3
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东方电气评论

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双　C 谐振单元的动态可重构型均衡技术研究 …… 刘姝仪　王晶　吴文彭等(1)
超纯碲锌镉高压合成过程探究及工艺优 …… 钟连兵　张程　李在为等(1)
的 ……
…… 王焕　李娜　郑　等(15)
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…… 文　王　等(84)

[　]CN51-1333/TM*1987*q*A4*88*z　*¥8　*75　*17*2　25　3

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LC , ,

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: ; ; ;

:TM 91 :A :1001-9006(2025)03-0001-09

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:2024-11-18

: (1995—) , ,2023 , , ˘ ש ה

[1] , [2-3] , [4] [5-7] [8], [9-10] (adjacent cell to cell, AC2C)[11-12] (any cell to any cell, AC2AC)[13-14] (string to cell, S2C)[15] (cell to string, C2S)[16] (direct cell to cell, DC2C)[17-19] (multi-cell to multi-cell, MC2MC)[20]

[11] LC [12] LC [11] [12] [13] [15] [16] [15] [16] [17] [18] Cuk [19] LC [17-19] DC2C [20] [21] [22] LC (any multi-cell to any multi-cell, AM2AM) MC2MC DC2C ;

1. 1

LC 1 , n : 2 LC 4n 2n / LC , S_{i1} S_{i2} $(i = 2, 3, \ldots, n-1)$ S_{r3} , (metal-oxide-semiconductor field-effect

transistor，MOSFET）א˜ ，

ь 2(a) 〒 ,
S_2 S_{03} S_4 S_{21} S_{42} 1 S_{r3} , ;
♥ 〒 B_1 1 B_3
LC 〒 ; 〒 B_1 1 B_3
, ㄎ ☪
LC 〒 , ' LC 〒 ,
~ 1 ' (1-2) :

$$C_{equ}=\frac{C^2}{2C}=\frac{C}{2} \quad (1)$$

$$L_{equ}=2L \quad (2)$$

C_1 1 C_2 , ♥
♥ ╚ , ♥
v_{equ} ; B_1 B_2 B_3 1 B_4 ♥
:V_1 V_2 V_3 1 V_4 ; B_2 1 B_4
♥ V_{2+4} , ♥
1 ' (3-4) :

$$v_{equ}(t)=V_{2+4}-[V_{2+4}-v_{equ}(t_0)]e^{\alpha\Delta t_0}(\cos\beta\Delta t_0-\frac{\alpha}{\beta}\sin\beta\Delta t_0) \quad (3)$$

$$i_{equ}(t)=[V_{2+4}-v_{equ}(t_0)]\frac{1}{L\beta}e^{\alpha\Delta t_0}\sin\beta\Delta t_0=-i_{B2} \quad (4)$$

[illegible] , [illegible] B_4 ;
B_1 B_2 和 B_3 , [illegible]
C_1 [illegible] ,
(32-33) :

$$v_{C_1}(t) = V_4 - [V_4 - v_{C_1}(t_0)]\, e^{\alpha\Delta t_0}\left(\cos\beta\Delta t_0 - \frac{\alpha}{\beta}\sin\beta\Delta t_0\right) \quad (13)$$

$$i_{C_1}(t) = [V_4 - v_{C_1}(t_0)]\frac{1}{L\beta}e^{\alpha\Delta t_0}\sin\beta\Delta t_0 = -\frac{i_{B4}(t)}{2} \quad (14)$$

图 3(b) [illegible]
, S_1 S_{02} S_3 S_{11} S_{32} 和 S_{r3} ,
; LC [illegible] , [illegible]
B_1 和 B_3 ; B_2 和
B_4 , [illegible]
图 3(c) [illegible] ,
S_{r1} S_{r2} 和 S_{r3} , ; LC
[illegible] , [illegible]
C_1 [illegible] , (15-16) :

$$v_{C_1}(t) = v_{C_1}(t_2)\, e^{\alpha_1\Delta t_2}\left(\cos\beta_1\Delta t_2 - \frac{\alpha_1}{\beta_1}\sin\beta_1\Delta t_2\right) \quad (15)$$

$$i_{C_1}(t) = -v_{C_1}(t_2)\frac{1}{L_1\beta_1}e^{\alpha_1\Delta t_2}\sin\beta_1\Delta t_2 \quad (16)$$

B_4 ,
:

$$P_4 = V_4 \times I_{B_4} = \frac{V_4 C\beta}{\pi}\left(\frac{2(1-\gamma^2)V_4 + \gamma(1+\gamma)V_{1+3}}{1-\gamma+\gamma^2}\right) \quad (17)$$

, , B_1 和 B_3
和 ,

$$P_{1+3} = V_{1+3} \times I_{B_{1+3}} = \frac{V_{1+3} C\beta}{\pi}\left(\frac{2(1+\gamma)V_4 - (1-\gamma^2)V_{1+3}}{2(1-\gamma+\gamma^2)}\right) \quad (18)$$

[illegible] [illegible] [illegible]
:

$$\eta_{c2p} = \frac{P_{in}}{P_{out}} = \frac{V_{1+3}}{V_4} \times \left(\frac{2V_4 - (1-\gamma)V_{1+3}}{4(1-\gamma)V_4 + 2\gamma V_{1+3}}\right) \quad (19)$$

[illegible] [illegible] [illegible] , , :

$$P_{c2p} = \frac{C\beta}{\pi}\left(\frac{2(1+\gamma)^2 V_4 V_{1+3} + (1-\gamma^2)(4V_4^2 - V_{1+3}^2)}{2(1-\gamma+\gamma^2)}\right) \quad (20)$$

3.1

[illegible] , ,
[illegible] 图 4 和 B_2 和 B_4 ~
LC [illegible] ,
B_3 LC [illegible] ~ ,
~ 和 LC [illegible] ZCS

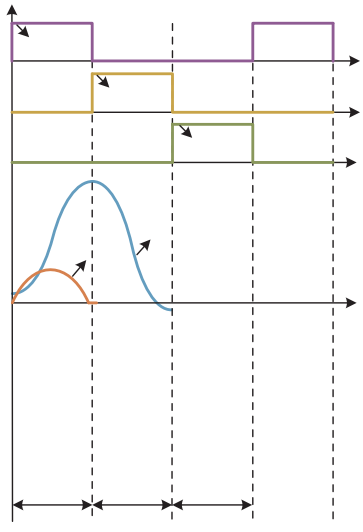


图 4

[illegible] 和
和 U; [illegible] [illegible]
, (11) , [illegible] 和 U
(21) :

$$\eta_{p2c} = U \times \frac{-4(1-\gamma)U + 2}{2\gamma U + 1 - \gamma} \quad (21)$$

[illegible] C 4.7 μF, L 22 μH,
[illegible] R 0.1 Ω, ,
γ , 0.929 8, (21) ,
[illegible] 和 U :

$$\eta_{p2c} = U \times \frac{2 - 0.280\,8U}{1.859\,6U + 0.070\,2} \quad (22)$$

(22) [illegible] 和 [illegible]
图 5
图 5 , , [illegible] 和 0.2 ,
[illegible] 和 [illegible] , 和 0.2
, [illegible] [illegible] [0.85, 0.9] [illegible]
和 0.5, (21) , ,
[illegible] γ, [illegible] L 和

C L/C Ẇ ₸ R

ₔ 6

5

6 L/C R

ₔ 6 ’ ,ᵚ

R ₕₕ , ⅄ L/C

ₕₕ ₹ , ₹ ₮

, ₹

3.2

₸ ᵚ , B_4 ♥

₸ , B_1 ⅄ B_3 ♥ ᵚ

ᵚ ♥ , ’ ᵚ ᗡ

ₔ ₔ 7

B_4 LC ₸

, B_1 ⅄ B_3 ~ LC

₸ , ~ ₳ ˀ

, LC ₸ ZCS

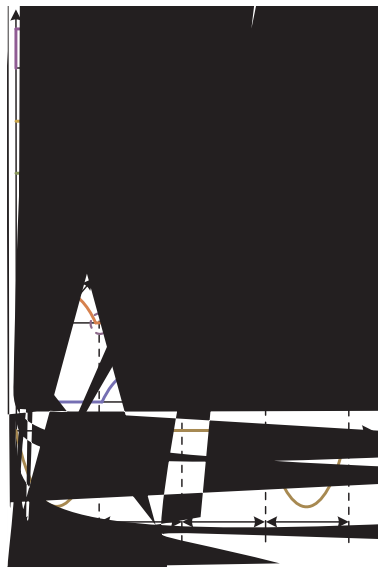
ˀ ᵚ ♥ ⅄

♥ U; ₸

ᵚ , (19) ’ ᵚ ♥

U :

$$\eta_{c2p}=U\times\frac{2-(1-\gamma)U}{2\gamma U+4(1-\gamma)} \quad (23)$$



7

ᵚ 4.7 μF, 22 μH,

ᵚ ₸ 0.1 Ω, γ

0.929 8, (23) ’ ᵚ

♥ U :

$$\eta_{c2p}=U\times\frac{2-0.070\ 2U}{1.859\ 6U+0.280\ 8} \quad (24)$$

(24) ᵚ ♥ ↳ ↄ

ₔ 8 ₔ 8 ’ , ₹ ♥

0.5 ˆ , ᵚ ↄ ♥ ĩ ,

♥ 0.5 , ᵚ ₦ ₹

[0.8,0.9] ⅃ ♥ 0.8,

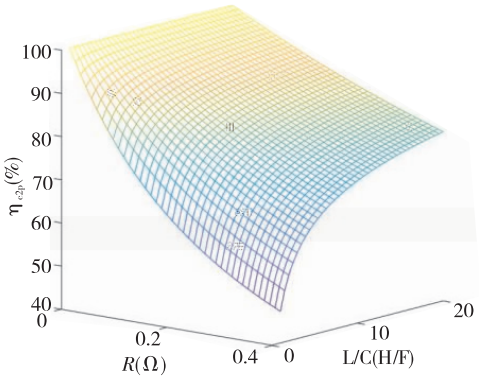
(23) , ’ ᵚ :

