The key Research on Improving the Anti-jamming Performance of POF Displacement Sensor

Sen Zhang a, Huili Xue
School of Information Engineering, Guangzhou Nanyang Polytechnic, Guangzhou 510925, Guangdong, China

a 1398804839@mail.nylg.edu.cn

Abstract. In weak signal detection, interference and noise have become important factors that limit and affect measurement sensitivity, accuracy, and repeatability. In order to comprehensively improve the anti-interference performance of the POF displacement sensor, it is necessary to reduce and eliminate the harmfulness of interference and noise. However, in the actual application environment, the optical signal of the measured information is often submerged in interference and noise. In order to effectively detect the weak signal under test and improve the anti-jamming performance of the entire sensor, the techniques often used include frequency domain narrowband technology, time domain averaging processing technology, discrete counting statistics technology, computer processing technology, light modulation technology, Amplification technology, correlation detection and low-pass filtering and other key technologies are the key to improving the anti-interference performance of the POF displacement sensor.

Keywords: POF displacement sensor; anti-interference performance; frequency domain narrowband, time domain average processing, discrete count

1. Introduction
Compared with traditional sensors, fiber-optic sensors have more powerful advantages in environments such as noise, high vibration, extreme high temperature, and humidity, because fiber-optic sensors modulate the intensity, wavelength, polarization, phase and other parameters in the optical system to monitor The physical state of the measured object can be detected according to the change characteristics of the acquired light signal. However, if it is a weak optical signal, eliminating the interference of noise and comprehensively improving the anti-interference performance of the POF displacement sensor in terms of sensitivity and accuracy has actually become an important bottleneck in current practical research.
2. Overview of the development of displacement detection technology and displacement sensors

Displacement measurement technology is the basic technology of vibration, pressure, strain, acceleration, temperature, flow and other measurement technologies, and it is also an important technology in the field of precision calculation. Because of the many physical variables, the displacement variable is easy to detect and easy to obtain accurate detection results, that is, the measurement of many other physical variables can also be converted into displacement for detection.

Because displacement detection has different requirements for accuracy, resolution, use conditions, etc., there are many methods for displacement detection. The traditional and common detection methods are mainly mechanical, resistive, capacitive, analog, etc. Although these methods have their own advantages, their shortcomings are also very obvious. For example, most mechanical measurements cannot be used in the production process. Resistance measurement will cause additional errors when the resistance changes with temperature. Capacitive measurements are greatly affected by parasitic capacitance. In short, temperature, magnetic field, current, pressure, vibration, bending, volume, range and other external factors will affect the accuracy of the measurement.

With the development of optical detection elements, the improvement of precision manufacturing processes, and the use of photoelectric combined detection methods, various problems existing in traditional detection methods are basically solved, and its response speed is high, measurement accuracy is high, and it is easy to realize digital measurement. The unique advantages of optical fiber sensing technology are very obvious, but the quartz optical fiber with good transmission performance is expensive, and the back-end circuit and digital processing device are extremely complicated. Therefore, Polymer Optical Fiber (POF) with low cost, light weight, simple installation and convenient use has emerged [1].

The development history of polymer optical fiber displacement sensors can be traced back to polymer optical fibers with polymethyl methacrylate (PMMA) as the core, which is a step-type polymer optical fiber manufactured by DuPont in 1968. In 1972, Toray Corporation of Japan used polystyrene (PS) as the core of step-type polymer optical fiber [2], and applied for a patent in 1974. The patent mainly uses polystyrene (PS) as the core and fluoroplastics as the cladding material. The transmission loss of the polymer optical fiber manufactured from this can be reduced to 350dB/km. On the basis of this research, Japan's Mitsubishi Optical Fiber Company improved the manufacturing process and applied for a new polymer optical fiber manufacturing patent. Later, the Eska polymer optical fiber produced in Japan was mainly manufactured based on this innovative process.

By 1982, Keio University in Japan produced a graded polymer optical fiber for the first time. When the light wavelength is 670nm, its loss rate is as high as 1070dB/km. In 1986, Fujitsu introduced PC optical fiber coated with polyolefin-based materials. In 1990, Professor Koike of Keio University successfully developed A Graded Index POF for high-speed transmission [3], synthesized in Japan in 1994. The rubber company successfully developed a heat-resistant polymer optical fiber. With the continuous improvement of polymer optical fiber development technology and level, in 1995, Professor Koike of Keio University replaced the hydrogen atoms in the polymer with fluorine atoms and successfully developed A Perfluorinated fiber was developed. In the light wavelength range of 600-1300nm, the loss rate of this perfluoropolymer fiber is reduced to 50dB/km. In theory, when the wavelength is 1300nm, this fiber can achieve a low loss rate of 0.25dB/km, which is almost the same as the transmission performance of silica fiber. By 1998, on the basis of Professor Koike’s perfluorinated fiber, Japan’s Asahi Glass Company produced a perfluorinated polymer fiber with stronger light transmittance. When the wavelength is in the range of 850~1300nm, the loss rate is about 50dB/km [4].

