

DOI 10.3901/JME.2010.11.014

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### Research on Decoupling Performance of Major-motion Mechanism for Forging Manipulators

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**Abstract** Heavy-duty forging manipulators play an important role in the extreme manufacturing. Decoupling performance of major-motion mechanism for three commonly used forging manipulators is studied to simplify the control of manipulators. The kinematics of the forging manipulators are analyzed, and the input-output relationship matrix in terms of velocity shows that all the three types of forging manipulators are coupled according to the definition of conventional output parameters. A new decoupling concept is established, which redefines the output based on the realistic working condition. The input-output relationships are considered independently for each main motion, and the process is simulated in Matlab to validate the results. The major-motion mechanism of one forging manipulator is decoupled, while the other two are partially decoupled. From the viewpoint of decoupling of the main-motion mechanism of forging manipulators, the proposed method is intuitive, which provides a new idea for the decoupling of parallel mechanisms.

**Key words** Forging manipulator Major-motion Decoupling Parallel mechanism

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[8]

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[10]

[1] 20 60  
[2-3] 70 80

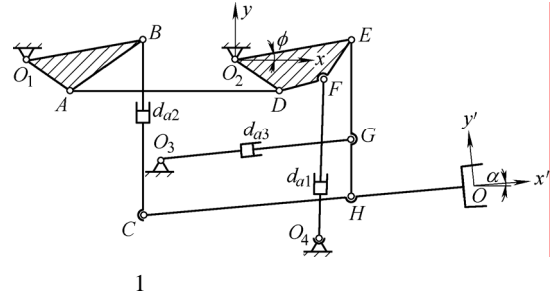
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[11]

$$d_{a1} \quad d_{a2} \quad d_{a3} \quad O_2$$

$$(x, y, \alpha) \quad d_{a1} \quad d_{10}$$

$$\angle EO_2F = 0$$



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3  
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Matlab

$$l_{EH}^2 = (x - l_{OH} \cos \alpha - l_{O_2E} \cos \phi)^2 + (y - l_{OH} \sin \alpha - l_{O_2E} \sin \phi)^2 \quad (1)$$

$l_{ij} \quad i \quad j \quad ( ) \quad \phi$

1 3  
 $O_4F \quad BC \quad O_3G$

$$\begin{cases} d_{a1} = \sqrt{[l_{O_2F}(1 - \cos \phi)]^2 + (l_{O_2F} \sin \phi + d_{10})^2} \\ d_{a2} = \sqrt{[x - l_{OC} \cos \alpha - (l_{O_2E} \cos \phi - l_{CH})]^2 + (y - l_{OC} \sin \alpha - l_{O_2E} \sin \phi)^2} \\ d_{a3} = \sqrt{\left[\frac{l_{GH}l_{O_2E}}{l_{EH}} \cos \phi + \frac{l_{EG}}{l_{EH}}(x - l_{OH} \cos \alpha) - (l_{O_2E} - l_{CH})\right]^2 + \left[\frac{l_{GH}l_{O_2E}}{l_{EH}} \sin \phi + \frac{l_{EG}}{l_{EH}}(y - l_{OH} \sin \alpha) + l_{EG}\right]^2} \end{cases} \quad (2)$$

$$\phi = \arctan\left(R \pm \sqrt{R^2 - (P^2 - Q^2)} / P + Q\right) \quad (3)$$

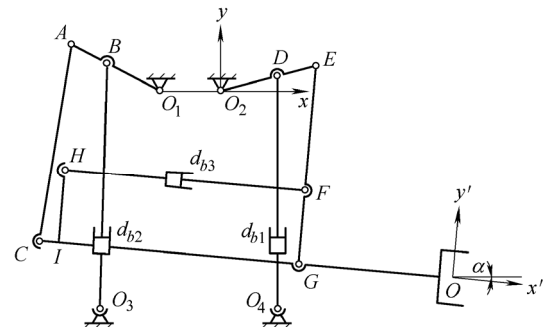
$$\begin{cases} P = (x - l_{OH} \cos \alpha)^2 + (y - l_{OH} \sin \alpha)^2 + l_{O_2E}^2 - l_{EH}^2 \\ Q = 2l_{O_2E}(x - l_{OH} \cos \alpha) \\ R = 2l_{O_2E}(y - l_{OH} \sin \alpha) \end{cases}$$