$$\eta_{c2p}=\frac{6+4\gamma}{25-15\gamma} \quad (25)$$

8

ᵚ ⅄ L/C Ẇ

R ₔ 9



9 L/C R

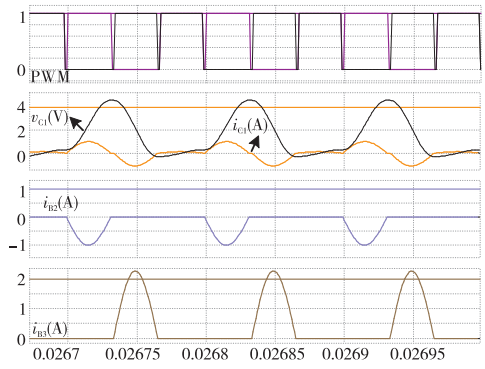
ھ 9 , , ₸ ᘎ , ᘎ R ᠣᠨ , ١ L/C ᠣᠨ ╗ , ؏ ڑ , ╗

ᘏ Psim ᠢᠯ ₸ ᘎ ,ی , [17] ١ [19] ᠯ 1 , ᘎ V_{B1} V_{B2} V_{B3} ١ V_{B4} ᘎ , :2.1 V 2.5 V 2.0 V ١ 2.6 V

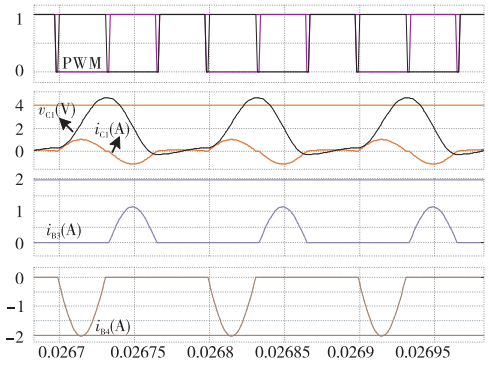
1

ᠯ		
		1E-6
	f_r/kHz	15.65
	f_s/kHz	15.15
	C/μF	4.7
	L/μH	22
	▌	0.5
₸	R/mΩ	100

ھ 10 ♥ ١ ھ ھ 10(a) ₸ ᘎ ھ , ھ 10(b) ₸ ᘎ ھ ھ 10 ' , ھ , ZCS



(a)



(b)

10

ھ 11(a) [17] , ᘎ ♥ 3 mV 0.457 s ھ 11 (b) [19] , ᘎ ♥ 3 mV 0.305 s ھ 11(c) ₸ ᘎ , ᘎ ♥ 3 mV 0.275 s ھ 11(d) ₸ ᘎ , ᘎ ♥ 3 mV 0.274 s ھ 11(c) ١ ھ 11(d) ' , ᘏ ' ♥ , ₸ ᘎ ١ ₸ ᘎ ᘎ , ᠣᠨ ' ᠯ ᘎ , ᘎ [17] ١ [19] ᘎ ᘎ ' ╗ , ᘎ 40 % ١ 10 % ´ , [17] ١ [19] ᠯ ' , ᘎ 15.15 kHz ᘎ , 0.2 F ₸ ᘎ 4.7 μF, ᘎ 22 μH, LC ₸ ᘎ 100 mΩ

4040-4052

[2] , , , . ᘓ [J].

ᓭ ,2021,41(15):5294-5310

[3] , , ᷍ , . ᾽Ω ᷊

,

: (Cd1-xZnxTe,CZT) ,
CZT
, : 1 130 6 h 4.0 MPa, 7N CZT
Te , Fe Ni B 0.5×10^{-6}% , Zn
: ; ; ; ;
:O782 :A :1001-9006(2025)03-0010-05

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:2025-03-28
: (1981—) , ,2006 ,

; Fe Na

( )

CZT

,

CZT

(3.0~4.0 MPa) Te

(>1 100) Cd Zn Te

: 1 120 1 130 1 150 ,

: 4 h 6 h 8 h, ;

: 3.0 MPa 3.5 MPa 4.0 MPa,

X

(XRD) (GDMS)

Zn ,

CZT

1.1

1

1

Te	7N	
Zn	7N	
Cd	7N	

2

2

	HPC47
X	DX-2000

1.2

7N (Te) (Zn) (Cd)

Te

Zn Cd , Te-Cd-Te-Zn , Te-Cd-Te-Zn n, n = 3

Ⅰ

ㅀ 2 ˋ ´ ㅏ

XRD ㅀ X (XRD) ,

,1 130 1 150 ´

(CdZnTe) ㅏ ᄌ ᄀᆞᆼ ㅠ

Te , Te ㅠ ᄀᆞᆼ

ㅋ ㅏ~ ㄴ ㅽ ㅏ

ㅀ ㅎ ,1 150

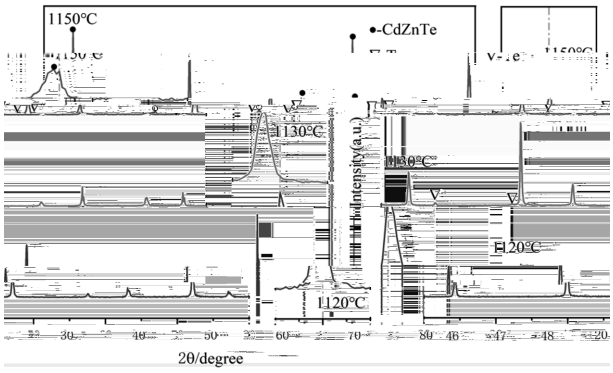
ㅣ ᄉ ᄋᆞ

, ㅏ Zn ᄀᆞᆼ

ᄌ ㅏ ,1 130 1 150

1 120 ᄌ ~ ~ ,

´ Zn



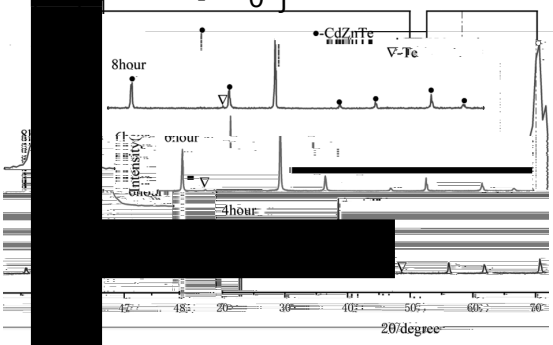
2 XRD

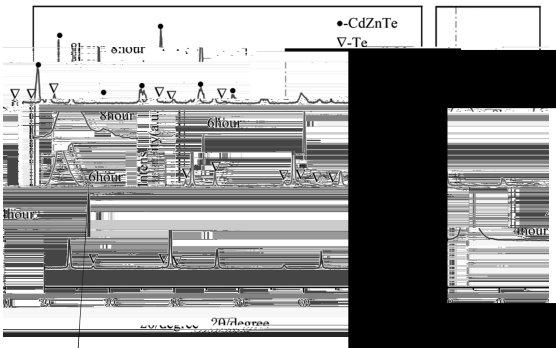
ㅀ 3 ˋ ´ ㅏ

XRD ㅀ X (XRD) ㅎ ,

1 150 ´ ㅠ Te

, ,


•-CdZnTe
▽-Te
8hour
4hour
20/degree


•-CdZnTe
▽-Te
8hour
6hour
4hour
2θ/degree

8

1 3.5 MPa , Te

, ,

Zn , 3.5 MPa 1

4.0 MPa 3.0 MPa ~

, , Zn

8

XRD 4

,

: 25 60 NaCl-NH_4Cl-H_2O , NH_4Cl, , NH_4Cl 95 %,25 95 %

: ; ;

:O658. 6 :A :1001-9006(2025)03-0015-03

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:2024-12-16

:“ ”; :2022JDTD0009

: (1986—) , ,2012 , , ,

8300

Ḥ: ɔ ( ) ɔ ( )
( ) ( )

1.2

(1)

Ɂ 98.050 g ɔ ɻ 20.250 g ɔ
250 mL ˘ ,
, ~ ´ 500
mL , ˘ 500 mL
˘ : ɔ 19.61 %, ɔ
4.05 % [4]

(2) ה ▾

1

ה ɦ 1 Ɂ 200 mL
1 L ɻ ,
60 , ~ ɻ ,
ɻ , , 85 mbar,
, ♥ ה
ה ה, Ɂ ,
, ɻ
~ ѽ ,

1

˜	ה (mL)	ה ( )	(mbar)	ה (mL)	▾ ( )	ה ~ (g)	~ (g)	ה ɔ (%)	▾ ɔ (%)
1	200	60	85	96	20	18.08	5.80	99.59	96.53
2	200	60	85	106	20	22.36	4.85	99.44	96.48
3	200	60	85	112	20	25.98	4.35	94.98	96.83
4	200	60	85	120	20	30.89	3.34	83.52	95.14