After improving the production process, Japan's Asahi Glass Company produced a perfluorinated ring polymer graded fiber in 2000. When the wavelength is 1300nm, its loss has been as low as 16dB/km. At present, the transmission loss of many types of optical fibers has basically fallen below 0.2dB/km, and a variety of optical fibers are emerging in an endless stream, such as birefringent fibers, evanescent field fibers, and rare earth-doped fibers. These fibers with different characteristics are not only used for signal transmission, but also widely used for signal processing and signal acquisition [5].
In this article, the author mainly conducts innovative research on the anti-jamming performance of POF displacement sensing technology, especially the innovative research on Weak Signal Detection. Because weak signal detection is the cutting-edge technology in optical fiber displacement sensing measurement technology, by using the methods of electronics, information theory and physics, it measures those weak quantities that are covered by background noise and are considered impossible to be measured by traditional concepts. Therefore, in order to improve the anti-interference performance of POF displacement sensing technology, it is necessary to reduce and eliminate interference and noise, and comprehensively improve the sensitivity, accuracy and repeatability of measurement.

3. The main technical indicators of the displacement sensor

Refer to the National Military Standard of the People’s Republic of China GJB2715-96 "General Terminology of National Defense Metrology", National Metrology Technical Specification JJG1010-87 "Terms and Definitions of Length Measurement", "Sensor Technology Manual" published by the National Defense Industry Press, and the General Assembly of the People's Liberation Army The relevant clauses of the metrological personnel training textbook "Basic Knowledge of Metrology" published by the Technical Foundation Bureau of the Ministry of Electronics and Information, the performance indicators of displacement sensors are generally divided into two parts, static characteristics and dynamic characteristics. When the sensor input and output are constants that basically do not change with time, or change very slowly, and their changes can be ignored during the observation time interval and regarded as constants, we mainly investigate its static characteristics, which are important technical indicators for displacement sensors. It mainly includes the following four.

(1) Span: It mainly guides the mode of the difference between the two limit values of the nominal range. The nominal range is usually expressed by the upper and lower limit values allowed by the sensor. The upper limit is also called full scale (abbreviated as F. S.).

(2) Accuracy: It is mainly used to indicate the degree of agreement or deviation between the measurement result and the measured true value. This is a qualitative concept. Because it is impossible to know the measured value (ie true value), so It is impossible to determine the value of accuracy accurately and quantitatively. According to the traditional error theory, accuracy is considered to be the combination of systematic error and random error, and there has been no unified international standard for their synthesis method.

(3) Linearity: the degree of deviation of the relationship curve between sensor output and input from the working straight line [6]. The least square method is commonly used to fit the working straight line. The linearity of the sensor is expressed by the ratio of the maximum deviation between the working straight line (yi) and the actual working curve (y(xi)) to the full-scale output (yn).

\[
\text{Linearity} = \frac{y_i - y(x_i)}{y_n} \times 100\%
\]

(4) Repeatability: Under the same measurement conditions, the consistency between the results of multiple consecutive measurements on the same object. The same measurement conditions mainly include the same observer, the same measurement procedure, the same measurement equipment, the same measurement location, and repeated measurements in a short period of time. Repeatability is often expressed quantitatively by the dispersion of measurement results. The experimental standard deviation S calculated from the measurement value is the repeatability of the measurement result. The calculation formula is as follows:

\[
S = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (X_i - \bar{X})^2}
\]

(5) Sensitivity: mainly refers to the ratio of the sensor's response change to the corresponding excitation change, usually expressed by the slope b of the working straight line. For sensors with obvious non-linearity, use \(dy/dx\) to express, or use the slope of a certain interval to fit a straight line.
4. The key technology to improve the anti-interference performance of POF displacement sensor

Weak Signal Detection is not only a key technology in measurement technology, but also a cutting-edge technology for sensor anti-interference performance, because the ultimate goal of this technology is to use electronics, information theory and physics to analyze the cause and law of noise, study the characteristics of the measured signal, measure those weak signals that are covered by background noise and are considered undetectable by traditional concepts, so weak signal detection technology is a technology that specializes in fighting noise, and only eliminates it. Noise, eliminating interference, can accurately obtain the signal, so as to ensure the sensitivity, accuracy and repeatability of the measurement [7].

