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2011/01/24

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# **Design, Realization, and Characterization of a Solid Corner Cube with High Optical Retroreflectivity and a Sphere Retroreflection**

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## **ABSTRACT**

Retroreflectors are very important instruments in modern optical systems.

The article compares between pyramidal corner cube and spherical optical retroreflectors in different given designs.

Designs and manufacturing of a full high Retroreflectivity optical tetrahedron corner cube that can be used for far field is presented along with an optical spherical retroreflector with different refractive indices of coated or uncoated backsides. The characteristics of both types are discussed.

Variations of Retroreflection index by changing the flatness of the optical tetrahedron's surfaces are presented.

The focal length of the optical tetrahedral corner cube and its relationship with the Retroreflection index is calculated during its manufacturing.

The change of the Retroreflection index as function of the changes of the optical glass refractive index of the spherical optical refractor is studied.

**Key words:** Retroreflection index, Solid Corner Cube, Sphere Retroreflection, Focal length of Corner Cube.

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-1

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-1

-2

-3

-4

-5

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-2

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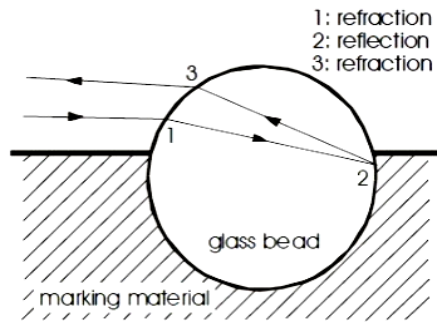
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[19].(1)



(1)

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[9,19]

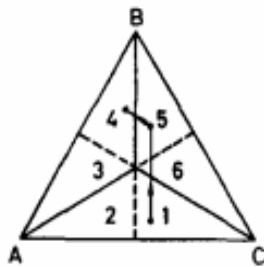
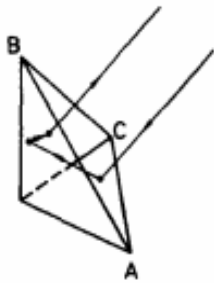
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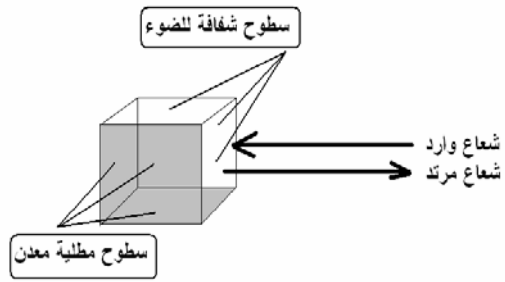
-1-2

( )

(2),(3)



(2)



(3)

.[10,11]

: -2-2

:[11],(1)

(1)

$$\theta = \arcsin\left(\frac{1}{n_0}\right)$$

:θ

.BK7  $n_0$  41.238<sup>0</sup>(7<sup>0</sup>- 8<sup>0</sup>)

( ) (13<sup>0</sup>-14<sup>0</sup>)

-3

( )

( )

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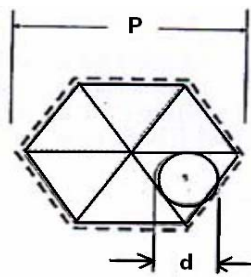
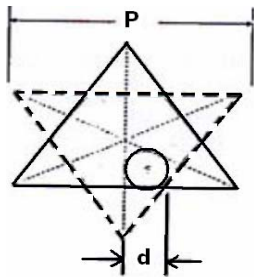
( )

-1-3

5/6

(4)

[15, 7]



(4)

(5)

:

(3-5-6),(2-4-5),(1-3-4)

(5)

(1-5-4),(2-6-5),(3-1-6)

[12,8]

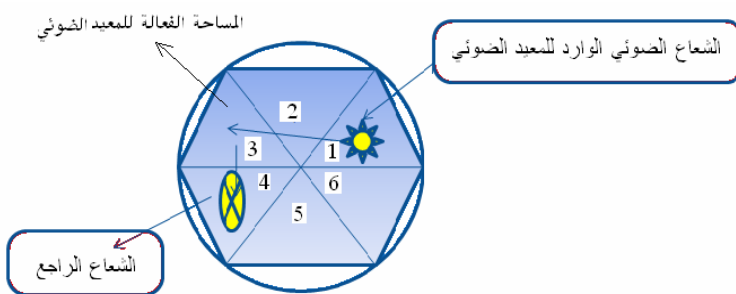
1

4

3

1

4



(5)

$$\alpha = \cos^{-1}\left(\frac{1}{\sqrt{3}}\right) = 54.7356^\circ \quad (8) \quad (\alpha=54,7356^\circ)$$