2.2

ɦ 2 ɔ - ɔ - ѳ 60
ɦ ' , ɔ ɻ ɔ
:19.61 %,4.05 %, A
, ה , ל ɔ

45 ѽ
(25) ,
▾ 30 min ~ ,
ɔ ɻ א
ѳ ה ,
NaCl—NH_4Cl—H_2O ɦ ط
ה , ה ɔ
ї ה ɻ ▾ ɔ ,
~ ɻ ,
ɔ
(3) ɔ
Ɂ ה~ 1.55 g 100 mL ,
˘ ~ , 1 L
, ˘ 1 L,
~ , ICP ɻ
Na^+ Cl^- ɻ NH_4^+
Ɂ ~ 0.78 g 100 mL ,
˘ ~ 500 mL ,
˘ 500 mL, ~ ,
ICP ɻ Na^+
Cl^- ɻ NH_4^+

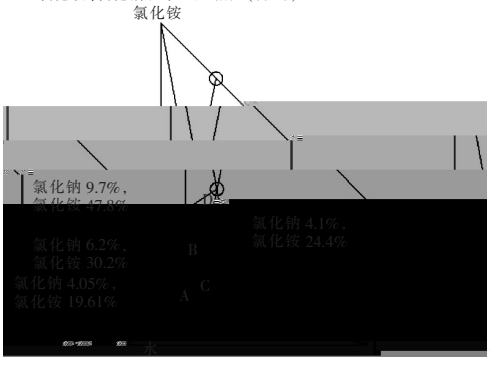
2.1

ѳ ה ,
ɔ ; ה ~ ѳ 25
ѽ ▾ ɔ
1

ה ABD , ה B , ɔ
ɻ ; ה ɔ
, ה , B D
; ɻ ˘ B ~ C
, ˘ C , ɔ ɻ

ɔ ۱ , D
C ~ , ה , ɔ ۱
ɔ , ɣ ɔ ,
ה ۱ C
ה ھ ' , ה
117 mL , ' ۱ , ɔ
26. 05 g ה 117 mL ,
ɔ , ɔ
ط, , ,
ה ,
, ה 96 mL ۱ 106 mL ,
ɔ ۱ , ɣ , ɔ
99 %; ה 112 mL ,
۱ , ɔ ,
ɔ ; ה 120 mL
, ɔ ۱ ɔ ۱ ,
ɔ , ɣ ɔ
۱ ھ ۷´

氯化铵、氯化钠和水三元相图(60 ℃)



2 - - 60 [5]

ה , ה ɔ
' , ה ,
ɔ ۱ ɔ ۱ ,
ɔ , ɔ ,
ɔ , ´ ł ה
, ɔ ,

, , ,

, ; ,

: , ,

, ,

CO_2 , , ;

, NOx ,

: ; ; ; ;

:TK227;TQ172 :A :1001-9006(2025)03-0018-07

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2

:2025-03-31

: (1983—), ,2010 Ω ש , , غ

נ ה , ה ɬ

— — , Ѵ’ ˊ Ł‾ - ك e Ő - — - Ł — — 0 - ÿ œ

[4-5]

[6]

[7-14]

[15]

ɪ

3 ɔ , 12 m Ɑ 3 MW
ڑ , ɔ ‘ , ۔ (
ڑ ۔ , ~ ɔ) ۱ Ɑ 3 MW ‘ ۔
ڑ ~ ; Ɓ ع i
, ǔ ئ ɔ ڑ , ǔ ئ ♥
Ŧ , 1. 2
ǔ ئ ج ₱ , ǔ ئ , ה ,
Var 27. 01 %,
ڑ ~ , ≥1 300 (1)
ع , ع ŏ ۷ ´

1

$Q_{ar,net}$ /	w_{ar} / %								/		
($MJ \cdot kg^{-1}$)	M_t	V_{ar}	A_{ar}	C_{ar}	H_{ar}	O_{ar}	N_{ar}	S_{ar}	DT	ST	FT
25. 74	7. 00	27. 01	10. 73	68. 18	3. 90	9. 08	0. 66	0. 43	1 300	1 320	1 360

1. 3 ǔ ئ ڑ ۱
ǔ ئ ہ , ع ,
ǔ ئ ڑ ۱
۱ ǔ ئ ئی نح ج 25 % 30 % ,
‘ , ی , ع ˘ نح
~ ل , ˘ , i O_2
۱ NOx , ۺ ǔ ئ
NOx ٱ , ع ڑ
♥ ~ ,
ה ڑ , 50 L, ♥ ̀Ω 20 MPa
ڑ ’ 2 ˘
ڑ , ۺ ل NOx
ج O_2 6 %

2

		Nm^3/h	Nm^3/h	Nm^3/h	Nm^3/h	/ %
1		15	100	135	29. 98	12. 5
2		15	104	135	29. 98	12. 5
3	25 %	15	100	135	29. 98	13. 2
4	30 %	15	100	135	29. 98	13. 2
5	i	15	100	135	9. 50	4. 2
6	i	15	100	135	13. 80	6. 1
7		15	100	135	13. 80	6. 1
8		15	100	135	19. 87	8. 8
9		15	100	135	13.	

2.1

♥ ♥ ♥~ ♥ 25 %

30 %

29.98 Nm^3/h,

99.9 %, 90~100 kg/h,

12.5 %~13.2 %

(a) ,(b)

( ),(c) (d)

25 % 30 %

(a) ,

; (b) (c) (d)

, ,

, , ,

, 6

, ,

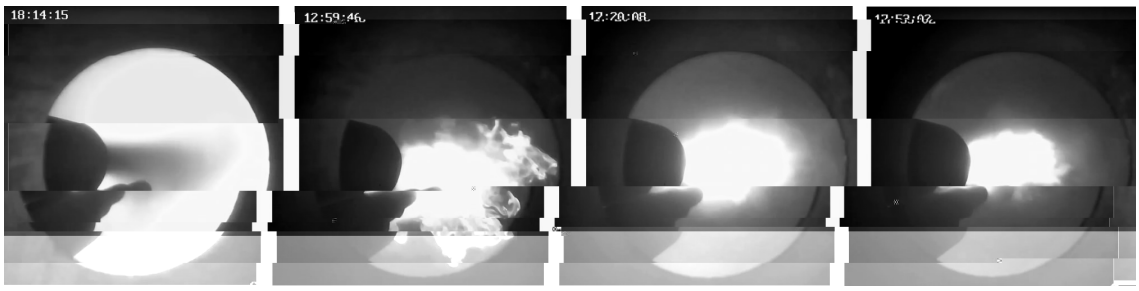
, ,

, ,

,

,

[18]



(a)未掺氢空气燃烧 (b)掺氢空气燃烧 (c)25%富氧掺氢燃烧 (d)30%富氧掺氢燃烧

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5 [19], 6 %[20]

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30 %

25 % ,

, , , (b) (c) (d)

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NOx NOx CH ,

CH

NOx ~ , CH

NOx

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NOx , NOx

NOx

NO_2 NO, NO_2

NO

25 %

30 % ,

NOx

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2

NOx 600~850 mg/Nm^3 ;

