scaling (attenuation or amplification), conversion from current to voltage, impedance level transformation, signal integration and differentiation. One of the basic requirements in signal conditioning is that of amplification. The low level signals have to be often amplified to the standard levels with suitable instrumentation.

![Image of Input conditioner for SFH 350 detector]

Fig. 2.16 Input conditioner for SFH 350 detector

amplifier before further processing can be done. The output signal from the detector is in the range of 0-5V. The signal for processing has to be given to Data Converter to
convert data into digital form for the processing required. For the present instrumentation application ultra low offset voltage op-amp OP07 has been used in a simple non-inverting amplifier configuration with an adjustable gain control to compensate for the input signal level. The signal conditioning circuit is as shown in figure 2.16.

Here the input signal is from the phototransistor detector (SFH-350). The resistance $R_f$ adjusts the gain of the amplifier. The op-amp plays a very vital role in conditioning circuit. Some of the silent features of the Op-amp used (OP07) are as follows.

Very low $V_{io}$ (Input offset voltage): 75μV, which is obtained by trimming at the wafer stage. These low offset generally eliminates the need for external arrangement for nullification of the offset. Low offsets and high open loop gain make OP 07 particularly useful for high gain Instrumentation applications. Wide Input voltage range: ±13V max combined with high CMRR of 106dB. High open loop gain: 200V/mV. High input impedance provides high accuracy in noninverting circuit configuration. Excellent linearity and gain accuracy can be maintained even at high closed loop gains. Low Noise 0.6μV peak to peak max. Stability of offsets and gain with time or variations in temperature is excellent. The accuracy and stability of OP07, even at high gain, combined with the freedom from external nullification have made the OP07 an industry standard for the Instrumentation applications.

The output of the signal conditioner is given to signal processing stage of the microcontroller circuit.

### 2.3.5.3 Microcontroller

The Cygnal series controller C8051F005 provides fully configurable hardware through software. Using the port configuration can do all the required settings and crossbar digital priority registers. The Flash Program memory which supports in system serial programming saves much of R&D time and thus leads to faster software upgradation thus leading to faster execution of product development. The on-chip I²C and SPI serial protocols give versatility in the programming and external hardware used. Accessing the external memory and applications like RTC uses serial protocols like I²C, which is only two wire hardware interface and leads to better hardware resource utilization. The advantage of having on-chip efficient resources makes the C8051F005 an ideal choice for applications requiring efficient handling of data from ADC, DAC’s, PWM output, external interrupts, etc manipulation and usage.
The functional block diagram of used microcontroller is as per figure 2.17.

![Block diagram of microcontroller C8051F005 and Photograph of Microcontroller based PCB used.](image)

Smart devices require analysis and exact interpretations of the incoming signals to give a required output. So there is a need of some intelligent device like controller which can perform the required tasks.

Calculating and interpreting pressure in terms of voltage signal. Facility is provided for auto calibration. Password protected calibration mode. Display data to LCD module. For data base applications, interfacing of the data to PC via RS232 interface is provided.

The ADC (figure 2.18) used for signal conversion is a 12 bit SAR type on chip ADC of popular Cygnal series precision controller C8051f005. C8051f005 has on chip 12 bit ADC, which is fully software controlled and has 9 channels out of which 1 is dedicated to take the data of on chip temperature sensor. Each of the ADC channel can be...
configured into differential mode and single ended mode of operation by simple software instructions. It has PGA (Programmable gain amplifier), configurable analog multiplexer. C8051F005 on chip ADC Functional Diagram is shown in figure

2.3.5.4 Display

Two types of display were used for the balance. One is using LED seven segment (figure 2.19) and other is LCD (figure 2.20). The MAX 7219 is an efficient way to drive several seven-segment displays using only three of the I/O ports. An added benefit was that by driving the clock for the LED driver and the keypad driver.

![LED display](image1.png)

*Fig. 2.19 Photograph of seven segment LED display (8 digits)*
*Used for MBW sensor weighing balance*
*(With 4 keys at bottom, for settings mode, tare, enter, up etc.)*

Another low power configuration is made using Liquid Crystal Display. The liquid crystal display has two rows of 16 characters.

![LCD display](image2.png)

*Fig. 2.20 Photograph of Liquid Crystal Display (16x2) for low power version of MBW Sensor weighing balance*
2.3.5.5 Program algorithms for MBW Balance

To achieve the desired functionality the microcontroller has to program accordingly. Brief algorithms are given here.

1. Initialize and configure the micro controller C8051F005.

   Initializing the micro controller C8051F005 is required to configure the necessary and associated hardware peripherals on-chip. The software routine makes the hardware simply active and thus usable.

2. Initialize the associated hardware like LCD display module.

   To display the weight on the LCD, the LCD has to be refreshed and configured in the desired mode to be able to display data. LCD has its own controller, so the initialization makes the LCD functional.

