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Peculiarities of the optical elements manufacturing in Chinese optical industry

Wang Yan*[a], Irina L. Livshits[a], Igor S. Potemin[a], Dmitry D. Zhdanov[a], Alexey Voloboy[b]
[a]ITMO University, 49, Kronverksky pr., Saint Petersburg, Russia, 197101;
[b]Keldysh Institute of Applied Mathematics, Miusskaya sq., 4, Moscow, 125047, Russia

ABSTRACT

In the long-term production and processing practice, China's optical manufacturing industry has formed a coexistence model with traditional optical classical polishing and high-speed polishing. China's optical experts are familiar with many optical standards such as the US military standard, German standard, ISO10110, and China national standard, promote optical elements production which can meet the needs of high precision instruments. High efficiency production methods are used to lay a foundation for meeting the market demands of China and other countries. The application of virtual prototyping methods, the emergence of a large number of professional optical specialists, and the popularization of advanced processing and testing equipment have all contributed to the development of China's optical industry.

The number, shape and type of the optical components and test requirements are critical to the mass production of the optical components. An optical manufacturer's sustainable operations not only depend on professional lens design, but also rely on advanced processing and testing equipment, effective cost control management and China's mature industrial chain.

In this paper, we analyze the current state and characteristics of China's optical industry from the aspects of component design, processing methods, optical standards, processing and inspection equipment, and cost control. The cost information is valid for China. We propose a way to optimize a mass production cost which is based on the complexity of the optical system. As result it makes it possible to produce complex optical systems in China.

To demonstrate the efficiency of the proposed method of analysis, we present examples of the lenses produced.

Keywords: optical components, mass production, virtual prototyping, Chinese optical cold processing, peculiarities of China's optical industry, optical design

1. INTRODUCTION

We discuss the peculiarities of the optical elements manufacturing in Chinese optical industry. Optical components are simple optical elements that are used in the construction of optical systems. Generally, it mainly includes optical lenses, mirrors, optical filters, prisms, optical windows, and so on. Optical components are a very important part of the optical lens. The quality of each optical component directly affects the imaging performance of the entire instrument. Optical lens is an indispensable part of machine vision system, which directly affects the image quality of the system. It is affecting the implementation and effect of image algorithms. The ability of an optical lens to restore real things in the real world directly affects the judgment of the user.

The main method of optical component processing is optical cold processing, which provides optical components such as lenses and lens for downstream industries such as optical instruments and optoelectronic image information processing products. It is in the middle of producing semi-finished products in the whole industrial chain structure. The main processes of optical cold working are pressing, cutting, milling, fine grinding, polishing, edging, gluing, coating and so on. China's optical industry optical components manufacturing mainly presents the following characteristics:

1. Optical elements manufacturing in Chinese optical industry is a capital-intensive industry;

The fixed assets investment in the optical cold-adding industry is mainly used for the purchase of production and processing equipment. Increasing equipment is one of the prerequisites for the increase of production capacity. The fixed assets of equipment and other fixed assets usually account for 70%-80% of the total investment.

*sales@awoptics.com; phone 7 931 386-16-24; 86-13104307581

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2. Optical elements manufacturing in Chinese optical industry is a technology-intensive industry;

The optical cold processing industry has a high technical content. The process technology and production management level directly affect the product quality and the high qualified product rate, which determines the cost advantage of the company in the market competition and restricts the scale of production capacity.

3. Optical elements manufacturing in Chinese optical industry is also labor-intensive. The degree of automation in the optical cold-processing industry is not high. Many aspects require manual operation. The requirements of each process are fine. It requires a large number of operators who are familiar with the process skills. Operators need long-term expertise and experience.

4. Optical components produced by Taiwanese and Chinese companies in the past decade have not only met the needs of China, but also exported to optical technology developed countries. The Chinese optical industry has formed a coexistence model with high precision and large scale processing.

5. With the growing demand for optical components in emerging optical downstream industries such as smartphones, security surveillance, automotive lenses, virtual reality, sports DV, drones and home projectors, China's optical component manufacturers have adjusted planning to meet the demand for traditional optical market share such as digital cameras and camcorders while ensuring the demand in emerging markets.

6. In the Chinese market, the rapid development of the optical downstream market, led by smart phones and security surveillance, has raised the production capacity, product quality and delivery time of components such as optical glass and optical lens in the middle and upper reaches. As a result, this makes the industry resources more concentrated in leading enterprises.

7. With the rapid development of China's optical component manufacturing level, the design and manufacturing of China's optical imaging products level are increasing. The quality and performance of optical components in China are also constantly improving.

8. The scale of China's optical component manufacturing market has grown significantly. In 2017, the scale of China's optical components market increased significantly to 53.2 billion yuan.