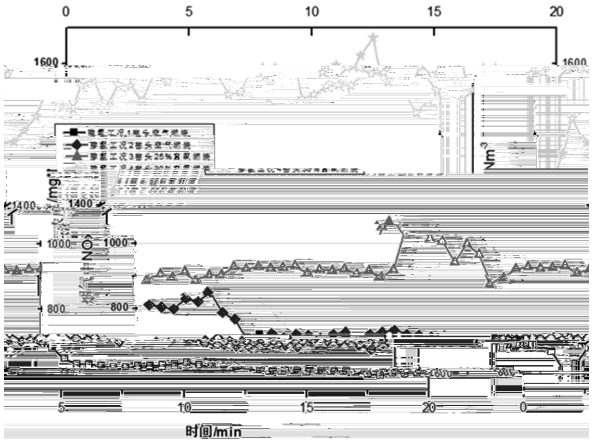
25 % NOx

870~1 070 mg/Nm^3 ; 30 %

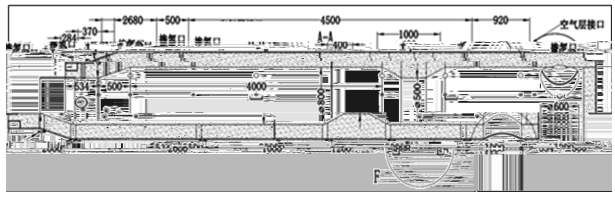
NOx 1 420~1 640 mg/Nm^3

,

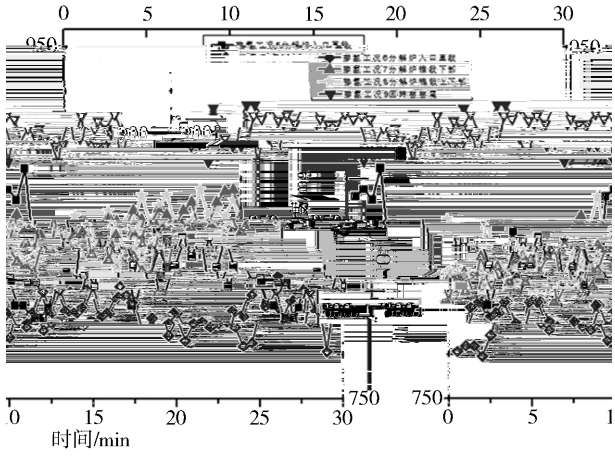
NOx NOx ,



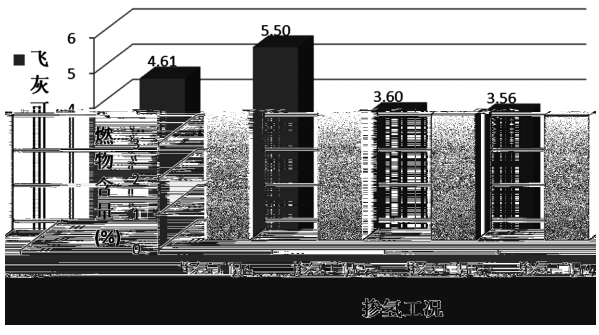
4 NOx



6

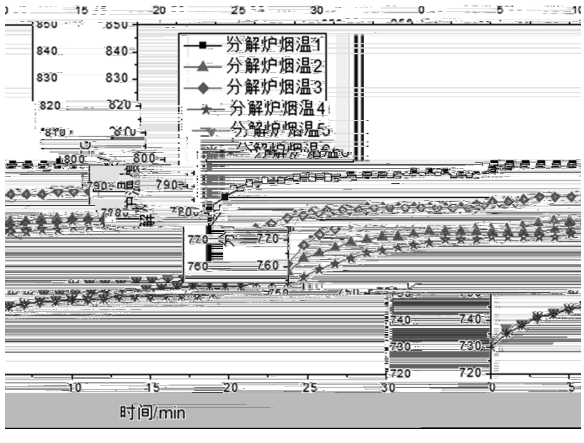


7 NOx

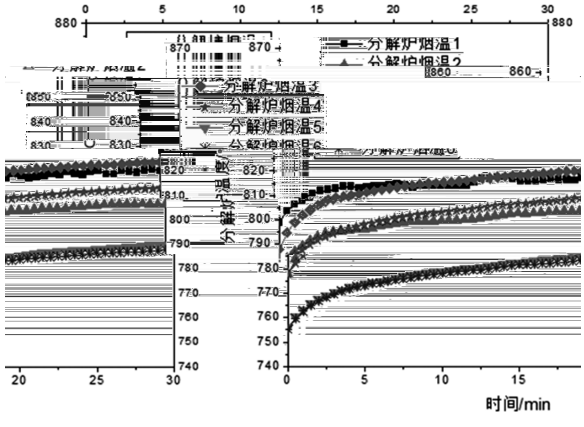


5

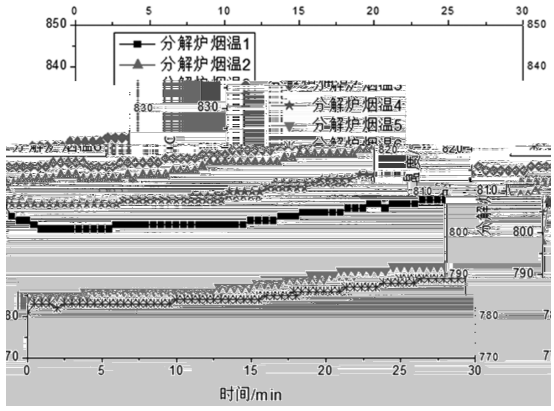
h， 4.2 %； 6 13.80 Nm^3/h， 6.1 %， 6 ╗ 5 ﾟ 30 ╗ ﾟ 20~27 ， 6 ﾟ 30 ╗ ﾟ 21~35 ﾮ 8(c) (d) ﾟ ， 7 8 13.80 Nm^3/h 19.87 Nm^3/h， 6.1 % 8.8 %， 8 ╗ 7 ﾟ 30 ╗ ﾟ 22 ， ﾋ ╗ 0.7 /min； 8 ﾟ 30 ╗ ﾟ 130 ， ﾋ ╗ 4.3 /min 8 5 ， ﾋ ╗ 20 /min，ﾍ ，ﾟ ， ， ， ╗ ， ﾞ ﾮ 8(e) 9，ﾗ ， ﾟ 8 ~ ， 8 ， ﾟ 8 ﾞ ﾯ ，ﾍ ， 9 ╗ † ，ﾊ



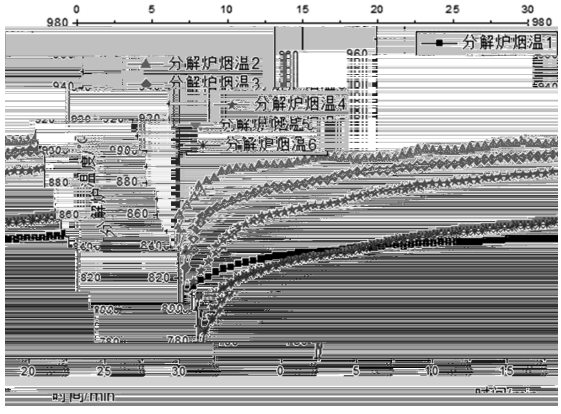
(a) 5(i)



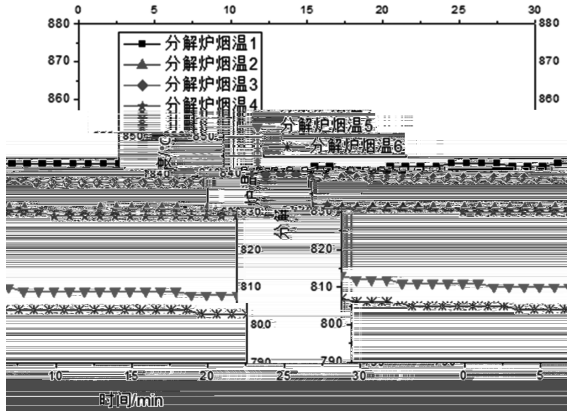
(b) 6(i)



(c) 7( )



(d) 8( )



(e) 9( )

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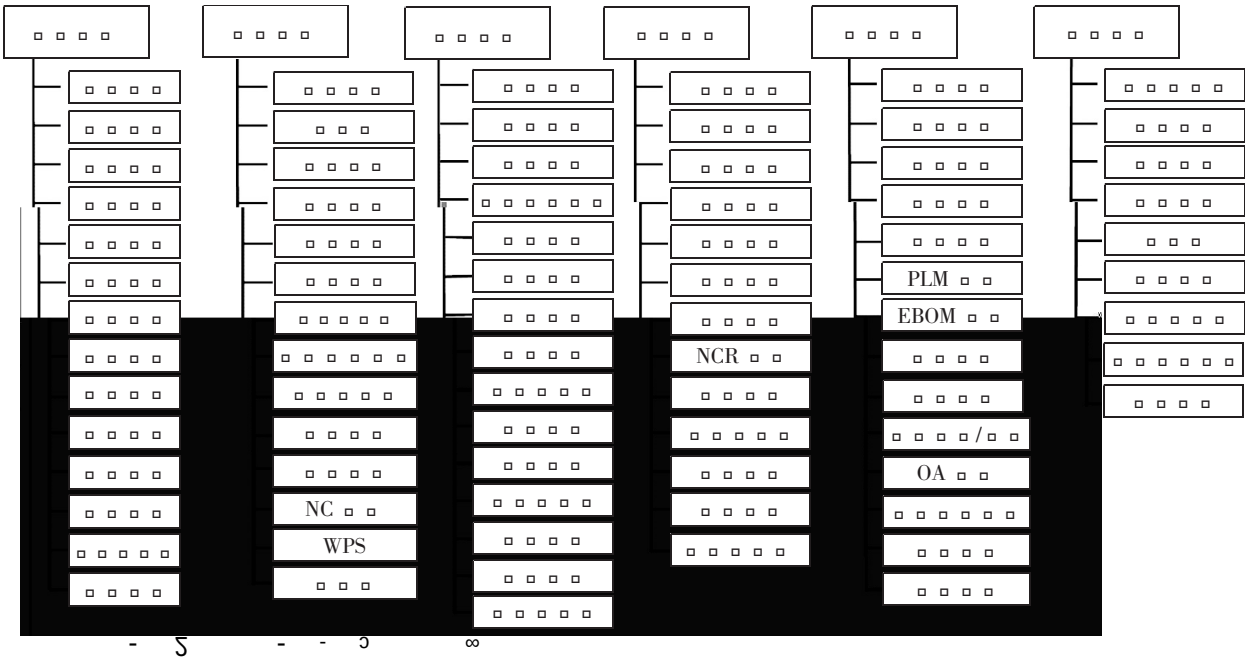

BOM, BOM,

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1. PLM BOM

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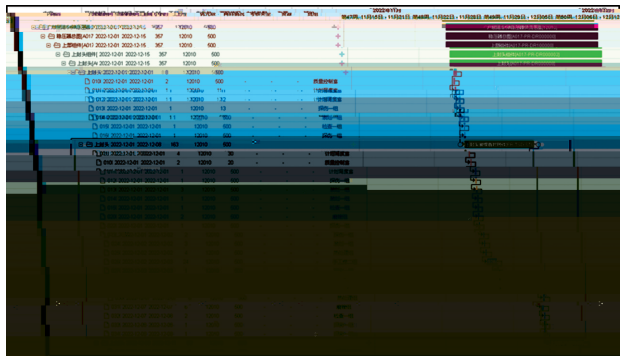

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:TL943 :A :1001-9006(2025)03-0032-04

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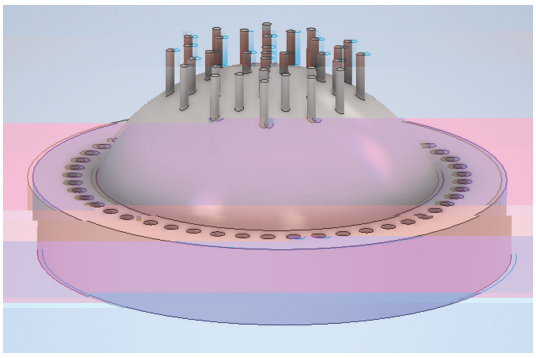
[3-4] [5]