3. Initialize on chip ADC and give it start of conversion to convert the input voltage signal into the required digital data.

   C8051F005 controller has many on chip peripherals of which ADC is one and needs to be configured for the intended read operation. After initialization ADC is able to convert the input voltage signal, and its data registers are accessible.

4. Read initial ADC counts for checking whether the system display output is zero or not. Confirm the weighing scale for zero reading on display, when the input applied weight is zero.

5. If the output is not zero then, take the current ADC data and subtract the counts from the reference and null (zero) the system.

6. Every time sense the input weight and read the ADC counts and can compare with look up table or calculate using the transfer function to show the weight output on LCD.

7. If required, by pressing the “Tare” key, the system can be tare to the desired input weight.

   To have accuracy and precision in the output readings both methods i.e. look up table and transfer function method is used. The data is averaged to get minimum error and maximum closeness to the true value.

The experimental setup to evaluate the MBW sensor and further the weighing balance using MBW sensor is elaborated in next article.
2.4 Experimentation

The experimentation part is divided into two parts. The first part deals with performance of the MBW sensor while the second evaluates the performance of the fabricated single pan balance using MBW sensor.

The MBW sensor performance is evaluated by using HP multimeter (HP-34401A), Tektronix storage oscilloscope (THS 730A) and standard calibrated weights as shown in figure 2.21.

![Experimental Test Setup for MBW sensor (With multimeter and oscilloscope)](image)

The response of the MBW sensor is tested for all the deformer plates (3 pairs of length 30 mm and pitch of 2.5, 5 and 10 mm respectively) as described in table 2.3. The effect of deformer pitch is analyzed by measuring the detector output voltage for 0 to 3000 grams.

To evaluate the sensitivity of the sensor of detector output for different weights is measured for all the deforming plates.

For repeatability of reading it was checked at lowest and highest of the linear range (1-gram to 3Kg), at least 6 times for all deforming plates.

Response of the MBW sensor for 2.5, 5 and 10 mm pitch for fixed weight (3000 grams) is plotted on oscilloscope to measure the rise time and fall time, while loading and unloading the weights.

Hysteresis is checked by incrementing the force by adding weights one at a time, noting the reading after each addition up to 3 Kg and then removing the weights in a
reverse order, noting the reading after each removal. Readings are compared for the same load. Reproducibility for MBW sensor was tested using about 15 pieces of POF and for deforming plate pairs.

Finally the detector output is connected to electronic circuit described in article 2.3.5, to evaluate the performance of the single pan balance using MBW sensor. The single pan balance is tested for all its specifications. The calibration was checked and linearity by using standard calibrated weights and by using deformer plates. Weight displayed on the balance display is checked for calibration and linearity with applied standard weights on the pan.

Hysteresis, linearity and repeatability of reading were carried out as per National Physical laboratory (NPL) electronic balance assessment guideline 29. Electronic balances are widely used and the simple operation means that a full assessment takes the form of relatively few tests. Before starting the assessment of an electronic balance, it is kept switched on for an hour. Hysteresis is occurring when a balance, for the application of the same weight, displays a different reading when the load is ascending compared to when it is being reduced.

The repeatability of MBW single pan balance is assessed by repeated application of the standard mass. As per the NPL standard 30, in general ten measurements were taken to analyze the performance. The repeatability is measured for two loads (half and full load) of the balance.

The scale error and linearity of the balance is checked with a suitable set of calibrated mass standards. Measurements are carried out across the full range (0 to 3 Kg.) of the balance.
2.5 Results

In order to evaluate the performance of the MBW sensor against used deformer plates for light intensity variation was systematically compared with standard calibrated weights. Figure 2.22 shows the effect of deformer pitch for change in intensity in terms of detector output voltage for standard calibrated weights ranging from 0 to 3000 grams.

![Graph showing variation of detector intensity in terms of voltage with respect to weight for three deforming plates pitch.](image)

*Fig. 2.22 Variation of detector intensity in terms of voltage with respect to weight for three deforming plates pitch. (2.5, 5, & 10 mm pitch and length 30 mm)*

The sensitivity of the MBW sensor for three deformer plates is shown in figure 2.23.

![Graph showing sensitivity plot for 2.5, 5, and 10 mm pitch deformer plate (30 mm long).](image)

*Fig. 2.23 Sensitivity plot for 2.5, 5, and 10 mm pitch deformer plate (30 mm long)*
The repeatability of the POF sensor under loading was found to be very encouraging for both sets of deforming plates and the results of 6 sets for three different deforming plates are summarized in from Fig. 2.24 to 2.26. The repeatability is found up to 1% of a full span in all the cases.