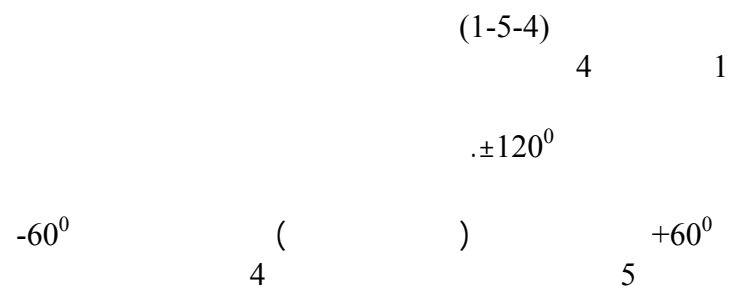
S                      P                      δ

$$\tan \frac{\delta}{2} = \frac{\cos \alpha \sqrt{\sin^2 \alpha - \frac{1}{n^2}}}{\sin^2 \alpha} \quad (3)$$

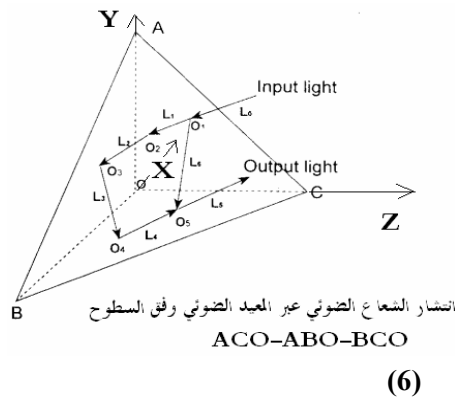
: n                      : n

$$\delta = 44.6^\circ \quad n = 1.517$$

(Jones)

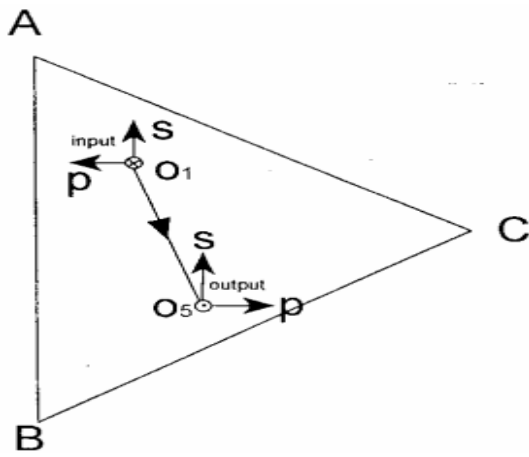






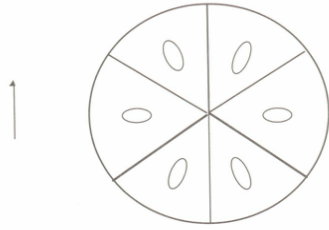
$\delta(p)=124.75^\circ$ ,  $n=1.517$   
 (7)  $\delta(S)=79.55^\circ$   
 (180°)  $[6,7,16,17]$  S,P P  
 $[4,6,16,17]$

[18] (8)



S,P .ABC (7)

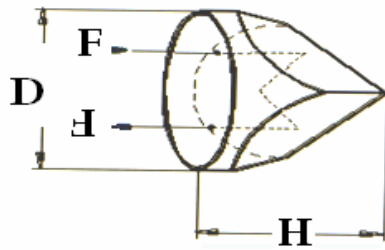
المعد الضوئي الهرمي يدور الاستقطاب ليصح اهليلجياً



الأشعة الخارجة من المعد الضوئي يصح استقطابها اهليلجياً عندما تكون الأشعة الداخلة للبعد الضوئي مستقطبة خطياً

(8)

∴  
(9)



(9)

$\Delta N$  N

-2-3

.N

(flatness)

(Irregularity)

$\Delta N$

[20]

(250-255nm)

N

$\lambda = 500 - 560nm$

) :N h = (D\* $\alpha$ )/8 :N=4h [nm] :

30>

:α ( :h

-3-3

$$1'' - 3'' \quad \theta \quad (10)$$

[4,14,18]