The sensitivity of weak signal detection technology is mainly expressed by the signal-to-noise ratio (SNR). The larger the signal-to-noise ratio, the higher the sensitivity, which means that the higher the detection level, the stronger the ability to deal with noise. The signal-to-noise ratio (SNR) is the ratio of the output signal-to-noise ratio (S/N)\text{out} to the input signal-to-noise ratio (S/N)\text{in}, and its calculation formula is as follows:

\[
SNR = \frac{(S/N)_{\text{out}}}{(S/N)_{\text{in}}}
\]

According to the different characteristics of weak signals, the detection technology is also different. In the process of weak signal detection, there are three main technical routes commonly used: one is to reduce the inherent noise of sensors and amplifiers, and to maximize the signal-to-noise ratio; the second is to develop detection devices suitable for weak detection environments and principles; the third is to continuously improve weak signals Detection technology to accurately extract weak signals. These three technical routes are indispensable, but the most important thing is to continuously improve the route of weak signal detection technology. Different signal characteristics require different detection methods. Therefore, the process of improving the detection method is actually the process of continuously improving the weak signal detection technology. This process is very critical, which is also the key to continuously improving the anti-interference performance of the POF displacement sensor.

4.1. Narrowband technology in the frequency domain

If the detected signal is a frequency domain signal, or a sinusoidal frequency domain \( f_0 \) signal modulated to a fixed frequency, then the frequency domain narrowband technology can be used for detection at this time. The first technique for narrowing the frequency domain is achieved by a band-pass filter (BPF), but the bandwidth of the BPF only allows signals and noises of \( f_0 \pm \Delta f \) to pass. When the value of \( \Delta f \) is smaller, the noise components pass through. Less, the better the detection. However, in practical applications, it is difficult to directly detect weak signals with BPF. If it is assumed that \( f_0=0 \) (ie direct current DC), then the value of \( \Delta f \) can be as small as possible. This method has been used to detect weak signals but has received very good results. This is the band pass filter (BPF) Based on the updated low-pass filter (LPF) [8]. However, this kind of narrowband technology must use a phase-sensitive detector for spectrum relocation, which is the heart of the entire frequency domain narrowband technology. The weak signal detection instrument developed following this technical route is called a lock-in amplifier (LIA). In fact, LIA is not only a kind of coherent detection, but also related reception. Its integration process can be expressed by the following formula:

\[
\int_{0}^{\infty} [S(t) N(t)] (t) dt
\]

Where (t) is a weighting function. When (t)=s(t)+N(t+), (t) is a delayed autocorrelation function, this delayed input function, in the frequency domain signal, (t) not only has a fixed Frequency also has a certain phase difference. Therefore, the weighting function (t) appears as a fixed delay in the time domain and as a fixed phase in the frequency domain. Randomness is the inherent characteristic of noise that is different from the weighting function (t). This means that when the fixed phase of the weighting function (t) is detected in the frequency domain, the lock-in amplifier will only amplify, and it is detected that there is no fixed phase. The noise signal is not amplified, which can easily eliminate the noise.
4.2. Average processing technology in time domain

The frequency-domain narrow-band processing technology is mainly for coherent detection technology with fixed phase characteristics. However, if the measured signal is a pulse waveform in the time domain, then the frequency-domain narrow-band processing technology will be particularly difficult to use, because The conversion from the time domain to the frequency domain is very troublesome, and the relevant parameters with obvious correlation and intuitive relationship are lacking in the conversion process.

At this time, averaging processing technology based on time-domain features has become the first choice for detecting time-domain signals. This technology is mainly used to improve the signal-to-noise ratio through the BOXCAR integrator and restore the waveform. If during the detection, only one sample is taken during the signal appearance and repeated m times within a fixed sampling interval, then the signal-to-noise ratio (SNR) is the value of $\sqrt{m}$. If the detected signal is divided into $n$ intervals in chronological order, and then the average result of each interval is recorded in turn, then the signal waveforms contaminated by noise can be restored. If $n$ is divided into finer points, the more accurate the recovery will be, and the greater the average number $m$, the greater the SNR. When recording a complete waveform, the detection signal needs to be repeated $n \times m$ times. That is to say, because the sampling efficiency is relatively low, the acquisition of the signal-to-noise ratio (SNR) often takes a long time to measure, which is relatively time-consuming.

However, with the popularization of computers, the disadvantages of BOXCAR integrator, such as low sampling efficiency and unfavorable signal recovery at low repetition rates, have been well resolved. The current multi-point digital averager is developed on the basis of the BOXCAR integrator.