2 3  
 $O_4D \quad O_3B \quad HF$   
 $d_{b1} \quad d_{b2} \quad d_{b3} \quad O_2$   
 $(x, y, \alpha)$

(4)

$$\begin{pmatrix} \dot{d}_{a1} \\ \dot{d}_{a2} \\ \dot{d}_{a3} \end{pmatrix} = \begin{pmatrix} f_{11} & f_{12} & f_{13} \\ f_{21} & f_{22} & f_{23} \\ f_{31} & f_{32} & f_{33} \end{pmatrix} \begin{pmatrix} \dot{x} \\ \dot{y} \\ \dot{\alpha} \end{pmatrix} \quad (5)$$

$f_{ij} (i, j = 1, 2, 3) \quad x \quad y \quad \alpha$



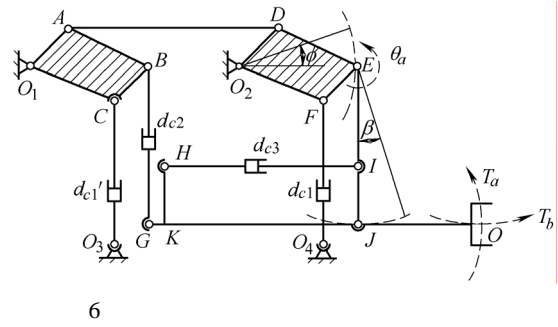
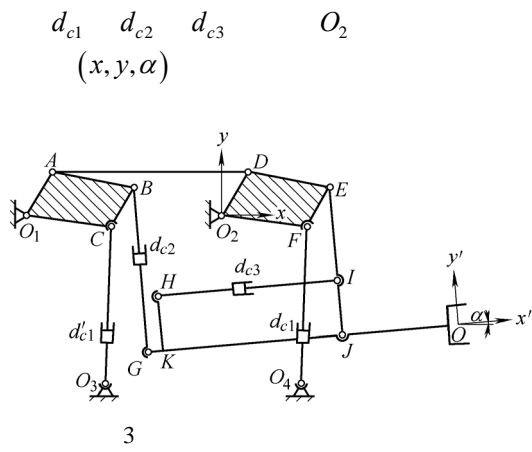
(5)

$$f_{ij} \equiv 0 \quad (6)$$

$i, j = 1, 2, 3 \quad i \neq j$

(2) (6)

2 4  
3  
 $O_4F \quad O_3C$   
 $O_4F \quad BG \quad HI$



2

2.1

(1)  $T_a$

$T_a = S\phi$  (7)

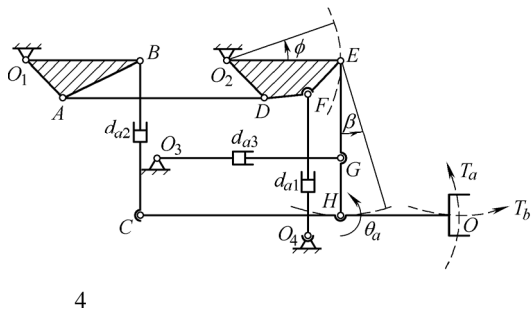
(2)  $T_b$

(3)  $T_a$

$T_b = l_S\beta$  (8)

(3)  $R_\alpha$

$T_b$   $\theta_\alpha$  4 6  $T_a$



$\theta_\alpha = \alpha$  (9)

$\alpha$  (7) (9)

$(d_1, d_2, d_3)$   $T_a$

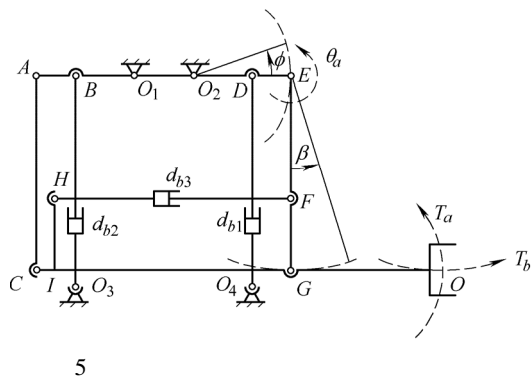
$T_b$   $\theta_\alpha$

2.2

4 1

(1)