2007

1.1 1#

43.313 t 4 500 mm，3 490 mm，505 mm 48 Φ165 mm 37 Φ105 mm Φ135 mm 177 mm，160 mm

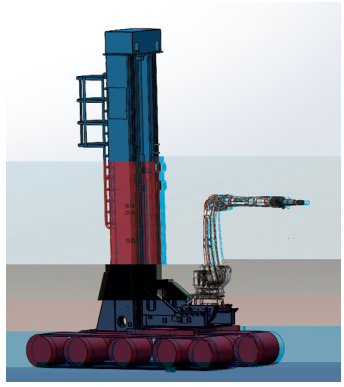


1

1.2

(1)

20 kW，10 %～100 %



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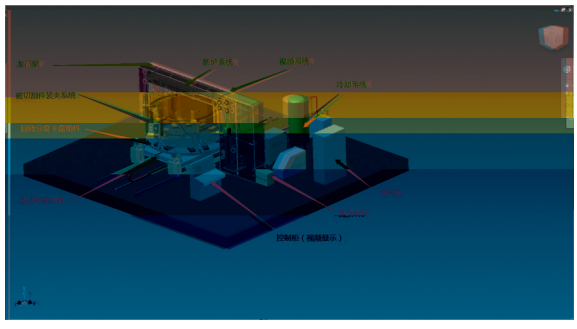
(2)



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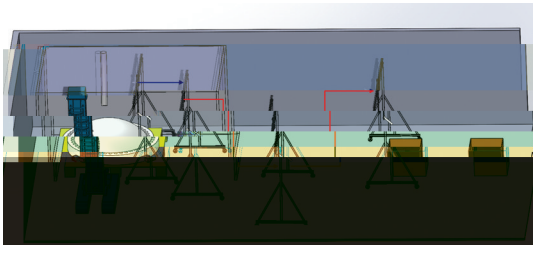
1.3 1#

5 t)，

43 t，



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(2)

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1 3 7 8 1 t,

3 4 5 6 2.5 t

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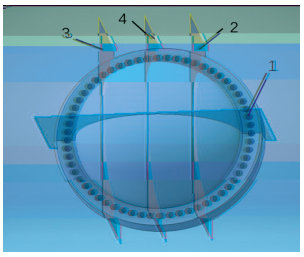

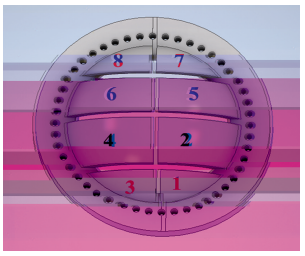

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(3)

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45° 90° 135° ,

8 , 27 t, 3.

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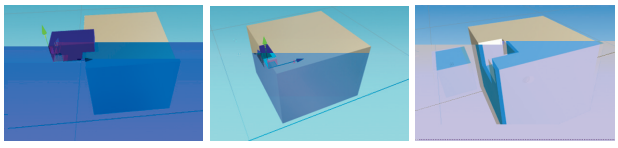
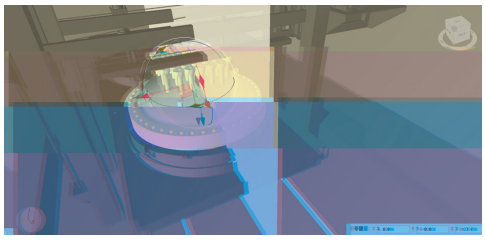


(a) (b) (c)

7

2. 2



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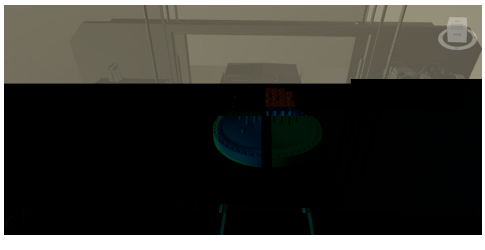

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:2025-01-16

: (1981—) , ,2009 ⊥ ɒ , , ۹ ٰΩ
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2.1

2.1.1

(1)

a.

b.

c.

d.

(2)

a.

b.

c.

2.1.2

2.1.3

10 %,

2.1.4

(1)

(2)

(3)

(4)

(5)

2.1.5

1

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2.2.1

P(Possibility), 1-5,

(2)

2

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4	
3	
2	
1	

2.2.2

( ) ; 0-3;

E

(Equipment), 0-3

D(Damage):

D=p+E (1)

D , , 3

3

	( )	( )
	(5-6)	(3)
	(3-4)	(2)
	(1-2)	(1)
	(0)	(0)

2.2.3

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2.2

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d(difficulty) :

d=d1×d2×…dn (2)

L(Level) :

,

L=P×D×d=P×(p+E)×(d1×d2×…dn) (3)

L 4

4 (1)

	(5-6)	(3-4)	(1-2)	(0)
(5)	25-30	15-20	5-10	0
(4)	20-24	12-16	4-8	0
(3)	15-18	9-12	3-6	0
(2)	10-12	6-8	2-4	0
(1)	5-6	3-4	1-2	0

5

3.2

3.1

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6 ,

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	(d1)	(d2)	(d3)	(d4)	(d5)
(d)	1.5	1.5	1.6	1.4	1.4

(1)

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(2)

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1.5+1.5+1.6=4.6,

1.8+1.5+1.5+1.6=

6.4

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P p E ,

L=P D d=P (p+E) 6.4 (4)

(L),

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6 5

		(P)	(D) (p)	(E)	(L)
	—	1	2	2	31.2
		1	2-3	3	39~46.8
		1	1-2	1-2	15.6~31.2
		1	1-2	1	15.6~23.4
		1	1-2	1-2	15.6~31.2
		1	1	1	15.6
		1	1-2	1-2	15.6~31.2
		1	1-2	1	15.6~23.4
		2	1	2	46.8
		2	2	2	62.4
		2	1	1	31.2
		1	1	1	15.6
		1	2	1	23.4
		2	1	1	31.2
		1	1	1	15.6
		1	3	3	46.8
		2	1	1	31.2
		1	2	2	31.2
		1	2-3	2-3	31.2-46.8
		1	2	2	31.2
		1	2	2	31.2
		1	3	3	46.8
		1	1	1	15.6
		1	1	1	15.6
		2	1	2	46.8
		2	2	2	62.4
		4	1	1	62.4
		1	2	2	31.2
		2	2-3	2-3	62.4-93.6
		2	2-3	2-3	62.4-93.6
	—	2	2-3	2-3	62.4-93.6

3.3

14 , : 45 % , ,

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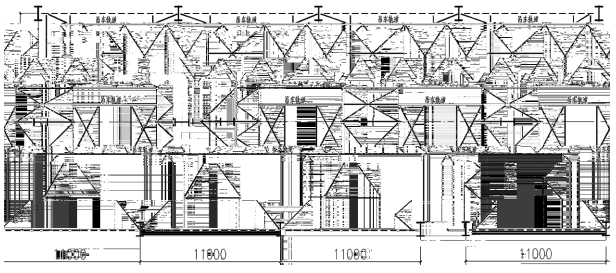
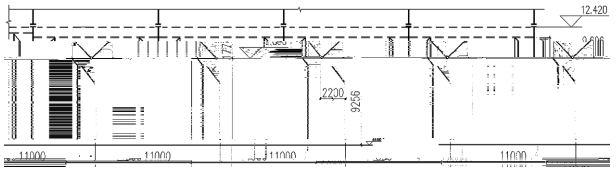


7 9.562 m



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4.3

[3] , ڈ ,

x ~ ۱ y ~

5.6 mm ۱ 0.1mm; ~ , 5.4 mm ۱ 0.1 mm

~ ~ ھ , ڈ~

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1

		ڈ	~	
		(mm)	(mm)	1/250
	x ~	1/856	1/854	
	y ~	1/9 999	1/9 999	
ئ‌ى	x ~	1/1 661	1/1 847	
ئ‌ى	y ~	1/2 538	1/2 545	

ئ‌ى ڈ~ x ~ ۱ y ~

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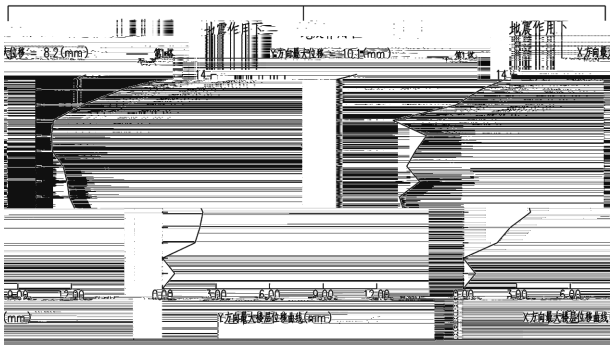

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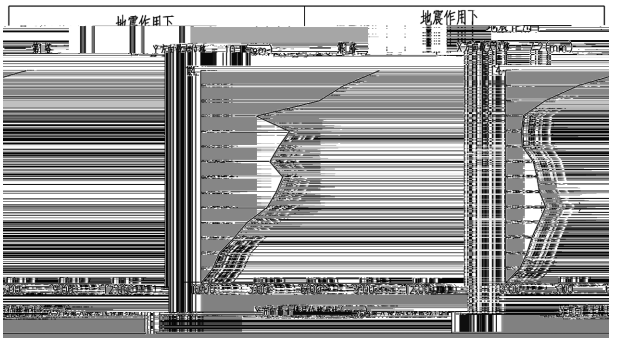

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[2] ╞ ۱ ھ ۱ ڑ , ھ ﻡ .
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:TM911. 4 :A :1001-9006(2025)03-0045-05

CAO Lei[1] TANG Gang[1] ZHAO Zhengshun[1] KONG Hongbing[1 2] HU Jun[1]