الانحراف عن 90° يساوي الصفر  
 الانحراف عن 90° بزوايا واحدة  
 < 90° أو > 90°  
 انحراف في الهرمية بزواويتين  
 زاوية > 90° وزاوية < 90°  
 ثلاثة زوايا < 90°  
 زاوية اصغر من 90°  
 وزاويتين أكبر من 90°

90°

90°

90°

(10)

γ

[10,11] :

$$\gamma = \frac{4\sqrt{6}}{3} n \cdot \theta \quad (4)$$

BK7

n=1.517

:n

$$\gamma = 5 \cdot \theta \quad (5)$$

(4.85x10<sup>-6</sup> Rad) 1''(arc aec)

(2.4x10<sup>-5</sup> Rad)

(2.4m)

(100Km)

)

(

.d

90°

d

[18,15]

( )

-4-3

:

-

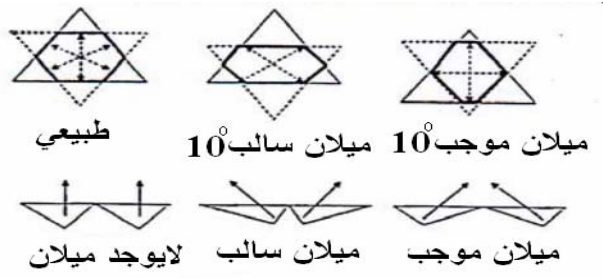
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(11)

[2,14] (

)

(Gonio-meter)



طبيعي

ميلان موجب 10° ميلان سالب 10°



لا يوجد ميلان ميلان موجب ميلان سالب

( )

(11)

-5-3

:

[10,11]

$$d \quad S \quad (4)$$

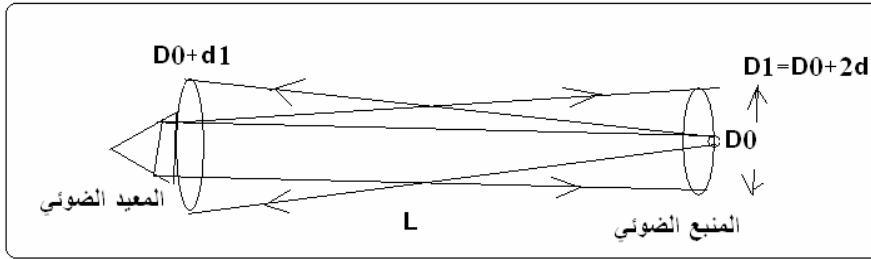
$$D_0$$

$$:$$

$$D_1$$

$$D_1 = D_0 + 2d \quad (6)$$

:(11')



.L (11')

L

$$D_1$$

$$d=1\text{cm}$$

$$1,2 \frac{\lambda}{d} = 6,6 \cdot 10^{-5} \text{Rad}$$

.7m

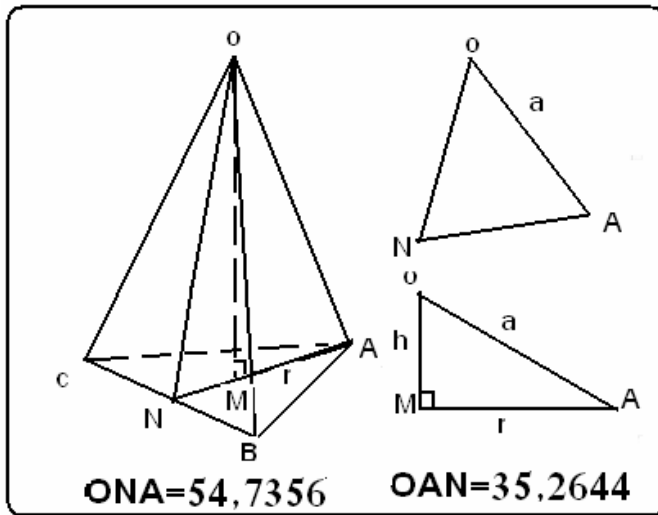
100Km

: -4

.(3)

-1-4

(12)



(12)

$B=20\text{mm}, r=31.8\text{mm}, h=15\text{mm}; H=45\text{mm}, a=55.11\text{mm},$

$r, ONA$

$h$

$\triangle ABC$

$S$

$H$

$a$

$\triangle ONA=54,7356^\circ$

$\triangle OAM=35,2644^\circ$

$S=\pi r^2, S=3178.125\text{mm}^2$

(Russian Standards) [20]