$$\begin{cases} d_{a1} = \sqrt{[S(1 - \cos\phi)]^2 + (S \sin\phi + d_{10})^2} \\ d_{a2} = l_{EH} \\ d_{a3} = \sqrt{[l_{CH} - S(1 - \cos\phi)]^2 + (S \sin\phi)^2} \end{cases} \quad (10)$$



$$d_{a1} = F_{11}(\phi) \quad d_{a3} = F_{31}(\phi) \quad \dot{T}_a = S\dot{\phi}$$

$$\begin{cases} \dot{d}_{a1} = F'_{11}(\phi)\dot{\phi} = \frac{1}{S}F'_{11}\left(\frac{T_a}{S}\right)\dot{T}_a \\ \dot{d}_{a2} = 0 \\ \dot{d}_{a3} = F'_{31}(\phi)\dot{\phi} = \frac{1}{S}F'_{31}\left(\frac{T_a}{S}\right)\dot{T}_a \end{cases} \quad (11)$$

(2)

$$\begin{cases} d_{a1} = d_{10} \\ d_{a2} = l_S \\ d_{a3} = \left\{ l_{CH}^2 + 2l_{EG}^2 - 2l_{EG}\sqrt{l_{CH}^2 + l_{EG}^2} \times \right. \\ \left. \cos[\beta + \arctan(l_{CH}/l_{EG})] \right\}^{1/2} \end{cases} \quad (12)$$

$$d_{a3} = F_{32}(\beta) \quad \dot{T}_b = l_S\dot{\beta}$$

$$\begin{cases} \dot{d}_{a1} = \dot{d}_{a2} = 0 \\ \dot{d}_{a3} = F'_{32}(\beta)\dot{\beta} = \frac{1}{l_S}F'_{32}\left(\frac{T_b}{l_S}\right)\dot{T}_b \end{cases} \quad (13)$$

(3)

$$\begin{cases} d_{a1} = d_{10} \\ d_{a2} = \left\{ 2l_{CH}^2 + l_{EH}^2 - 2l_{CH}\sqrt{l_{CH}^2 + l_{EH}^2} \times \right. \\ \left. \cos[\alpha + \arctan(l_{EH}/l_{CH})] \right\}^{1/2} \\ d_{a3} = l_{CH} \end{cases} \quad (14)$$

$$d_{a2} = F_{23}(\alpha) \quad \dot{\theta}_\alpha = \dot{\alpha}$$

$$\begin{cases} \dot{d}_{a1} = \dot{d}_{a3} = 0 \\ \dot{d}_{a2} = F'_{23}(\alpha)\dot{\alpha} = F'_{23}(\theta_\alpha)\dot{\theta}_\alpha \end{cases} \quad (15)$$

$$\begin{pmatrix} \dot{d}_{a1} \\ \dot{d}_{a2} \\ \dot{d}_{a3} \end{pmatrix} = \begin{pmatrix} \frac{1}{S}F'_{11}\left(\frac{T_a}{S}\right) & 0 & 0 \\ 0 & 0 & F'_{23}(\theta_\alpha) \\ \frac{1}{S}F'_{31}\left(\frac{T_a}{S}\right) & \frac{1}{l_S}F'_{32}\left(\frac{T_b}{l_S}\right) & 0 \end{pmatrix} \begin{pmatrix} \dot{T}_a \\ \dot{T}_b \\ \dot{\theta}_\alpha \end{pmatrix} \quad (16)$$