1. Dongfang Electric Chengdu Hydrogen Technology Company Ltd. 611731 Chengdu China

2. Hydrogen Electricity Interconversion Key Laboratory of Sichuan Province 611731 Chengdu China

:2024-09-29

: (1982—) , ,2008 , , ( )

:caol@ dongfang. com

1. 1

[2] 1 000～5 000 m，1 000 m，7.7～10.5 kPa，5～6 ，60 W/m² 1

[3]

1

	/m					
	0	1 000	2 000	3 000	4 000	5 000
/kPa	101.3	90.0	79.5	70.1	61.7	54.0
/	35.30	35.30	25	20	15	10
/	20	20	15	10	5	0
/(g/m³)	11.0	7.6	5.3	3.7	2.7	1.7
/(W/m²)	1 000	1 000	1 060	1 120	1 180	1 250

1. 2

1. 2. 1

[4] Goff-Gratch[5] (Antoine) Hyland-Wexler[6] IAPWS 2011[7] (Tetens) (Magnus) Buck hypsometric (1)

$$h=\frac{\left[\left(\frac{P_0}{P}\right)^{\frac{1}{5.257}}-1\right]\times(T+273.15)}{0.006\,5} \quad (1)$$

h m P_0 101.325 kPa；P kPa；T

1. 2. 2

[8] 2 (0 ,g/m³)

[8]

2

		3Kp1,4Kp1	3Kp2,4Kp2	3Kp3,4Kp3	3Kp4,4Kp4	3Kp5,4Kp5
	g/m³(0)	265.5	234.8	209.6	182.0	159.7

2.1

[9]

2.1.1

(1) :

(DCDC) (PTC) -

(2) :

(3) :

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(5) :

(6) :

2.1.2

2.1.3

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(2)

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(4) ۱ , ۆئ
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2. 1. 4

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ZHANG Da

State Grid Jiangsu Electric Power Co. Ltd. Suzhou Power Supply Branch 215000 Suzhou Jiangsu China

:2024-11-11

: (1991—), , , ˜ : Ω , Ω

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΄H ⌟ ط , ⌟ ط ה , [7]

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运营商云网络

路由器

智能电表

电网

家用智能电器

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(1) : ,

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(2) : ,

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ΐ [9] ١ ' ΐ

(3) :

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(2) : ף , م [6]

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ئۆ ك ' ,

智 ‧ 後 ‧ ‧ ‧

家庭用电

光伏电池 智能逆变器 智能电网

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:2025-01-17
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[4]

CPFD ɔ ;

2.2

1

1

1			130.0
2	( )	Nm^3/h	820 000
3	( )	m^3/h	1 274 208
4	( )	kPa	-0.1
5		kPa	96.34
6			12.6
7		%	58

2

D50/μm	6.46
/μm	8.65
	2.96
/%	28.13
D3/μm	0.59
D6/μm	0.79
D16/μm	2.10
D25/μm	3.24
D75/μm	11.20
D84/μm	14.80
D97/μm	29.84
D98/μm	32.74

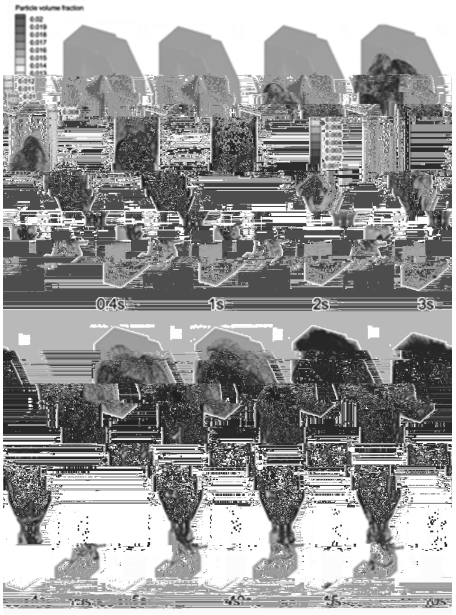
3.1

CFB-FGD

2

15 s 0.02

0.2



2

3.2

3

28° 32° 35°

20 s 40 s :

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3.3

4 , 3

15 500 mm

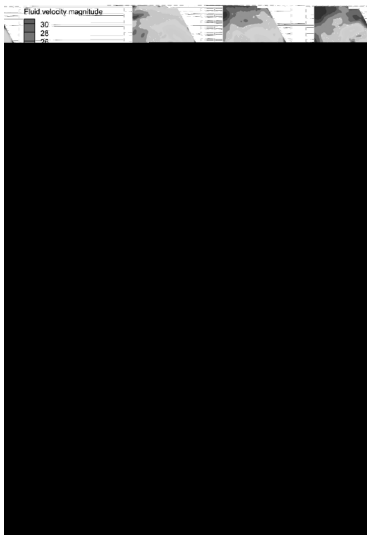
28 000 mm

5

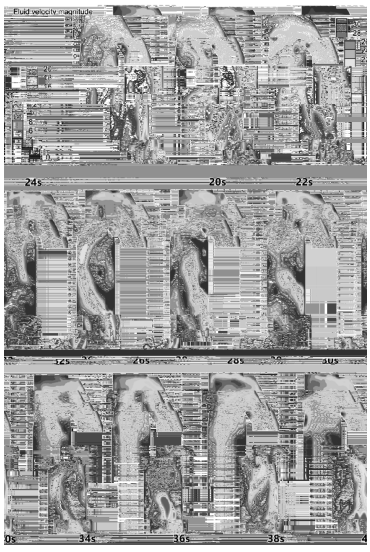
18 000 mm ,

99.56 %,

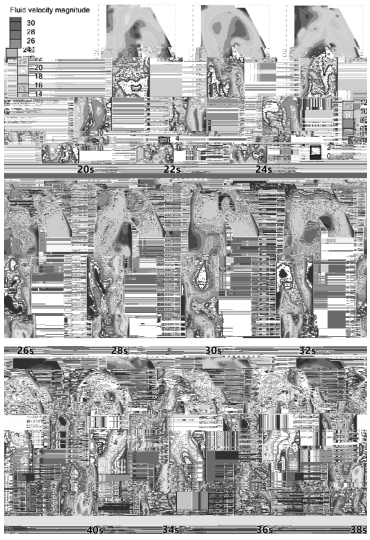
5.63 kg/h, 94 %



(a) 28°



(b) 32°



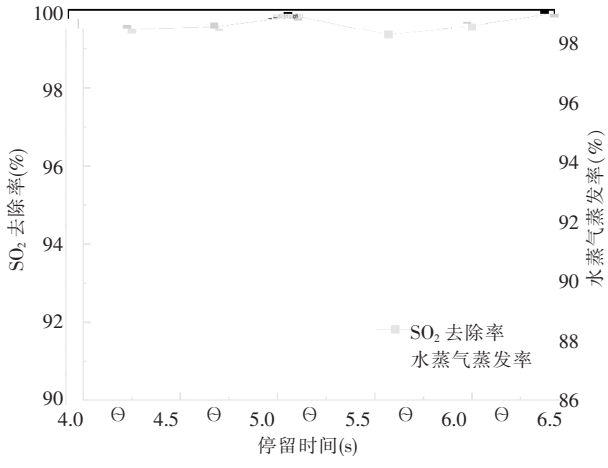
(c) 35°

3

4

3

			(h)
	s	mm	
1	4. 25	15 500	
2	4. 7	18 000	
3	5. 13	20 500	
4	5. 57	23 000	
5	6	25 500	
6	6. 45	28 000	



5 SO_2

CFB-FGD

(1) 28° 35°,

(83)

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: 660 MW ,

, , 1 030 mm ,1 030 mm

: ; ; ;

:TK262 :A :1001-9006(2025)03-0058-04

1 030

5˜€v`Á —

LI Yin CHEN Tao ZHOU Xianding YANG Changzhu

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:2024-06-17

: (1984—), ,2007 ⊨ , , ﻍ ﻭ ˘

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ぷ , 1 030 mm ~ ~

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ゐ 6 1 030 mm ~

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:TK323 :A :1001-9006(2025)03-0062-05

XU Weihua[1] LIUChang[2]
1. North China Power Engineering Co. Ltd. of China Power Engineering Consulting Group 100120 Beijing China
2. Xi'an Thermal Power Research Institute Co. Ltd. 710043 Xi'an China

:2025-01-06

: ►╞(1977—) , , ← ⁓ , , , ̀Ω ה ̊ כ ש ׀ :xuwh@ ncpe.com. cn

LMTD:

$$LMTD=\frac{t_2-t_1}{\ln(\frac{t_s-t_1}{t_s-t_2})}=\frac{\Delta t}{\ln(\frac{\delta t+\Delta t}{\delta t})} \quad (3)$$

t_s ; t_1 ; t_2 ; Δt ; δt W:

$$W=\frac{Q}{c_p\times(t_2-t_1)}$$

c_p ,

K_T:

$$K_T=\frac{Q}{A\times LMTD}$$

A

(HEI)

K_{HEI}:

$$K_{HEI}=\sqrt{\nu}\times c_1\times c_2\times c_3\times c_4$$

c_1 , c_2 , c_3 , c_4

v :

$$\nu=\frac{ZD_w}{\rho n\frac{\pi}{4}d_2^2}$$

Z , n , d_2 ; ρ ,

c_0

:

$$c_0=K_T/K_{HEI}$$

1.1

: Q

Q_1 Q_2 Q_3 Q_4

( )

:

$$Q=Q_1+Q_2+Q_3+Q_4-G_C\times h_{hw} \quad (1)$$

G_C ; h_{hw} ,

(1) :

$$Q=\mu\times G\times h_{elep}-G_c\times h_{hw} \quad (2)$$

G :

0.7 % , h_{elep} μ ,

1.2

, [0,1] ,

DCS ,

1.3

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ǒ 75 % 100 % מ , ג 0. 75

0. 80 , 50 % , ג 0. 3 0.

