The Process Capability Analysis Model of Hexagonal Infrared Optical Lenses

C. H. Hsu

Department of Business Administration, Asia University, Taichung, Taiwan, R.O.C. pci@asia.edu.tw

Abstract—Development of the optical technology is extremely important in the field of science research, industrial production and daily appliances. Although a lot of researches have conducted in the area of processing optical lenses, very few attempts have been made at the quality of optical lenses. We established a Process Capability Analysis Model (PCAM) to discover the ineffective areas of quality items. In this paper, the PCAM flow is used to evaluate the process capability of hexagonal infrared optical lenses. As a result, we discovered the lens' diameter is qualified, but the total thickness is not.

Index Terms—Process Capability Analysis Model (PCAM), Hexagonal Infrared Optical Lenses, C_{pk}

I. INTRODUCTION

The development of optical industry has grown rapidly because of the highly usage of electronic and digital products. The optical instruments are ones that use of the theory of optical reflection such as projectors, digital camera, and space telescopes. The optics experiment instruments are those related to the light components such as spectroscope, luminosity, and colorimeter. There are many components in optical instruments and optics experiment instruments. There can be divided into two categories according to the functions - optical and machinery. The optical components are ones that based on the theory of light reflection, such as lenses, prisms, and reflectors. The machine components are used to hold the optical components in the correct position, such as metal frame, lens cone, and bracket. Therefore, the optical technology integrated with the concepts of precision machinery, electronics and computer technology is important in the field of science research, industrial production and development of daily appliances.

Optical lenses are used in both optical instrument and optics experiment instrument. The abrasive technology plays a critical role in manufacturing the precise optical lenses. Such technology is divided into diamond grinding, grinding and polishing. The process of grinding is adding the milling liquid between the lenses and the mold, creating the friction while circulating the glass and the mold, and then grinding the surface of the lenses. The purpose of the grinding process is to pare off the cutting grain in the process and to increase the degree of surface roughness of the lenses. The process of grinding is associated with the quality of optical lenses. Under a good grinding condition, expanded stripes can be created on the silicon and glass surface by using inexpensive machinery. It can certainly reduce the polishing time in any workable processed surface [1].

A lot of research works have been conducted in the process of optical lenses. However, there has been relatively little research on monitoring the quality after optical lenses are formed. Based on Chen et al. [2], process yield, process expected loss and process capability indices (PCIs) are three basic means that have been widely applied in measuring product potential and performance. Of the three, PCIs are easily understood and can be applied directly to the manufacturing industry. The larger the PCI, the higher the process yield with a lower process expected loss. Therefore, PCI can be viewed as an effective and excellent means of measuring product quality and performance. Besides, many statisticians and quality engineers such as Chen et al. [2], Kane [3], Chan et al. [4], Chou et al. [5], Boyles [6], Pearn et al. [7], Kotz and Johnson [8], Boyles [9], Spiring [10], and Hsu et al. [11] have emphasized PCIs in their researches to propose more effective methods of evaluating process potential and performance. In this paper, we developed a Process Capability Analysis Model (PCAM) to explore the ineffective areas in the process capability analysis model of hexagonal infrared optical lenses.

II. LITERATURE REVIEW

Process capability indices (PCIs) have been used to evaluate process capability and performance in many areas of manufacturing industry. Juran [12] combined the Process mean (μ), the Process variance (σ^2), and the product specification to bring up the idea of *PCIs*. Different products usually have different specifications, so process manager can't evaluate process performance from μ and σ immediately. For this reason, Kane [3] proposed C_{pk} to evaluate process capability and performance. PCIs have been widely discussed as a

Corresponding author: C. H. Hsu is with Department of Business Administration, Asia University, Taichung, Taiwan, R.O.C. E-mail: pci@asia.edu.tw

means of summarizing process performance relative to a set of specification limits [8]. Deleryd and Vannman [13] noted PCIs combine information about closeness to target and process spread, and express the capability of a process by a single number. Huang *et al.* [14] used PCIs to evaluate process capability which a resistor applying in computers, televisions, and other audio and video electronic devices. Based on the analysis of PCIs, the production department can trace and improve a poor process line to enhance the quality level as well as increasing the customers' satisfactions [15].

Many products have multiple characteristics. Customers will accept the products whenever preset specifications are met [2]. Hsu *et al.* [11] noted the manufacturing process for the TFT-LCD panel may be divided into the pre-cell process (array process) and panel assembly process (cell process). The array process includes three CTQ characteristics: (1) photo-resist coating thickness, (2) location of pattern, and (3) etching wire width. So univariate PCIs cannot meets the customers' requirements stated as above. Based on Kane's study [3], Chen *et al.* [16] used C_{pk} to construct a process capability analysis chart (*PCAC*) to evaluate process capability for a multi-process produce.

Based on Pearn and Chen's definition of different quality condition of process [17], an 'inadequate' process means when PCI is less than 1.00; it indicates that the process is not adequate to the preset manufacturing specifications. A 'capable' process occurs when PCI is between the ranges of 1.00 and 1.33, which means some process control is needed. A 'satisfactory' process is when PCI is between 1.33 and 1.50; it indicates that process quality is satisfactory. An 'excellent' process has the PCI between 1.50 and 2.00. And, a 'super' process is when PCI exceeds 2.00. Table I displays the five conditions and the corresponding values of C_{pk} .

