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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 Decupling Parallel mechanism

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[2-3] 70 80

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Matlab

1

1 3

O_4F BC O_3G

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

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

$$\begin{cases} P=\left(x-l_{OH}\cos\alpha\right)^2+\left(y-l_{OH}\sin\alpha\right)^2+l_{O_2E}{}^2-l_{EH}{}^2 \\ Q=2l_{O_2E}\left(x-l_{OH}\cos\alpha\right) \\ R=2l_{O_2E}\left(y-l_{OH}\sin\alpha\right) \end{cases} \quad (4)$$

—

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

$f_{ij}\,(i,j=1,2,3)$ x y α

3

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

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

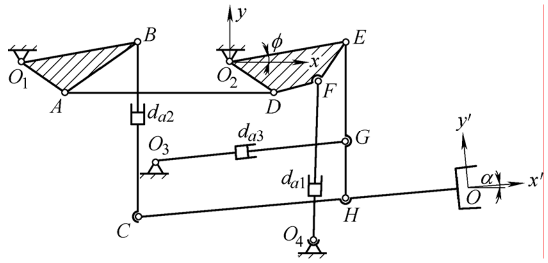
(2)

(6)

d_{a1} d_{a2} d_{a3} O_2

(x,y,α) d_{a1} d_{10}

$\angle EO_2F=0$



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

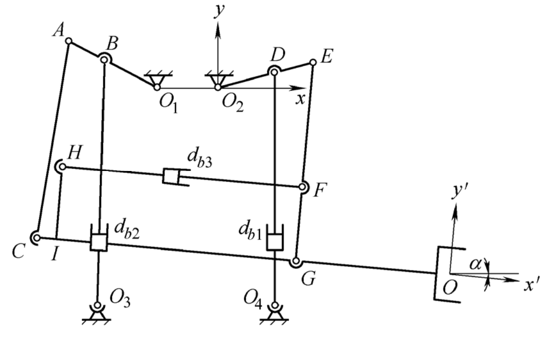
l_{ij} i j ( ) ϕ

2 3

O_4D O_3B HF

d_{b1} d_{b2} d_{b3} O_2

(x,y,α)



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3 4

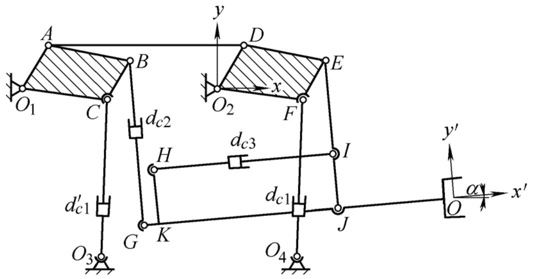
O_3C

O_4F 3

O_4F BG HI

d_{c1} d_{c2} d_{c3} O_2

(x, y, α)



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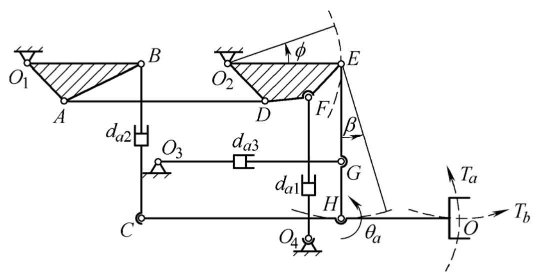
2.1

3

T_a

T_b θ_α 4 6



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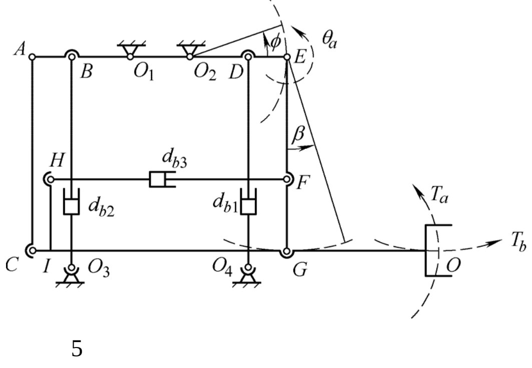

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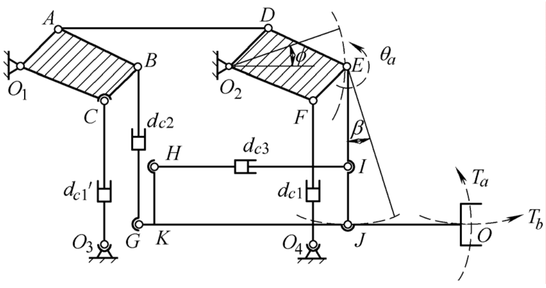