![Graph showing repeatability result for 2.5 mm pitch, 30 mm Deforming Plate](image1)

*Fig. 2.24 Repeatability result for 2.5 mm pitch, 30 mm Deforming Plate (With error bar of 1%)*

![Graph showing repeatability result for 5mm pitch, 30 mm Deforming Plate](image2)

*Fig. 2.25 Repeatability result for 5mm pitch, 30 mm Deforming Plate (With error bar of 1%)*
Hysteresis is one of the important parameters for any measuring devices. Fig. 2.27 is for deforming plate show hysteresis, while loading and unloading of the weights. From the figure it is clearly revealed that there is no sign of hysteresis.
The response time of the force sensor for three deforming plates is as shown Fig. 2.28. Figure 2.28 a) shows the oscilloscope graph plot for 2.5mm deformer plate for 3000 grams. The rise time was while loading is approximately 200 ms and fall time while unloading is approximately 200 ms.

![Figure 2.28 a) for 2.5 mm pitch, 30 mm length and 3000 grams load](image)

Figure 2.28 b) shows the oscilloscope graph plot for 5mm deformer plate for 3000 grams. The rise time was while loading is approximately 200 ms and fall time while unloading is approximately 200 ms.

![Figure 2.28 b) for 5mm pitch, 30mm length, 3000 grams load](image)

Figure 2.28 c) shows the oscilloscope graph plot for 10 mm deformer plate for 3000 grams. The rise time was while loading is approximately 200 ms and fall time while unloading is approximately 200 ms.
Fig. 2.28 Oscilloscope trace for response time of a) 2.5, b) 5 and c) 10mm pitch Deforming Plates, for 3000grams Load. (On 200 mV and 1Sec. Time scale)

Reproducibility of MBW sensor is checked using 15 pieces of plastic optical fiber for all deformer plates and no significant change was observed.

Hysteresis of single pan balance using MBW sensor is checked for the three deformer pitch and significant hysteresis was observed.

Figure 2.29 shows hysteresis for 2.5 mm pitch MBW single pan balance.

Fig. 2.29 MBW Single pan balance – hysteresis for 2.5mm pitch

Figure 2.30 shows hysteresis for 5 mm pitch MBW single pan balance
As explained in article 2.4, repeatability of the balance is checked as per the norms of NPL. The results of repeatability are found within 0.2% of the total range of the
balance i.e. 0 to 3000 grams. Figure 2.32 shows repeatability results for 2.5 mm pitch and 1500 gram load repeated for 10 times.

![Graph showing repeatability results for 2.5mm pitch deformer plate (1500 grams load).](image)

**Fig. 2.32** Repeatability results for 2.5mm pitch deformer plate (1500 grams load).

The observations on display of weighing balance are listed in table 2.8. The standard calibrated loads are used. The weights are kept on the pan one by one sequentially and weight measured by the balance, is noted down. The results are also encouraging and found within 1% of the total range of the MBW single pan balance.

<table>
<thead>
<tr>
<th>Applied weight gms.</th>
<th>P= 2.5mm L = 30mm</th>
<th>P= 5mm L = 30mm</th>
<th>P= 10mm L = 30mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50.2</td>
<td>50.0</td>
<td>50.1</td>
</tr>
<tr>
<td>10</td>
<td>50.3</td>
<td>100.1</td>
<td>100.0</td>
</tr>
<tr>
<td>50</td>
<td>100.0</td>
<td>100.1</td>
<td>100.0</td>
</tr>
<tr>
<td>100</td>
<td>500.0</td>
<td>500.1</td>
<td>500.2</td>
</tr>
<tr>
<td>1000</td>
<td>1000.3</td>
<td>1000.2</td>
<td>1000.1</td>
</tr>
<tr>
<td>1500</td>
<td>1500.4</td>
<td>1500.1</td>
<td>1500.2</td>
</tr>
<tr>
<td>2000</td>
<td>2000.2</td>
<td>1500.3</td>
<td>1500.0</td>
</tr>
<tr>
<td>2500</td>
<td>2500.1</td>
<td>2500.2</td>
<td>2500.1</td>
</tr>
<tr>
<td>3000</td>
<td>3000.0</td>
<td>3000.0</td>
<td>3000.0</td>
</tr>
</tbody>
</table>
2.6 MBW Single Pan Balance Specifications

The specifications of the single pan balance using microbend of POF are listed in table 2.8.