The working characteristic of the multi-point digital averager is that every time a signal appears, it is possible to sample many points one by one through the computer (such as $2^{10} = 1024$). With the powerful computing power of the computer, it can not only save time to the maximum, but also Improve the signal-to-noise ratio well. The signal with noise is $f(t)=S(t)+N(t)$. If sampling is performed every $T$ seconds, then the k-th sampling value of the i-th sampling point can be expressed as:

$$f(t_k+iT) = S(t_k+iT) + N(t_k+iT)$$

After the sampling value is converted by AD, it can be stored in the storage location corresponding to each sampling point. After $mT$ seconds, the total number of samples is $m$, and for point $i$, it means that $m$ averages have been done. If it is a simple linear cumulative average method, then the total value of the samples stored at point $i$ can be expressed as:

$$\sum_{k=1}^{m} f(t_k + iT) = \sum_{k=1}^{m} S(t_k + iT) + \sum_{k=1}^{m} N(t_k + iT)$$

Because the sampling interval is fixed, during this fixed interval, the output signal is $m$ times the amplitude of the input signal, and the noise at this time is random, and its effective value is $\sqrt{m}$, so the average signal-to-noise ratio $\text{SNR} = \sqrt{m}$. This time-domain averaging processing technology can not only be used to measure the amplitude of the signal and restore the waveform of the signal, but also to measure the unknown time interval. Therefore, the time-domain averaging processing technology can expand more measurement methods, and at the same time can penetrate into more measurement fields.

4.3. Discrete counting statistics technology

When the photons per unit time are neither emitted at the same time nor arrive in a regular order, they are distributed according to a certain probability, and more information is often distributed randomly. When detecting these discrete information, how to separate them one by one, how to record all of them, how to correct the accumulation process, and how to eliminate the noise in it is another difficult problem for weak signal detection.

For the detection of weak signals with discrete features, this is a key link in the discrete counting statistical technology. For example, in low light detection, because the light signal is too weak, these light signals can often only be presented in the form of particles and become quantized photons. Because
a photon is a particle with only momentum but no mass, its energy can be calculated by the expression $E_P = \frac{hc}{\lambda}$.

For the elimination of noise interference signals, this is the core technology of weak signal detection technology. In the process of low light detection, secondary electron emission, thermal excitation and amplifier noise are the main noise sources. Because these noises have a high probability of counting, the pulse amplitude of the light signal to be detected should be kept as much as possible. Consistent, so easy to identify; for noise sources such as secondary electron emission, thermal excitation, and amplifier noise, the pulse amplitude output by the photoelectric device should be as low as possible; for cosmic rays, it should be shielded as much as possible to prevent entry.

Based on the above analysis, in order to improve the detection effect of weak signals, first of all, the photomultiplier tube (PMT) must be reasonably selected and specially designed to ensure that the photomultiplier tube (PMT) has an obvious single photoelectron response peak. Second, the gain of the PMT dynode (electron multiplier) must be reasonably distributed, and a cooling jacket must be installed to reduce the temperature of the PMT photocathode and prevent thermionic emission. Third, the subsequent amplifier requires not only low noise, but also sufficient bandwidth. At the same time, two window discriminating circuits with adjustable thresholds are required to extract single-photon output pulses. Fourth, the information obtained and screened should be counted and processed with a discrete amount of counting statistical techniques, including correction of count errors, automatic background subtraction, source intensity compensation, and further improvement of the signal-to-noise ratio. These techniques In fact, digital phase-locked counting technology and time-domain average processing technology have been used for processing.

4.4. Computer processing technology

With the popularization and development of computers, detections that were originally completed by hardware can now be implemented with software. Therefore, the weak signal that is covered by noise can now be completed by computer for curve fitting, smoothing, digital filtering, fast Fourier transform (FFT), spectral density estimation and other processing techniques, which greatly improves the signal-to-noise ratio. An inherently certain physical quantity, because of the existence of random variables, its measured value often has errors. Therefore, when the measured signal is a certain value, the best way to reduce the error is to seek the best estimate of the parameter. The signal is an unknown functional relationship, so it is necessary to fit the functional relationship determined by the measured value. In fact, the essence of the fitting is the smoothing of the data. The partial smoothing can be regarded as the piecewise fitting, and the effective fitting method is The least squares rule is used, and the method of data smoothing is only effective for eliminating high-frequency noise, while averaging processing technology must be used for ultra-low frequency noise.