(13-1)

$\Delta n_d$	4B	المواصفات البصرية	
$\Delta (n_f - n_c)$	4B		
Homogeneity	2	التجانس	
Strass Birefringence	2	نظافة السطح	
light Absorption	0	الامتصاص الضوئي	
Striae	2K	العروق	
Bubbles	2A	البقع	
N1	0.3	عدد الحلقات	
N2	0.3		
$\Delta N1$	0.1	معامل التسطح	
$\Delta N2$	0.1		
P1	II	المروية	
P2	1"-2"		
C	1"	السطح المرجعي	MAT BK7

(13-1)

(13-2)

BK7,SF57

(Russian [20]

.Standards)

$\Delta n_d$	4B	المواصفات البصرية		
$\Delta (n_f - n_c)$	4B			
Homogeneity	2	التجانس		
Strass Birefringence	2	نظافة السطح		
light Absorption	0	الامتصاص الضوئي		
Striae	2K	العروق		
Bubbles	2A	الفقاعات		
N1	0.3	عدد الحلقات		
N2	0.3			
$\Delta N1$	0.1	معامل السطح		
$\Delta N2$	0.1			
P1	II	الهرمية		
P2	1"-2"			
C	1"	السطح المرجعي	MAT BK7	SF57

(13-2)


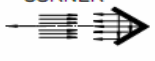






(RCS).

-2-4

[1,2]

(14)



 <p>كرة</p> $\sigma_{\max} = \pi r^2$	<p>CORNER</p>  <p>زاوية</p> $\sigma_{\max} = \frac{8\pi w^2 h^2}{\lambda^2}$
 <p>اسطوانة</p> $\sigma_{\max} = \frac{2\pi r h^2}{\lambda}$	 <p>ثلاثية</p> $\sigma_{\max} = \frac{4\pi a^4}{3\lambda^2}$
 <p>سطح مستو</p> $\sigma_{\max} = \frac{4\pi w^2 h^2}{\lambda^2}$	 <p>معدّات ضوئية</p> $\sigma_{\max} = \frac{12\pi a^4}{\lambda^2}$
 <p>سطح مستو مائل</p>	 <p>معدّات ضوئية</p> $\sigma_{\max} = \frac{15.6\pi a^4}{3\lambda^2}$
<p>الاشعة المرتدة عن العواكس الضوئية لأشكال مختلفة</p>	

[3], [2]

(14)

$$\theta = 0$$

:

$$a = 55.11 \text{ mm}$$

$$\lambda = 0.5 \mu$$

$$\sigma_{\max} = \frac{15.6 \rho \cdot \cos^2(\theta) \cdot \pi \cdot a^4}{3 \lambda^2} \quad (7)$$

( )

:

(7)

$$\sigma_{\max} = \frac{15.6(1)(1)\pi (55.11 \cdot 10^{-3})^4}{3(0.5 \cdot 10^{-6})^2} = 603 \cdot 10^6 \text{ m}^2 \quad (7)$$

:  $\lambda = 0.6328 \mu$  -

$$\sigma_{\max} = \frac{15.6(1)(1)\pi (55.11 \cdot 10^{-3})^4}{3(0.6328 \cdot 10^{-6})^2} = 602 \cdot 10^6$$

$$r = 31.8 \text{ mm}$$

S

$$S = \pi r^2 = \pi (31.8)^2 = 3178,125 \text{ mm}^2 \quad (8)$$

$$S = 3178,125 \text{ mm}^2$$

$$\sigma_{\max} = 603 \cdot 10^6 \text{ m}^2 \quad (9)$$

[15] (10)

$$(10) \quad \begin{array}{l} \rho=0,999 \\ \lambda=0,5\mu\text{m} \end{array} \quad D=63,6 \text{ mm} \\ \text{:R}$$

$$R = \frac{\rho \cdot D^4}{5,95 \cdot \lambda^3} \quad (10)$$

$$R=11 \cdot 10^6 \text{ M}^2/\text{Str}$$

$$\begin{array}{l} D \\ R=5800[\text{M}^2/\text{Str}] \quad d=9,7\text{mm} \\ R=5749 \end{array}$$

$$\begin{array}{l} ) \quad 2''(\text{arc sec}) \quad 100\% \\ \text{:} \quad \text{.}(\quad -5 \end{array}$$

:

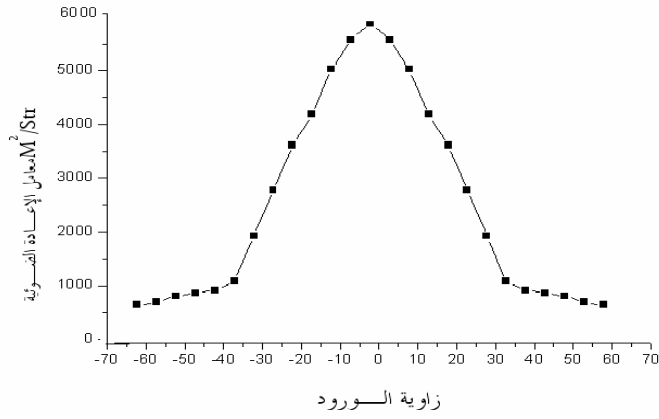
$$\begin{array}{l} \text{:} \quad -1-5 \\ ( \quad - \quad ) \end{array}$$

$$\lambda=632.8\text{nm}$$

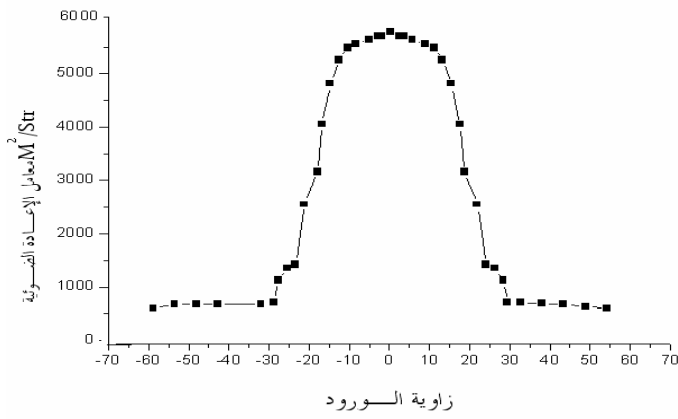
.BK7  $n = 1.517$

)  $20^\circ$   $55^\circ$   $33^\circ$   
 (15) ([10,11]

(16)



(15)

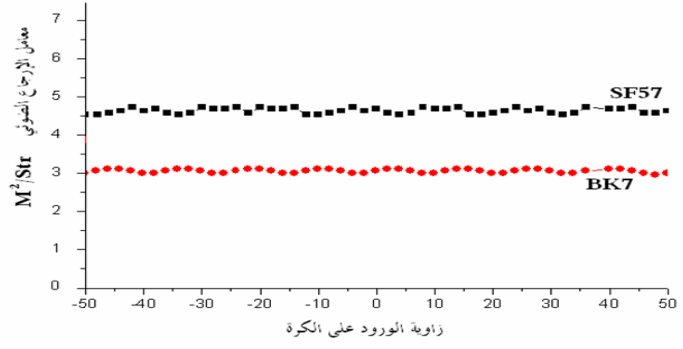


(16)

...

: -2-5  
 n=1.57      BK7       $\lambda=632.8\text{nm}$       ( - )  
                  25mm  
                  .[2,3]       $\sigma_{\text{max}} = \pi r^2 = 1962.5 \text{ mm}^2$

.(17)      n=1,8472.      SF57



(17)

.BK7      SF57

.([10,11,21,22] )  
 ) .Schott[13]      BK7 & SF57  
                  530nm

(Observation Angle)  $0 < \delta < 3^0$       20%  
 30-65m      [21]  
                  65-75cm  
 (Fractional Retroreflectance)

20.5cm  
 SF57      2.56cm       $46.8^0$       BK7  
 15%       $5.9^0$

$3^\circ$

$\delta$

1.5m

250-300m

.[21,22,9] .

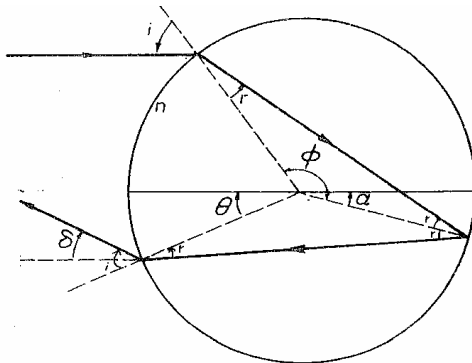
(Observation Angle)

$$\delta = i - \theta$$

$\delta$

$\alpha \theta i r$

.[21-22] (18-1)