9. China is the main producer of optical glass, accounting for more than 60% of the world's scale. For example, Chengdu Guangming and Hubei Xinhuaguang. China's optical components are processed by high and middle environmentally friendly glass with high transmittance, high uniformity and special properties, as well as high-end optical materials such as infrared materials, laser glass, optical fiber materials and optical plastics.

10. China is already the world's largest manufacturer and application of optical components such as optical lenses, mirrors, filters and prisms.

11. In recent years, China's optical component manufacturing technology upgrades have been significantly accelerated. The grinding of optical lenses is gradually automated from hand. Nowadays, wafer-level optical components for mass-copying and processing optical components using semiconductor processes have emerged, and it is expected that future optical component manufacturing will rely more on high-performance manufacturing equipment.

12. At present, China mainly produces medium and low-end lenses such as fixed focus and low pixel. The manufacturing technology of low-end lens is relatively low. There are many market participants and the competition is fierce. In the high-end areas such as large magnification zoom, ultra high definition, optical image stabilization, and integrated camera lens, only a few of the representatives represented. For example AW OPTICS LIMITED have begun to developing such kinds of lens. In the follow text we short named this company as "AWO". AWO is a high-tech enterprise integrating research, development, production and service of optical lenses and optical instruments.

13. The rapid development of the optoelectronic industry has resulted in the lack of high-quality professional optical lens design and production operations talents in China. At the same time, China's labor costs have gradually increased.

There are many different types of lenses from different manufacturers. The difference between them is mainly the construction of the camera lens. We take AWO Company as an example to illustrate how lens are designed, processed and finished in China.

Since developed countries have basically withdrawn from the optical cold processing industry and concentrated in the fields of modern optoelectronic technology and optical design, the pattern of global optical cold processing industry shifting to China has basically taken shape. Most of which are concentrated in the Pearl River Delta and the Yangtze River Delta[1]. China's South China region has become the world's largest digital camera production base, and is also the region with the largest optical cold processing capacity and the highest industry concentration in the world. In recent years, Taiwan's major optical manufacturers have been affected by factors such as rising labor costs and have set up factories in the mainland. The main technical development trends of the optical cold processing industry include plastic lenses, aspherical technology, and low-melting optical glass lens molding technology.

2. OPTICAL DESIGN AND DRAWING STANDARDS FOR OPTIICIAL ELEMENTS IN CHINESE LENS PRODUCTION

2.1 Optical design

Any kind of optical instrument will inevitably impose certain requirements on its optical system, so we must understand the requirements of the optical system before we start to do optical design. These requirements are summarized in the following aspects:

1. The basic characteristics of the optical system;
2. The external dimensions of the system;
3. Image quality;
4. Conditions of use of the instrument.

The design of the optical system is to determine various data that meet the requirements of use according to the conditions of use, that is to determine the performance parameters of the optical system, the external dimensions, and the structure of each light group. Analysis shows that the most important is a number of optical elements in the objective and not a complexity of each lens. The complexity of each lens is important only for physical prototyping. It is important to understand that when we design lenses we have to keep in calculation alternative solution. So, we have a guarantee that at least one of the solutions will work.

When we discuss the complexity of optical system we have to understand the difference between its complexity “in design” and “in production”.

Complexity “in design”- R (when we talk about camera lenses) includes such factors as technical requirements to the final optical system, qualification of optical designer and how much time the design process has taken. These aspects were discussed in the article[3], where index of design complexity is estimated by equation (1):

$$R=J+F+W+Q+L+S+D \quad (1)$$

where:

- J – light power;
- F – magnification;
- W – object size;
- Q – image quality;
- L – spectrum range;
- S – back focal lens
- D – aperture stop position.

Complexity “in design” varies from 0 to 14, where R=0 goes for a simplest system to design, for example, a singlet. R=14 means that we have to design fast objective with long focal distance, wide angle, diffraction limited image quality, which has to work in wide spectrum range, has long back focal distance and aperture stop removed forward – this is the description of the most complex system due to the classification [3]. These data and index of complexity for mobile camera lens “in design” is presented in table 1.

Table 1 Complexity of optical systems "in design"

Technical specification	Simplest system	Most complex system	Mobile phone camera lens
J	0	2	1
F	0	2	0
W	0	2	2
Q	0	2	2
L	0	2	2
S	0	2	1
D	0	2	1
R	0	14	9

In Figure 1 and table 2 we present an example of mobile phone camera lens which we designed[4].

Table 2 An example of mobile phone camera lens.