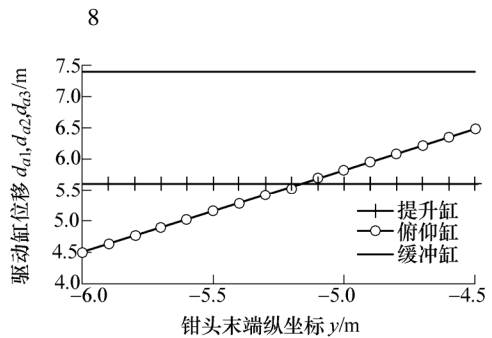
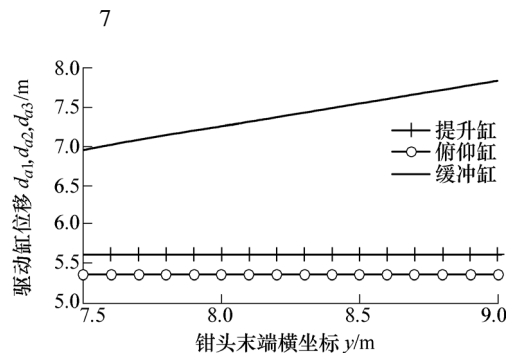
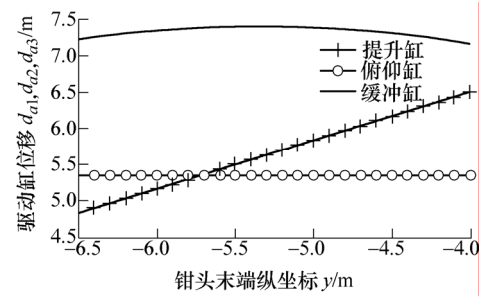
(16) 2 3

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( 1) 3

7 9

1		mm
$O_2E$	$l_{O_2E}$	2 700
$OH$	$l_{OH}$	5 550
$CH$	$l_{CH}$	7 400
$GH$	$l_{GH}$	2 250
$EG$	$l_{EG}$	3 100
$O_2F$	$l_{O_2F}$	1 800
$d_{a1}$	$d_{10}$	5 600



2.3

5

2

(1)

$$\begin{cases} d_{b1} = \sqrt{[S(1 - \cos\phi)]^2 + (S \sin\phi + d_{10})^2} \\ d_{b2} = \sqrt{(d_{20}^2 + l_{O_1A} \sin\phi_2)^2 + [l_{O_1A}(1 + \cos\phi_2)]^2} \\ d_{b3} = l_{CG} \end{cases} \quad (17)$$

$d_{20}$

$\phi_2$

$$d_{b1} = G_{11}(\phi) \quad \phi_2 \quad \phi \quad \dot{T}_a = S\dot{\phi}$$

$$d_{b2} = G_{21}(\phi)$$

$$\begin{cases} \dot{d}_{b1} = G'_{11}(\phi)\dot{\phi} = \frac{1}{S}G'_{11}\left(\frac{T_a}{S}\right)\dot{T}_a \\ \dot{d}_{b2} = G'_{21}(\phi)\dot{\phi} = \frac{1}{S}G'_{21}\left(\frac{T_a}{S}\right)\dot{T}_a \\ \dot{d}_{b3} = 0 \end{cases} \quad (18)$$

(2)

$$\begin{cases} d_{b1} = d_{b2} = d_{10} \\ d_{b3} = \sqrt{l_{CG}^2 + l_{EF}^2 - 2l_{CG}l_{EF} \sin \beta} \end{cases} \quad (19)$$

$$d_{b3} = G_{32}(\beta) \quad \dot{T}_b = l_S \dot{\beta}$$

$$\begin{cases} \dot{d}_{b1} = \dot{d}_{b2} = 0 \\ \dot{d}_{b3} = G'_{32}(\beta)\dot{\beta} = \frac{1}{l_S}G'_{32}\left(\frac{T_b}{l_S}\right)\dot{T}_b \end{cases} \quad (20)$$

(3)

$$\begin{cases} d_{b1} = d_{10} \\ d_{b2} = \sqrt{(d_{20}^2 + l_{O_1A} \sin \phi_2)^2 + [l_{O_1A} (1 + \cos \phi_2)]^2} \\ d_{b3} = l_2 \end{cases} \quad (21)$$

$$\phi_2 \quad \phi \quad d_{b2} = G_{23}(\phi) \quad \dot{\theta}_\alpha = \dot{\alpha}$$

$$\begin{cases} \dot{d}_{b1} = \dot{d}_{b3} = 0 \\ \dot{d}_{b2} = G'_{23}(\alpha)\dot{\alpha} = G'_{23}(\theta_\alpha)\dot{\theta}_\alpha \end{cases} \quad (22)$$

$$\begin{pmatrix} \dot{d}_{b1} \\ \dot{d}_{b2} \\ \dot{d}_{b3} \end{pmatrix} = \begin{pmatrix} \frac{1}{S}G'_{11}\left(\frac{T_a}{S}\right) & 0 & 0 \\ \frac{1}{S}G'_{21}\left(\frac{T_a}{S}\right) & 0 & G'_{23}(\theta_\alpha) \\ 0 & \frac{1}{l_S}G'_{32}\left(\frac{T_b}{l_S}\right) & 0 \end{pmatrix} \begin{pmatrix} \dot{T}_a \\ \dot{T}_b \\ \dot{\theta}_\alpha \end{pmatrix} \quad (23)$$