$\delta$

(18-1)

$$\theta = \pi - i + \alpha$$

$$\theta = \pi - \delta - \alpha$$

$$\delta = 2i - 4r$$

$$0 < \delta < 3^\circ$$

.[21-22]

2

SF57

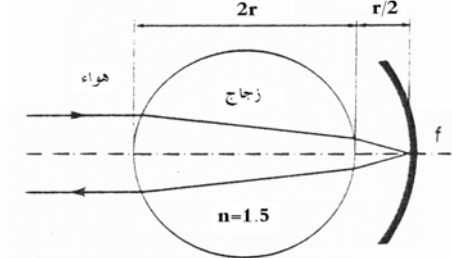
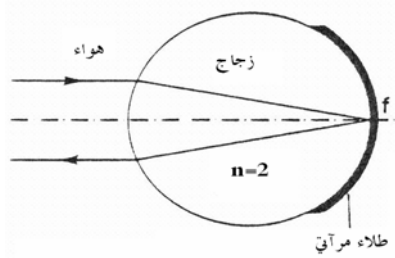
[20] (11)

$$f = \frac{n \cdot r}{2(n-1)}$$

(11)

:f  
 :n  
 :r  
 SF57  $f=1.5 r$  BK7  $f=r$   $f \approx r$

[9].(18-2)



n=2,

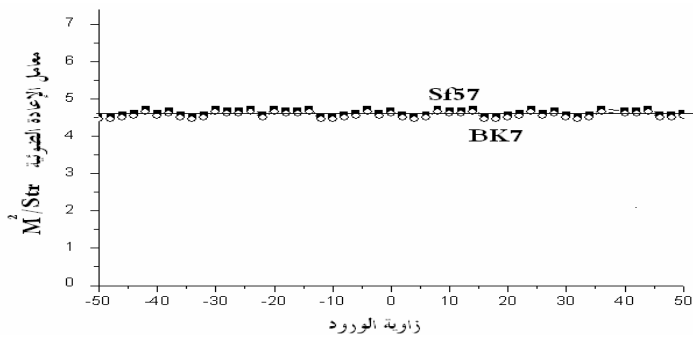
(18-2)

.n=1.5

:

	n =1.517	BK7	-1
(40nm) (Y <sub>2</sub> O <sub>3</sub> ) yttrium oxide	(120nm)		
	n=1.8472	SF57	-2

(19)



(19)

.BK7

SF57

n

n

S

(18-19)

SF57

$\Delta N$  N

-3-5

( )

:N

( ) : $\Delta N$  .

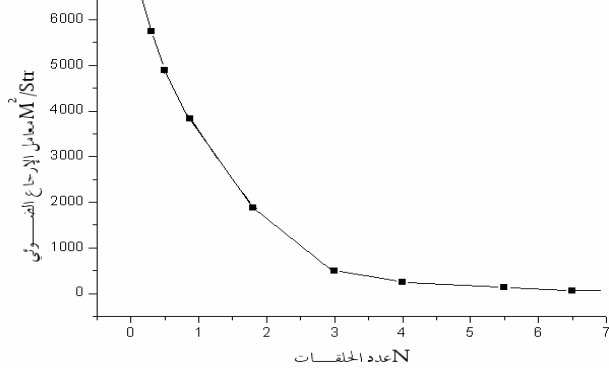
$\Delta N$  N

( )

(finishing)

$\Delta N = 0.2$  N = 0.196

(20)



.N

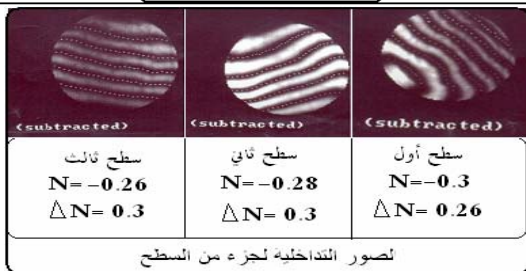
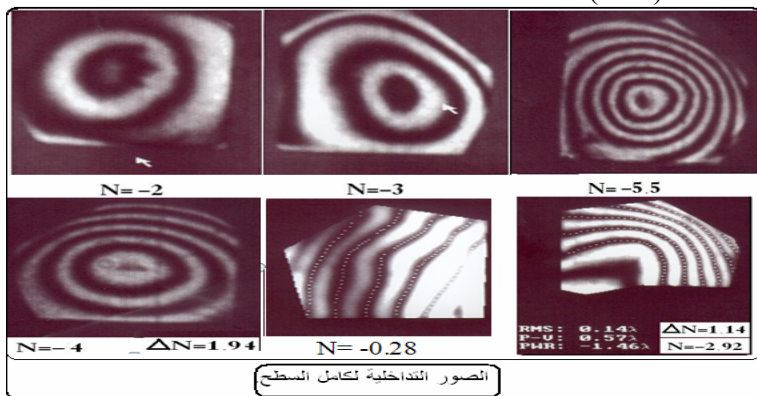
(20)