TABLE I.							
THE FIVE QUALITY CONDITIONS							

Quality condition	Values of $C_{\rm pk}$
Inadequate	$C_{\rm pk} \le 1.00$
Capable	$1.00 \le C_{\rm pk} < 1.33$
Satisfactory	$1.33 \le C_{\rm pk} < 1.67$
Excellent	$1.67 \le C_{\rm pk} < 2.00$
Super	$C_{\rm pk} \ge 2.00$

III. PROCESS CAPABILITY ANALYSIS MODEL

Because the specifications are different in different products, process manager can't evaluate process performance from Process mean (μ) and the Process variance (σ^2) directly. Juran [12] combined the process parameters with product specifications to bring up the idea of *PCIs*. Also, Kane [3] has proposed the formulas as following:

$$C_{pk} = \frac{d - |\mu - m|}{3\sigma} \tag{1}$$

Where *d* is the tolerance (d = (USL - LSL)/2), *USL* is the upper specification limit, *LSL* is the lower specification limit, μ is the process mean, σ is the process standard

deviation, and m is the target. Measuring *PCIs* is an efficient method to evaluate process capability and performance.

Chen et al. [2] mentioned that a product usually hold many quality characteristics. Chen et al. [16] indicated the yield of a multi-process product is lower than capability individual process of each quality characteristic. In other words, when process yield is set to meet the required level, then process capability of each quality characteristic should be greater than the preset standard for entire product. Based on Huang et al. [14], the minimum PCIs $C_0 = \{\Phi^{-1} [(\sqrt[t]{2\Phi(3c)-1} + 1)/2]\}/3$ of each individual process characteristic was asserted, where c is the integrated PCI, the total number of quality characteristics. The critical values C_0 for individual process capability can be attained by solving the previous inequality when the integrated PCI exceeds c.

Chen *et al.* [16] set $P = \sigma/d$, which means the precise index and $A = (\mu-m)/d$ means the accurate index. The relation between *P* and *A* can be found by using the formula of C_{pk} . That is from

$$C_{pk} = \frac{d - |\mu - m|}{3\sigma} = \frac{1 - |A|}{3P} = C_0$$
(2)

which implies

$$|A| + 3 C_0 P = 1$$
 (3)

Based on the above relationship, $|A| + 3 C_0 P = 1$, the measure model of *PCAC* can be gained (Figure 1). The PCAC can be used to evaluate process capability for a multi-process produce. If one characteristic is located within $\frac{1}{3C_0}$, which is called the qualified zone. If the

characteristic is outside the qualified zone, it can often reduce the characteristic and therefore increases the process capability.



According the above arguments, we have developed a PCAM to find the unqualified areas. First, observing the number of quality characteristics to check whether it is more than one. When it's less than one, C_{pk} can be applied to analyze the process capability. If the number is greater than one, the capability can be analyzed by PCAC (Figure 2).



IV. REAL CASE

Hexagonal infrared optical lens is one of the products of the L Company in Taiwan, besides its major product, the optic lens. This round-shape infrared filter is mainly used for instruments with 6~14um spectrum, which can be found in the Ear Thermometer, Non-contact Infrared Thermometer, Infrared Gas Analyzer, Infrared Moisture Analyzer, and Infrared Radiometer. It is composed of 99.999% to 99.99995% of silicon, and has an average transmission rate of 80%. The size of surface of the lens is critical in the optical lens module assembly (Figure 3), both of them are the nominal-the-best type quality characteristic.

Based on the description in section 3, we followed the PCAM flow to evaluate process capability of the hexagonal infrared optical lenses. The flow is as follows: Step 1: The number of quality characteristic of this

- product is more than one -- total thickness and lens' diameter. PCAM Flow Char is selected.
- Step 2: Satisfactory of quality condition is selected according to Table I. In other words, the process capability index C_{pk} exceeds 1.33 (c = 1.33). Because there are two quality characteristics (t = 2) in this case, $C_0 = \{\Phi^{-1} \ [(\sqrt[2]{2\Phi(3*1.33)-1} + 1)/2]\}/3 = 1.38.$

Step 3: Based on the above relationship which is |A| +4.14*P* = 1, the measure model of *PCAC* can be gained (Figure 4).

Step 4: The process capability value of two quality characteristics is calculated by examining the hexagonal infrared optical lenses (Table II).

Step 5: The lens' diameter is qualified; total thickness is unqualified. The process variation and Process mean of total thickness are too large. It's either to reduce the process variation of total thickness or set the process mean of total thickness back to the closer process target to increase the process capability.



Figure 3. The size of hexagonal infrared optical lenses



TABLE II: THE HEXAGONAL INFRARED OPTICAL LENSES' PROCESS CAPABILITY VALUE

Quality characteristic	Туре	USL	т	LSL	μ	σ	A	Р
Total depth	Nominal- the-best type	0.57	0.52	0.47	0.546	0.0075	0.52	0.15
Lens' diameter	Nominal- the-best type	5.51	5.46	5.41	5.481	0.0055	0.42	0.11

V. CONCLUSION

The optical industry has been particularly influential and widely used in science research, industrial production and daily appliances. The process of optical lenses has been extensively researched; however, little research has been conducted on the quality of optical lenses. Accordingly, PCAM is developed to find the unqualified points. When using PCAM, the number of quality characteristics should be more than one. When the number is less than one, C_{pk} can be used to analyze the process capability. If the quality characteristic is more than one, the capability can be analyzed by PCAC. In this paper, the PCAM flow is used to evaluate process capability of hexagonal infrared optical lenses. As a result, the lens' diameter is found qualified; total thickness is not. The process variation and Process mean of total thickness are too large. The process variation of total thickness should be reduced or the process mean of total thickness should be set back to the closer process target to increase the process capability.

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Chang-Hsien Hsu is a assistant professor in Department of Business Administration, Asia University, Taichung, Taiwan, R.O.C.. He received the Ph.D. degree in Graduate

Institute of Management Science from Tamkang University, New Taipei City, Taiwan, R.O.C., 2007. He has published international academic journal papers: 14{SCI(2), SSCI(2) and EI(10)} in 2006-2011, and his research interests include process capability index, quality management and control and quality engineering.