(23)

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2

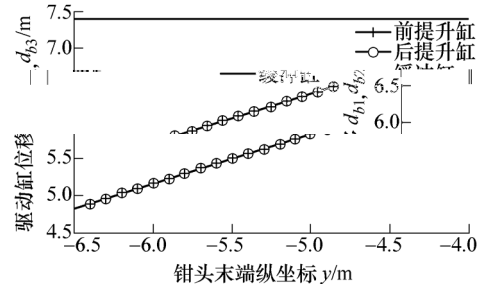
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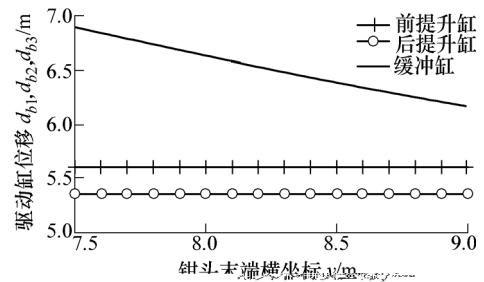
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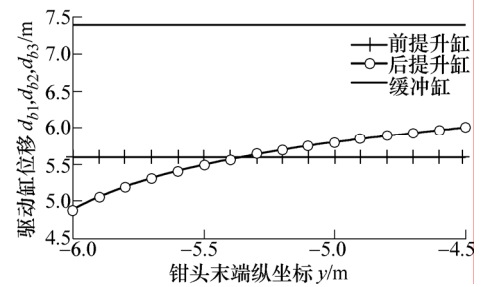
2		mm
$O_2E$	$l_{O_2E}$	2 700
$OG$	$l_{OG}$	5 550
$CG$	$l_{CG}$	7 400
$FG$	$l_{FG}$	2 250
$EF$	$l_{EF}$	3 100
$O_2D$	$l_{O_2D}$	1 800
$d_{b1}$	$d_{10}$	5 600



10



11



12

2.4

6

3

(1)

$$\begin{cases} d_{c1} = \sqrt{[S(1 - \cos \phi)]^2 + (S \sin \phi + d_{10})^2} \\ d_{c2} = l_{EJ} \\ d_{c3} = l_{GJ} \end{cases} \quad (24)$$

$$d_{c1} = H_{11}(\phi) \quad \dot{T}_a = S\dot{\phi}$$

$$\begin{cases} \dot{d}_{c1} = H'_{11}(\phi)\dot{\phi} = \frac{1}{S} H'_{11} \left( \frac{T_a}{S} \right) \dot{T}_a \\ \dot{d}_{c2} = \dot{d}_{c3} = 0 \end{cases} \quad (25)$$

(2)

$$\begin{cases} d_{c1} = d_{10} \\ d_{c2} = l_{EJ} \\ d_{c3} = \sqrt{(l_{GJ} - l_{EI} \sin \beta)^2 + (l_{EI} \cos \beta - l_{EI})^2} \end{cases} \quad (26)$$

$$\begin{aligned} d_{c3} &= H_{32}(\beta) & \dot{T}_b &= l_S \dot{\beta} \\ \begin{cases} \dot{d}_{c1} = \dot{d}_{c2} = 0 \\ \dot{d}_{c3} = H'_{32}(\beta) \dot{\beta} = \frac{1}{l_S} H'_{32} \left( \frac{T_b}{l_S} \right) \dot{T}_b \end{cases} & & & & & (27) \end{aligned}$$

(3)

$${}^1_{10} \sqrt{\sqrt{{}^2_2}^2 (0 \ )^2} \sqrt{{}^2_2}^2 (0 \ )^2$$

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- (1)
- (2)
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