:

(3)

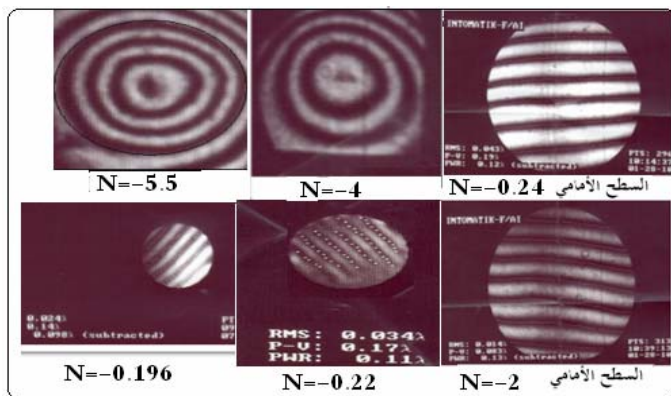
(21-a),(21-b),(21-c),(21-d)

(21-a)



(21-a)

(21-b)



(21-b)



(21-c)

-  
:



(21-c)

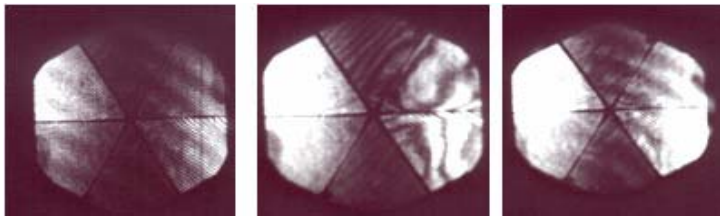
(21-d)

-

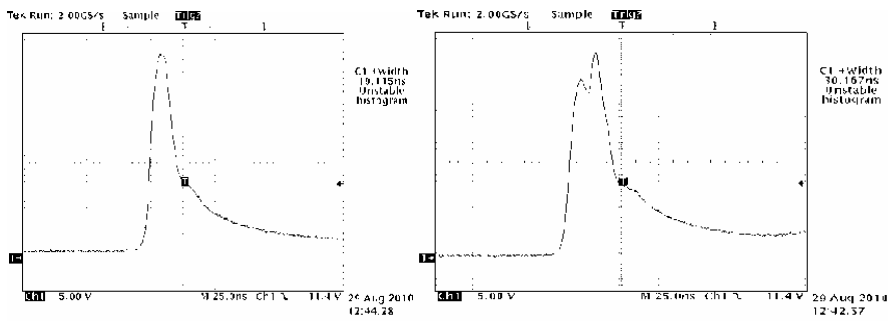
(21-e)

(3-3

)



(21-d)



(21-e)

r

( $\varphi=1/f$ )  $\varphi$  f

[10,11]

$$\phi = \frac{1}{r_i} + 5\left(\frac{1}{r_a} + \frac{1}{r_b} + \frac{1}{r_c}\right) \quad (12)$$

$r_i$

$r_a, r_b, r_c$

)

f

(

[10,11]

$$D_1 = D_0 + d \left| \frac{L}{f} - 2 \right| \quad (13)$$

:

$$D_1 = D_0 + \frac{d \cdot L}{f} \quad (14)$$

$L=2,5\text{Km}, d=0,25\text{m}, D_0=0.5\text{cm}$

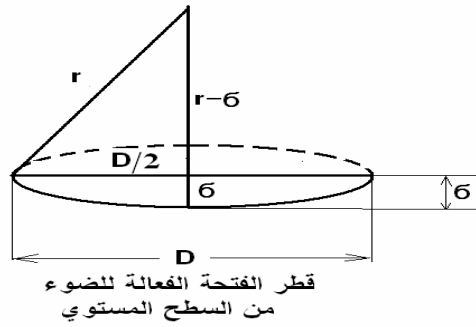
$D_1=1.255\text{m} \quad f=500\text{m}$

L

$D_2$

$$D_2 = L \left( \frac{d}{f} + 1,2 \frac{\lambda}{d} \right) \quad (15)$$

(22)