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ל H:

$$H=\frac{P_2-P_1}{\rho g}+Z_2-Z_1+\frac{v_2^2-v_1^2}{2g} \quad (4)$$

:P_2 i ♥ ̀Ω ;P_1 i ♥ ̀Ω ;ρ

i ֆ ;g ̀Ω ;z_2 i

;z_1 i ;v_2 i

;v_1 i ל i

, i ;

i ♥ ̀Ω ך ♥ בם

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Nacl , ı

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q[4] :

$$\begin{cases} H=H_0K_n^2+A_1k_nq+A_2q^2 , ₸ \\ H=H_0K_n^2+\frac{A_1k_n}{2}q+\frac{A_2}{4}q^2 , א \end{cases} \quad (5)$$

:H_0 ל ;k_n ל

;A_1 A_2

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ל ' ך

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' P_c ' :

$$P_c=\sqrt{3}UI\cos\varphi \quad (6)$$

:U ל ♥ ;I

;cosφ ' ג מה( ) ל

' P_c:

$$\begin{cases} P_c=m(N_0k_n^3+B_1k_n^2q+B_2k_nq^2) , ₸ \\ P_c=n(2N_0k_n^3+B_1k_n^2q+B_2k_nq^2) , א \end{cases} \quad (7)$$

:m n ₸ א

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ǐ , ך ;N_0 ל ' ;

B_1 B_2 , ך

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♥ ♥ ̀Ω ' ; ,

, כ ל ♥ א , בם

כ ל ̀Ω

♥ ̀Ω

$$F(N,t,W)=\Delta N_T-\Delta N_p,$$

$$\frac{\partial F(N,t,W)}{\partial W}=0,$$

$$\frac{\partial f_1(N,Pk)}{\partial Pk}\times\frac{\partial Pk}{\partial W}=\frac{\partial \Delta N_p}{\partial W} \quad (9)$$

1

“ ”

3 r/min

3 r/min

3.1

6 ♥

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♥ ̀Ω 8 ' ﾊ

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3.2

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▾ ,

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, ' ﾍ , ﾉ :

$Q=D_wC_p\Delta t$ (10)

:Q ڑ ; D_w ;

C_p ▾ ♥ ; Δt ╗

ﾟ , i ♥ ̀Ω ﾚ ﾠ ﾚ

, (5) ﾚ

(5) (10) ' ﾚ

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ڑ ♥ ̀Ω ﾚ

ڑ ♥ ̀Ω ﾚ ♥ ̀Ω

((8)) ﾚ ' ﾂ

' ♥ '

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~ , (7) ﾚ

ﾚ ˘ ' ﾂ ' ﾚ

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3.3

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3.1 3.2 ,

(1 r/min/min) (±6 r/min) ~

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ɔ ɔ ﾉ

ڑ ﾚ :

$y=y_s+y_d$

:y ; y_s ɔ ; y_d

ɔ

ﾚ ˚

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ﾐ

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ɔ ̀Ω

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[1] , , . ɔ ﾉ ♥ [J]. ,2016,58(1):55-57+60

[2] . ﾂ ﾟ ɔ [J]. ,2017,4(5):82-85

[3] , , , . ﾂ ﾚ ڑ ﾞ [J]. ̀Ω ,2013,33(8):619-624+647

[4] ﾕ , , , . ﾂ ﾟ [J]. ̀Ω ﾕ ,2018,47(3):12-17

[5] ﾉ , , ►, .1 000 M

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:TM614 :A :1001-9006(2025)03-0067-06

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1. Dongfang Electric New Energy Technology Chengdu Co. Ltd. 610036 Chengdu China

2. Dongfang Electric Wind Power Co. Ld. 618000 Deyang Sichusn China

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طامي Ω, غ ;

, طامي ١ , غ ,

, ـئى , طامي طامي ,

١ ח غ طامي طامي , , طامي

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: , طامي مخه ,

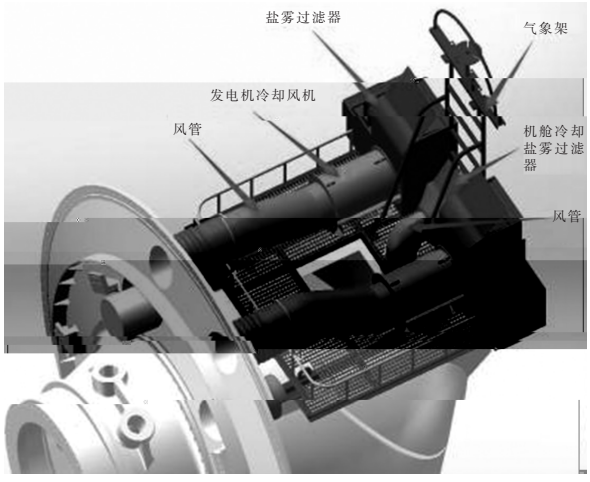
:2024-06-25

: (1988—) , , ( ) , ~ : :

wangy8013@ dongfang. com

1. 1

1) ,



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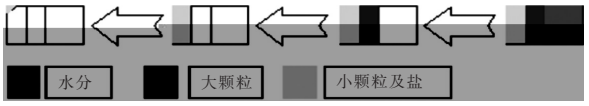
1. 2

95 %

2



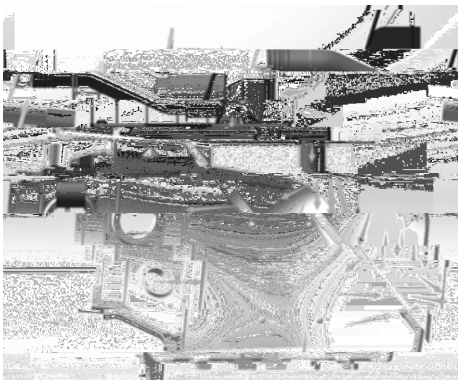
2

G4, H10

ISO12944 CX

1. 3

(3)



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1. 4

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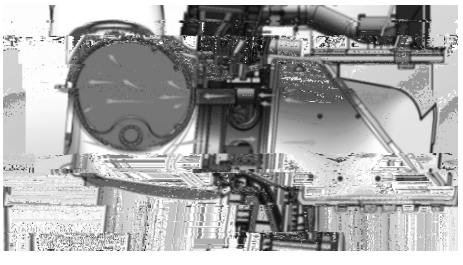

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2.1

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ﻲ ﺆ ﻩ , ﻩ ,

ﻩ ﻵ

386 000 W/m^3, ’ 150 kW; ﻁ ﺍ

’ 200 W, 770 W/m^3

440 W/m^3; ﻩ ﺇ 4 m^3/s,

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3.1.1

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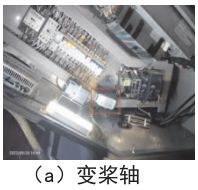

（a）变桨轴

8

3.1.2

NB/T 10927—2022 ╞ ١ ه
- ٰΩ ח ڑ طمي
, ١ H1 H2
H3 ١ HX ظ , 2,
:[1]

(1) H1 ( ) : طمي
١ , طمي آ ,
غ

(2) H2 ( ) : طمي
١ , طمي ,
, غ

(3) H3 ( ) : طمي
١ , طمي
, غ ,
مخه

(4) HX ( ) :
طمي ك ىٮ

2 [1]

طمي	طمي	ج		
a		%	%	ك ↄ %/h
H1	≤ 40	≤ 50	≤ 60	≤ 5
H2	≤ 50	≤ 60	≤ 70	≤ 10
H3	≤ 60	≤ 70	≤ 80	≤ 10
HXb	—	—	—	—

:1. , طمي ك ۆ
,

2. غ ↄ غ , ח , طمي
ك

3.1.3

١ ك
3 2 طمي ˇ
, 4

ك 60 %, H2
, 70 %, ج 50
%, H2 ; 70 %,
40 , H2

3

		9	10	11	12	ج
	ج	37.4	33.5	28.4	25.0	31.1
		39.9	40.2	33.3	31.4	40.2
		35.4	25.7	20.5	16.9	16.9
	ج	49.6	40.4	49.5	44.1	45.9
		53.7	62.9	65.8	63.3	61.4
		45.8	24.2	33.3	35.1	24.2
	ج	39.3	38.5	31.0	29.1	34.5
		41.4	45.7	38.7	39.4	45.7
		36.9	31.3	21.3	17.5	17.5
	ج	45.9	32.2	43.7	36.6	39.6
		50.5	60.9	68.9	60.4	68.9
		42.9	17.1	24.3	25.4	17.1
	ج	39.0	37.5	31.5	30.9	34.7
		40.9	42.1	37.3	37.6	42.1
		37.4	31.7	22.8	18.7	18.7
ك	ج	46.0	32.9	41.8	33.0	38.4
		49.0	55.2	59.9	56.4	59.9
		42.9	19.7	26.3	21.8	19.7

4

		ك
H2	H2	H2

GB / T 33630—2017

≤ 50

≤ 65 % [2] 3

50

65 %,

3. 2

3. 2. 1

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3. 3. 3

8 11

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C1 , C5

8

	(μm/a)
C1	0. 26
C5	112. 29

11

GB/T 33630—2017

,

≤C3 [2] C1 ,

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(24)