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(1) T_a

E

$$T_a = S\phi \tag{7}$$

S ϕ

(2) T_b

E

(4 H 5 G 6 J)

$$T_b = l_S \beta \tag{8}$$

β E

l_S

(3) R_α

$$\theta_\alpha = \alpha \tag{9}$$

α

(7) (9)

(d_1, d_2, d_3) T_a T_b θ_α

2.2

4

1

(1)

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

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

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

(2)

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

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

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

(3)

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

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

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

—

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

(16) 2 3

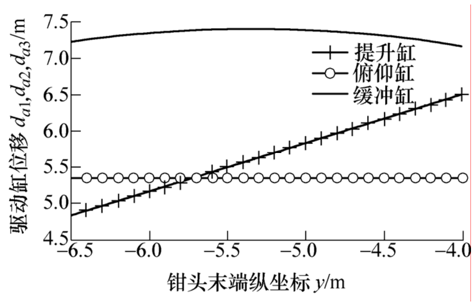
1

(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



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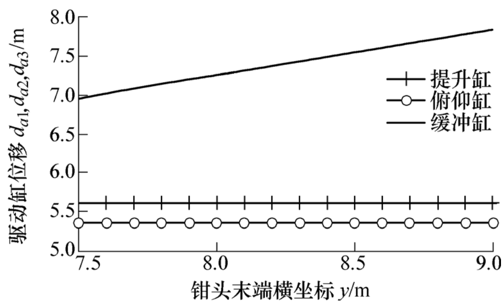

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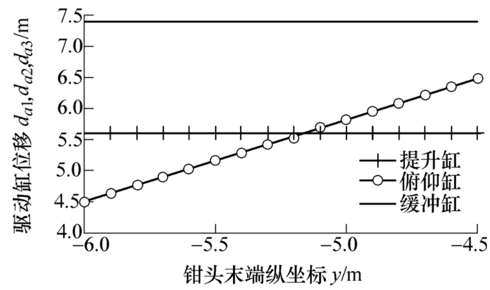

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2.3

5

2

(1)

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

d_{20} ϕ_2

ϕ_2 ϕ

$d_{b1}=G_{11}(\phi)$ $d_{b2}=G_{21}(\phi)$ $\dot{T}_a=S\dot{\phi}$

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

(2)

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

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

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

(3)

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

ϕ_2 ϕ $d_{b2}=G_{23}(\phi)$ $\dot{\theta}_\alpha=\dot{\alpha}$

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

—

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

(23) 2 3

1

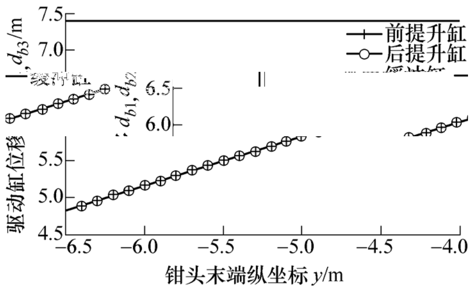
2

3

10 12

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



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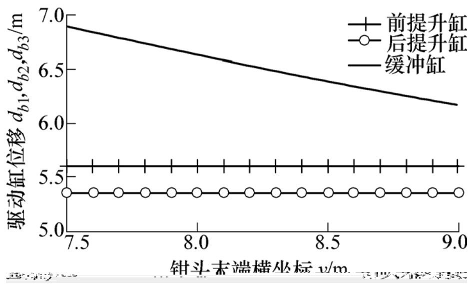

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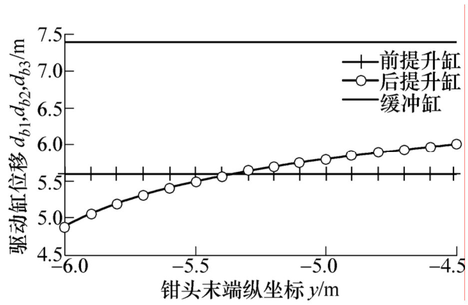

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2.4

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(1)

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

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

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

(2)

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

$d_{c3} = H_{32}(\beta)$ $\dot{T}_b = l_S \dot{\beta}$

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

(3)

1 10

2 $\sqrt{\quad \sqrt{\quad ^2 \quad ^2} \quad (\ _0 \quad)^2 \quad \sqrt{\quad ^2 \quad ^2} \quad (\ _0 \quad)^2}$

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(1)

(2)

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