In actual operation, the method of processing time-domain signals generally directly uses data smoothing processing technology, and the processing method of converting time-domain signals into frequency-domain signals often uses Fourier transform technology. In domain transformation, the amount of information remains unchanged. If the function $f(t)$ is periodic, then the spectrum processing uses discrete counting techniques. If $f(t)$ is aperiodic, the limit method can be used. The time domain and frequency domain in the Fourier transform technology can be expressed with each other. The form of mutual expression is also called Fourier transform pair, which can be expressed in symbols:

$$F(\omega) = \int f(t) e^{-j2\pi ft} dt$$

In order to facilitate the calculation of the computer, in actual operation, the Fourier integral formula is often transformed into the Fourier discrete formula:

$$S(k) = \sum_{i=0}^{N} S(t_i) e^{-j2\pi K \frac{i(t_i-t_0)}{N-1}}$$

In this formula, assuming that $S(t_i)$ has N data, then N^2 multiplication is required. When there are more data points, the calculation time will be longer. If the measured signal is continuous and infinite, then the time interval $t$ needs to be measured point by point. This is actually a waveform sampling problem. The Fourier transform after sampling is equal to the convolution of the two Fourier transforms.
before sampling. When the sampled spectrum is aliased, it is necessary to select a smaller sampling interval to eliminate aliasing.

Another problem is that when $S(t)$ has an infinite number of sample values, and the computer can only allow limited sampling, then the sampled waveform must be truncated and only N points are taken. In fact, the essence of a digital filter is a way of truncation. FFT has a variety of functions, such as instantaneous recording, power spectrum, linear spectrum, phase spectrum, three-digit spectrum, average density spectrum, probability density spectrum, continuous storage spectrum, differentiation and integration of spectrum, etc., which provide a good solution for weak signal detection. Signal processing tools.

In weak signal detection, the most important factors that limit or affect the sensitivity, accuracy, and repeatability of the measurement are interference and noise. Therefore, in order to comprehensively improve the anti-interference performance of the POF displacement sensor, measures must be taken to reduce and eliminate interference and The hazard degree of noise. In practical applications, the signal processing flow of the optical fiber displacement sensor is shown in Figure 1.

![Signal processing flowchart of optical fiber displacement sensor](image)

**Fig.1** Signal processing flowchart of optical fiber displacement sensor

5. Conclusion
To sum up, in the actual application environment, due to the background light, stray light, power frequency interference, electromagnetic interference, and the thermal noise of the circuit and the device itself, low frequency noise, shot noise, etc., the measured information is included. The signal is often submerged in these interference and noise. In order to effectively detect the measured signal and improve the anti-interference performance of the entire sensor, according to the different characteristics of the weak signal, the frequently used technologies include frequency domain narrowband technology, time domain average processing technology, discrete count statistics technology, and computer processing technology, Optical modulation technology, amplification technology, correlation detection and low-pass filtering and other key technical means, which can better meet the requirements of weak signal detection.

Acknowledgments
2020 Guangzhou Nanyang Polytechnic Natural Science Key Project "Optical Communication Module Research Based on 650nm Fiber" (NY-2020KYZD-01); 2020 Guangzhou Nanyang Polytechnic Natural Science General Project "Wireless Communication Research on POF Optical Fiber Displacement Sensor" (NY-2020KYYB-01).

References
[1] Nabeel Ahmed, Patricia Scully, John Vaughan, et al. Polymer Optical Fibre Sensor for Measuring Breathing Rate of Lying Person. International Journal on Smart Sensing and Intelligent Systems, 2020, 7(5):1-6.
[2] Zubia J., Arrue J. Plastic Optical Fibers: An Introduction to Their Technological Processes and Applications. Optical Fiber Technology: Materials, Devices and Systems, 2001,7(2):101-140.
[3] Koike Y, Ishigure T, Nihei E. High-bandwidth graded-index polymer optical fiber. Journal of Lightwave Technology, 1995, 13(7):1475-1489.

[4] Tanaka A, Sawada H, Takushima T, et al. New plastic optical fiber using polycarbonate core and fluorescence-doped fiber for high temperature use. Fiber and Integrated Optics, 1988, 7(2):139-158.

[5] Getinet Woyessa, Jens K.M. Pedersen, Kristian Nielsen, et al. Enhanced pressure and thermal sensitivity of polymer optical fiber Bragg grating sensors. Optics & Laser Technology, 2020, 130(10):157-163.

[6] Hao Mengmeng, Yang Kun, Zhang Cheng. A system for processing polymer optical fiber side light emission. Shanghai Textile Science and Technology, 2020, 48(09): 9-12.

[7] Han Yanjun. Research and implementation of embedded optical fiber displacement sensor and its signal processing circuit. Huazhong University of Science and Technology, 2015.

[8] Zhao Runyu. Research on rubber material polymer optical fiber strain detection sensor. Hubei University of Technology, 2019.