Technical General		
J	F2	1
W	2w=65	2
F	4mm	0
L	visual	1
Q	Diffract	2
S	1	2
D	inside	0
R		9

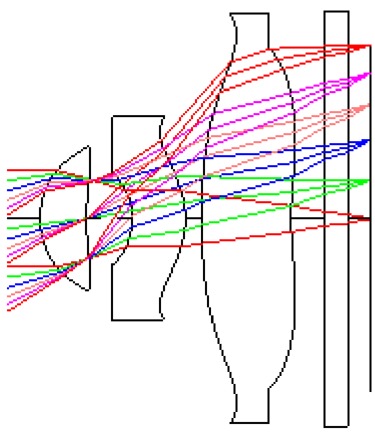

Figure 1 An example of mobile phone camera lens.

Complexity "in production" indirectly depends on R, and we propose to calculate it using equation (2):

$$P=N+E+M+C \quad (2)$$

where:

- N – number of produced elements;
- E – individual element complexity (shape, ratio of thickness and diameter, etc);

- M – manufacturing technology;
- C – complexity of element and system control.

The link between the classifications for N, E, M, C is presented in table 3.

Table 3 Links between general and technical specifications.

Characteristics (specifications)	**General**	**Technical**	**Description**
N	0	N>10	small number
	1	10<N<1000	Average number
	2	N>1000	Mass production
E	0	simple	
	1	average	
	2	complex	
M	0	ordinary	
	1	Diamond turning, molding	
	2	Specially designed	
C	0	Traditional (ordinary)	
	1	More complex	
	2	Specially designed control equipment	

In Table 4 we propose a classification which helps to calculate complexity “in production”.

Table 4 Complexity of optical systems “in production”

Requirement for production	Simplest optical system	Complex optical system	Mobile phone camera lens
N	0	2	2
E	0	2	1
M	0	2	1
C	0	2	1
P	0	8	5

In Figure 2 we present a sequence of mass production of a mobile phone lens[2].

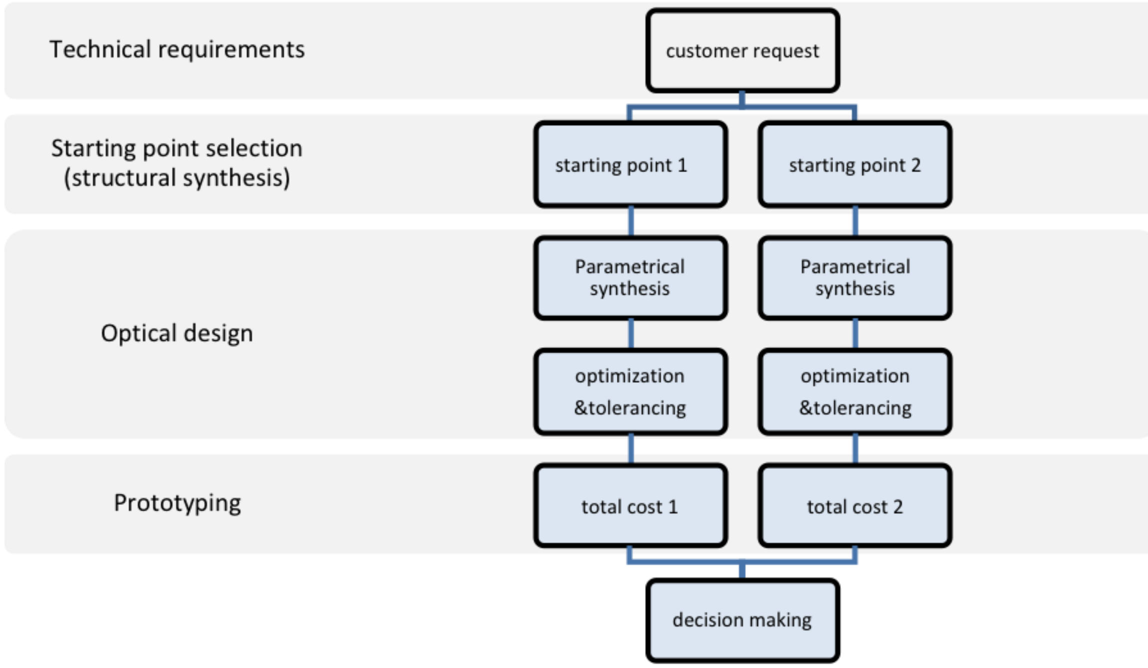

Figure 2. Procedure of lens selection.

2.2 Drawing Standard for optical elements and systems.

In table 5 we present several drawings standard which can be used in lens design.