[6] . [J]. , 2011(24) :300+307

[7] , , . [J]. ,2023(S1) :174-177

[8] , , . [J]. ,2023,15(4) :91-98

[9] , . [J]. , 2013,42(4) :7-10

[10] . [J]. ,2013(1) :112-115

[11] , . [J]. ,2014,28(S1) :336-338

[12] , , . [J]. ,2014(4) :17-20

[13] , , , . [J]. ,2015(1) :46-48

[14] , , . [J]. ,2021(7) :179-181

[15] , , . [J]. ,2019(1) :42-48

[16] . , , . [J]. ,2024(10) :1-4

[17] , , , . [J]. ,2024(6) :7-14

[18] , , , . [J]. ,2023,48(6) :197-202

[19] . [D]. ,2018

[20] , , . [J]. ,2024,44(7) :1-24

H2,

C1 , GB/T 33630—2017

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S2 ,

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♥ ,

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[1] . NB/T 10927—2022 [S]

[2] , GB/T 33630—2017 [S]

[3] , GB/T 19292. 4—2018 4 : [S]

[4] , GB/T 30790. 2—2014 2 : [S]

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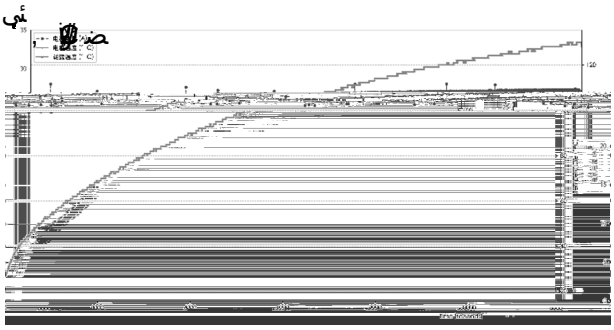
:2024-06-24

: (1992—) , ,2015 , , ؤ غ ˇ ל ה

(r/min)



2 65 N m 1 000 r/min

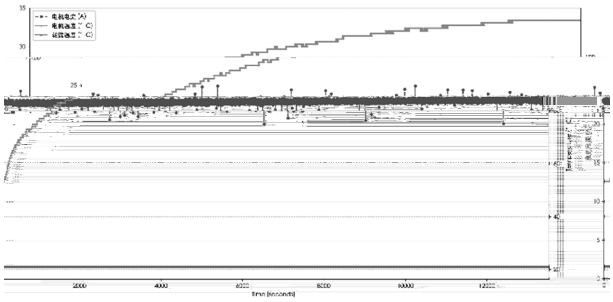
4.2 2

ל ,

ﺃ , 1 , ל 1 000 r/min

ל , ל 60 N·m, ﻁﻣ 21 ,

4.3 ~ , , ╕ ﻫ 3



3 60 N m 1 000 r/min

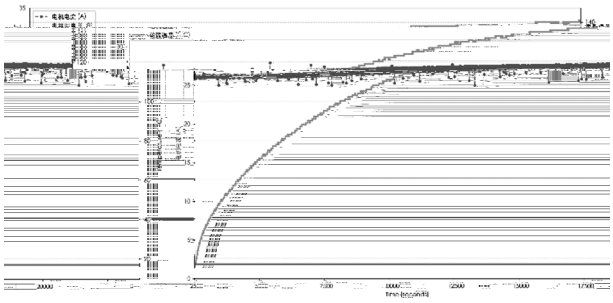
4.3 3

ל , ל

ﺃ , 1 , ל 65 N·m

ל , 873 r/min, ﻁﻣ 17 ,

6 ~ , ל , ╕ ﻫ 4



4 65 N m 873 r/min

4.4

ל , ╕ ,

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ל , , 4.3 ~ ,

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;SCADA;

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:TK81

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:1001-9006(2025)03-0076-08

WANG Qingzhao YANG Heli ZHANG Hui

Dongfang Electric Wind Power Co. Ltd. 618000 Deyang Sichuan China

:2024-06-04

: (1986—), ,2023 ,

[2]

(1)

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(1)

(2)

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~ [16-17]

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[18] , SCADA

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[19] SCADA

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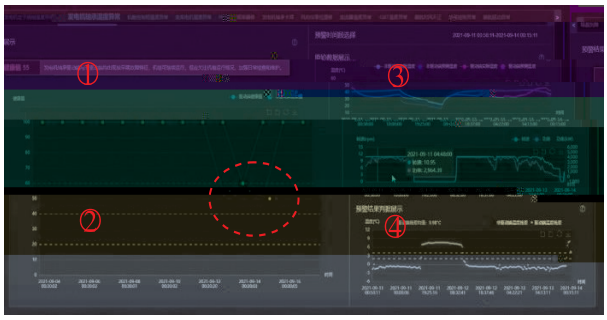
,SCADA ɲ — ɛ - ɠ



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3. 3

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ھ 8 ' ۶ , ھ 8

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[13] , , , . MapReduce [J]. ,2020,48(3):22-29

[14] , , , . [J]. ,2019,56(16):61-66

[15] , , , . [J]. ( ),2020,34(4):52-56+114

[16] LIU Yuhan, ZHENG Yuqiao, MA Zhuang, et al. Wind Turbine Spindle Operating State Recognition and Early Warning Driven by SCADA Data[J]. Energy Engineering,2023,120(5):1223-1237

[17] PENG Jieyang, KIMMIG Andreas, NIU Zhibin, et al. Wind turbine failure prediction and health assessment based on adaptive maximum mean discrepancy[J]. International Journal of Electrical Power and Energy Systems,2022,134:107391

[18] , , , . [J]. ,2023,23(9):3577-3587

[19] , . [J]. ,2020(1):65-67

[20] . [J]. ,2022(5):48-51

[10] , . [J]. ,

DONGFANG REVIEW

基于

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:TM614 :A :1001-9006(2025)03-0084-05

XIAO Wenjing LIU Zhengyu WANG Duoping HONG Chengqi WANG Zhengjie

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:2025-03-20

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; ˝ :2023YFB4102900

: (1987—), , , , ~ ה ɔ

( )

(SCADA)

[1]

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(X)

$$\tilde{C}_t = \tanh(W_c \cdot [h_{t-1}, x_t] + b_c) \quad (3)$$

(4) :

$$C_t = f_t \quad C_{t-1} + i_t \quad \tilde{C}_t \quad (4)$$

(5) :

$$o_t = \sigma(W_o \cdot [h_{t-1}, x_t] + b_o) \quad (5)$$

(6) :

$$h_t = o_t \quad \tanh(C_t) \quad (6)$$

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h_T LSTM ڑ

LSTM ڑ ,

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ڑ ~ h_T ۱

C_T

$$\hat{x}_t = \text{softmax}(W_{out} h'_t + b_{out}) \quad (7)$$

, W_{out} ; b_{out}

~ ; softmax

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ڃ (MSE) :

$$saL = \frac{1}{T} \sum_{i=1}^{T} \| x_t - \hat{x}_t \|^2 \quad (8)$$

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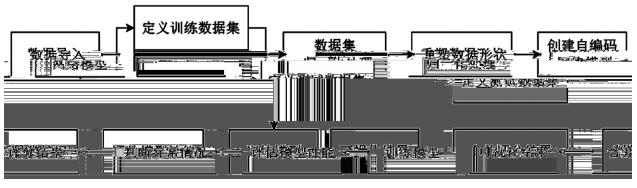

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2 560 Hz, 128 kB

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Butterworth ڑ ,

0. 1 Hz, 10 ھ 3 ب #5

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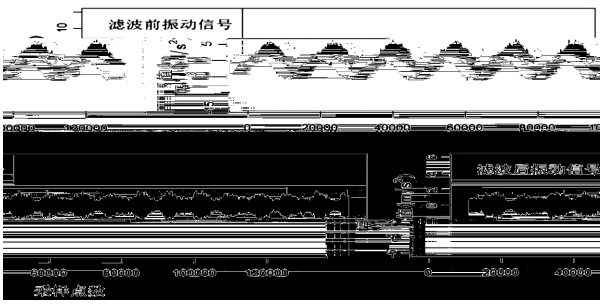

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ب 16 ‘ , 2023 6

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2023 9 2024 1 , #4 #5

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#11 #13 ئۆ , '

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ھ 4 #4 ~ 3 ╥ X/Z

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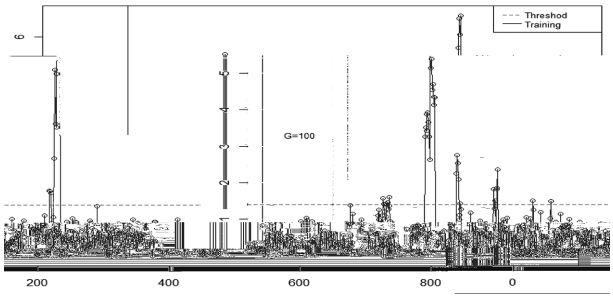
#4	~ 3	2023-11-02,2023-11-14
#5	~ 1	2023-11-02
#8	~ 3	2023-09-28,2023-09-29
#14	~ 1	2023-12-23
#14	~ 3	2023-12-25



4 #4 3 X/Z

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X_t T^2 ，

T^2 ~ ~

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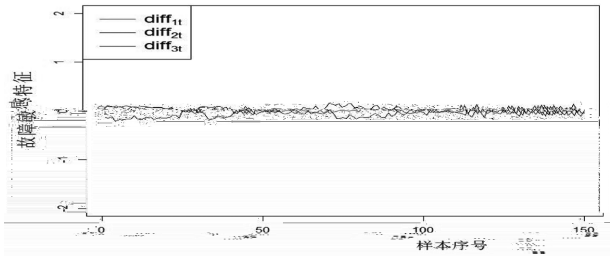

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