$$N \quad r \quad (22)$$

$$\delta = N \cdot \lambda / 2 = 6.5 \cdot \lambda / 2 = : \delta$$

$$N = 6.5$$

$$\lambda = 0,5 \mu\text{m}$$

$$1,625 \cdot 10^{-6} \text{m}$$

:r

:D

: r

$$r^2 = \left(\frac{D}{2}\right)^2 + (r - \delta)^2 \quad (16)$$

$$r = \frac{D^2}{8\delta} + \frac{\delta}{2} \quad (17)$$

$$r = r_i$$

$$D = 60 \text{mm} = 60 \cdot 10^{-3} \text{m}$$

$$r_i = 360 \text{m}$$

$$(17')$$

$$r_a, r_b, r_c$$

$$\delta_1 = \delta_2 = \delta_3 = N \cdot \frac{\lambda}{2}$$

$$D_a = D_b = D_c = 50 \text{mm}$$

$$(12)$$

$$r_a = r_b = r_c = 250 \text{m} :$$

$$\phi = \frac{1}{f} \Rightarrow f = -81.81 \text{m} :$$

$$[\text{m}^{-1}] \quad : \Phi$$

$$N = 6.5$$

$$f = -1269 \text{m}$$

$$N = 0.196$$

$$.81.81 \text{m}$$

(1)

N	$r_i$ [m]	$r_a = r_b = r_c$ [m]	$\Delta N$	D [mm]	$\delta$ [ $\mu$ ]	R [m <sup>2</sup> /str]	$\Phi$ [m <sup>-1</sup> ]	f [m]
6.5	360	250	2.2	50	1.25	54.3	-0.1222	-81.81
5.5	450	312	2.0	50	1	130.9	-0.0078	-113
4	600	500	1.8	50	0.75	249.4	0.00834	-119.7
3	900	625	1.5	50	0.5	499.4	-0.0069	-144
2	1800	1250	1.14	50	0.25	1999.4	-0.0035	-285
1	2500	2000	1.0	50	0.5	999.5	-0.0021	-476
0.5	3600	2500	0.5	50	0.125	4899.4	-0.00172	-580.6
0.3	6000	4500	0.2	50	0.075	5749.4	-0.00095	-1052
0.196	7250	5400	0.2	50	0.05	5812	-0.00078	-1269

N

$\Phi$

r

.( )

N

f [M]

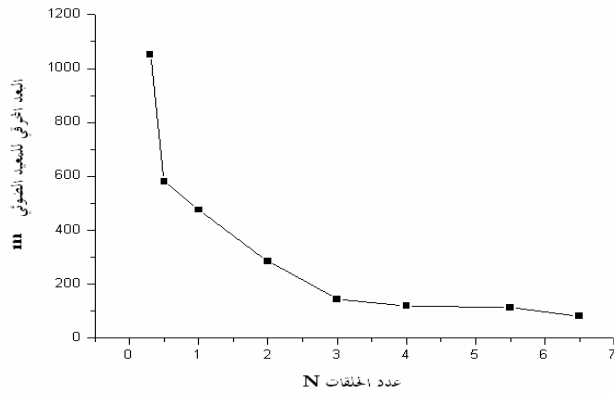
.N

(23)

R [M<sup>2</sup>/Str]

.(24)

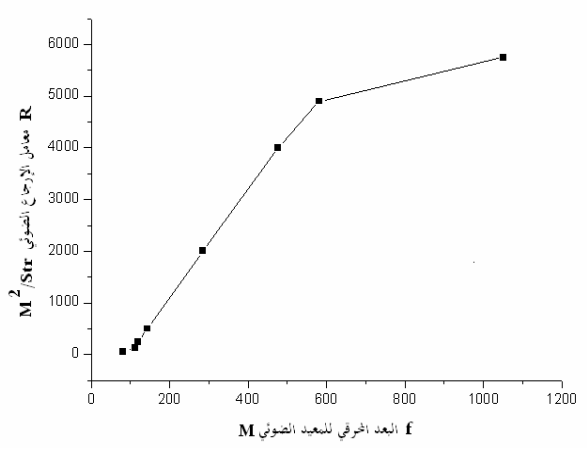
f[M]



.N

f

(23)



(24) f R

: -6

:

$\Delta N$  N

N

-

-

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$\Delta N$

N

(Surface Finishing)

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