Table 5. Drawing Standard for optical elements and systems

China Optical Drawing Standard	GB13323-91 Standard
International Optical Component Drawing Standard	ISO10110 Optics and Optical Instruments-Preparation of drawings for optical elements and systems.
British National Standard	BS4301
Russian national standard	GOST2.412
American National Standard	ASME/ANSIY14.18M-1986
US military standards and specifications	MIL-STD-34
German national standard	DIN3140

2.3 Optical design service

In table 6 we list lens design service which can be finish by Chinese engineer

Table 6. Lens design possibility

LENS DESIGN	
Application	Measurement, projection, photography, laser, surveillance, military.
Spectrum	Narrowband, visible achromatic, full visible apochromatic, near-infrared UV apochromatic.
Focal length range	Various ranges fixed focus lens and zoom lens

3. OPTICAL ELEMENTS MANUFACTURING AND TESTING

3.1 Common polishing methods

In table 7 we comparison the two common polishing methods for optical component processing.

Table 7.Widely used polishing methods

traditional optical classical polishing	advantage	Small surface roughness and small surface defects after processing; The precision of the polishing machine is low, the replacement rate of the polishing mold is high, and the input cost of the equipment and the fixture is small.
	disadvantage	Operators are required to have high operational skills and must be trained in the long run to master; Low production efficiency.
	application	Suitable for the production of small quantity prototype and small batches of higher precision grade optical component.
high-speed polishing	advantage	The surface quality of spherical lenses is relatively stable after used this processing method. The technical requirements for the operators are low, and new workers can be employed through simple training.
	disadvantage	The quasi-spherical polishing method requires high precision for the equipment. The polishing mold must be dedicated, and there are few substitutes. The equipment and fixtures have a large investment.
	application	Optical components produced in large quantities below medium precision.

3.2 Main technics which can be used for lens manufacturing

Two main technics are used for lens manufacturing:

1. Aspheric plastic injection molding;
2. Wafer level (mostly for low cost cameras).

3.3 Optical material

In table 8 There is listed a lot of present widely used optical glass, optical crystals,and plastics.

Table 8. Optical glass,optical crystals and optical plastics

optical glass	All the optical glass from CDGM and similar glass from HOYA,SCHOTT
optical crystals	IR quartz,CaF2,MgF2,Ge,ZnSe,Si,ZnS etc
optical plastics	PMMA,TPX,ADC,OZ1000,PS,SAN,MS,PC,PET,COC,COP,PSU,

3.4 Optical elements manufacturing and testing equipment

In the table 9 there is a listed of present widely used manufacturing and testing equipment resource

Table 9. Optical elements manufacturing and testing equipment and processing technology mainly from above country.

No	Manufacturing and testing equipment resource
1	China
2	Russia
3	Germany
4	Japan
5	Korea
6	UK
7	USA

In Figure 3 and figure 4 Two example of present used produce and test equipment.

Figure 3 and figure 4 Produce and test equipment

4. COST CONTROL METHOD IN OPTICAL ELEMENTS MANUFACTURING IN CHINA

4.1 Virtual prototyping to optimize the cost of a lens in lens mass-production

The cost of lens mass production could be calculated[2] due to formula (3):

$$C = (C_1 + C_2 + C_3 + C_4) \bullet n \tag{3}$$

Where

- C – cost of one lens in mass production;
- C_1 – material cost
- C_2 - labor cost

- C_3 –prototyping cost;
- C_4 – factory overhead
- n – quantity of produced lenses.

We see that really we can save only on C3 –if we replace physical prototyping by virtual prototyping which is made on the computer on the special optical design software available to save prototyping time and money.

Virtual prototyping cost could be $C_3 = 0$, if you agree to put this job on optical designer. Then total price could be reduced.

CONCLUSION

1. The peculiarities of the optical elements manufacturing in Chinese optical industry have been introduced.
2. We studied lens design method.
3. Widely used polishing methods for optical component processing was listed.
4. Popular optical standards which can be understand by Chinese engineer was analyzed.
5. Widely used optical component processing and inspection equipment resource was listed.
6. Cost control method in Chinese optical industry was given.
7. We recommend to replace physical prototyping by virtual prototyping to optimize the cost of a lens.

REFERENCES

[1] Article"The Present Situation of Chinese Optoelectronic Industry and COEMA'S Development" ,Laser & Infrared, 820 (2006) https://max.book118.com/html/2018/0311/156882051.shtm (2018)

[2] Article "Virtual prototyping as an approach to optimizing starting point selection in a mass production of camera lenses" , Proc. of SPIE Vol. 10695, p.106950K ,2 (2018).

[3] Livshits I.L. Vasilyev V.N. (2013) "Q &A Tutorial on Optical Design", Adv.Opt.Techn. N2 (1): pp.31-39

[4] Anitropova I.L. Formalizing the heuristic synthesis procedure in lens design. In OSA Proc. Of the IODC, Rochester, USA, June 1994.