*Table 2.8 MBW single pan balance specifications*

<table>
<thead>
<tr>
<th>Sr.No</th>
<th>Parameter</th>
<th>Specification</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cost</td>
<td>40</td>
<td>$</td>
</tr>
<tr>
<td>2</td>
<td>Weighing capacity</td>
<td>3000</td>
<td>Grams</td>
</tr>
<tr>
<td>3</td>
<td>Minimum weighing</td>
<td>50</td>
<td>Grams</td>
</tr>
<tr>
<td>4</td>
<td>Repeatability</td>
<td>0.5</td>
<td>Grams</td>
</tr>
<tr>
<td>5</td>
<td>Linearity</td>
<td>±1</td>
<td>Grams</td>
</tr>
<tr>
<td>6</td>
<td>Tare range</td>
<td>To capacity by subtraction</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Stabilization time</td>
<td>2</td>
<td>seconds</td>
</tr>
<tr>
<td>8</td>
<td>Weigh mode</td>
<td>Grams</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Operating temp.</td>
<td>5 to 40</td>
<td>Deg. Cen.</td>
</tr>
<tr>
<td>10</td>
<td>Display type</td>
<td>LCD/LED</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Display refresh</td>
<td>10 times/sec.</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Pan size</td>
<td>100</td>
<td>mm</td>
</tr>
<tr>
<td>13</td>
<td>Power (AC)</td>
<td>110/230</td>
<td>VAC</td>
</tr>
<tr>
<td>14</td>
<td>Net weight</td>
<td>1000</td>
<td>grams</td>
</tr>
</tbody>
</table>

Other than above specifications following features are added in to MBW single pan balance.

- Suitable for Laboratory and General Application
- Equipped with Manual Zero.
- Long Battery Operating Time: 100 Hours Plus
- Bright Red LED Display Digits
- Power Adaptor
2.7 Discussion

The main contribution here is use of Optical Fiber for force sensing and hence weighing on Plastic Optical Fiber, Which made Microbend Weighing Sensor of small size and low cost device.

Just like load cell the different capacity MBW sensors using different pitches of the deforming plates will determine the maximum range and sensitivity of the sensor. The beauty of this sensor is that the 'force' on the pan is directly transmitted to the fiber, without noticeable frictional loss because of ball bearing as coupler and high elasticity (hardness) of SS deforming plates. The sensor like load cell is in a way indirect force sensor which needs to have good signal processing for calibration to account for non linearity to the force and change in electrical resistances.

The use of microbend technique has given adjustability for sensitivity through adjustment of pitch for a fixed length of deformer plates (see figure 2.23).

The lower pitch introduces low microbend resulting in lower sensitivity but offering high weighing capacity on the other hand increase in pitch (decreasing no. teeth for the given length of deformer plate) increases the sensitivity because of high microbending of the POF. (See figure 2.22). The reason for this result lies in the force experienced per tooth. For the given force, with the increasing number of teeth the force distributed per tooth is lower than for that for higher pitch and hence the microbending.

The present experimental study has shown that for all used deforming plates with different number of teeth (pitch) the sensitivity curves are quite linear, repeatable and have apparently show no hysteresis (See figure 2.24-2.27) This may be attributed to the proper choice of ball bearing. The signal conditioning might have played the roll in the sensitivity curve to become more linear. The dependence amount of bending on experienced force is studied by simulation in chapter 5 article 5.1.1.4.

The response and recovery time constants of Microbend sensor are found to be approximately 200 milliseconds. Thus we get promising results for microbend weighing sensor and with further work we can improve on performance and variations.

As far as replacement of the fiber after wear and tare is concerned, alignment is not at all a problem because of the specifically used connectors. The cost of the fiber used is not more than a dollar. The wear and tare of the connector's could be after $10^7$ operations. Therefore the balance is expected to give long life.
Though in the lab model the weighing capacity of three Kg is tested the capacity of the balance can be enhanced up to 100 Kg. This is estimated for smaller pitch of 2.5 mm deform plate. The sensitivity and maximum weighing capacity are inversely proportional to the force experience per tooth for the given length of deforming plate.

The sensor offers a number of advantages including ease of fabrication, high microbend sensitivity, linearity and a high signal to noise ratio, EMI free. The sensor is found to offer excellent linearity. Repeatability tests have confirmed that the signal was highly reproducible. The finding of an analysis performed to evaluate the accuracy of the sensor measurement has shown that POF's are capable of force measurement to within a standard deviation of 0.5 %.

The specifications of the MBW single pan balance are found comparable with available general purpose load cell based single pan balances.

2.8 Conclusion

The Microbend based weighing sensor is successfully demonstrated and a prototype is successfully fabricated. To the best of our knowledge this is the first time report. This investigation has demonstrated the potential of this inexpensive plastic optical fiber system for measuring force (weights). The relation between the pitch of the deforming plate for the given length and its range has to be thoroughly investigated. The proper designing of deformer plates can enhance the microbend sensitivity. Thus we get promising results for MBW sensor and with further work we can improve of performance and variations.
References:


28. Plastic Optical Fiber – Data, Optical Fiber Department, MITSUBISHI RAYON Co., Ltd.
29. "Electronic Balance Assessment Guideline" NPI.