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Shaking Moment Optimum Balancing of Planar Mechanisms

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Abstract. A new method of shaking moment balancing of force balanced linkages is presented in this paper. The shaking moment balancing is gained based on the angular momentum principle. The method of synthesizing a dyad to balance the shaking moments is given, two kinds of structure types are calculated, all the maximum absolute values of the shaking moments are decreased by more than 75 % and the f1uctuation values of those are reduced by more than 68 %.

Introduction

During machines run, all components produce inertia forces and moments. The forces and moments may cause noise, wear, vibration and make the input crank wind up. In 1971, Berkof and Lowen dealt with the shaking moment optimization [1]. In 1973，Berkof represented a complete force and moment balance of an inline four-bar linkage [2]. In 1982, Begci gave the method to completely balancing shaking force and moment of linkages using balance idler loop [3]. In 1985, Huang presented the method of synthesis of a dyad to balance inertia input torque [4]. In 1999, Esat and Bahai dealt with the complete force and moment balance of planar linkages mechanisms [5]. In 2001, Arakelian and Dahan dealt with the partial shaking moment balancing of fully balanced linkages [6]. In 2010, the method with active balancer based on planar linkages was presented [7].

As mention before, balance of shaking moment of planar linkages is usually accomplished by means of appropriately chosen counterweights or attached motive components. The method of choosing appropriate counterweights is usually used for four-bar linkages. The method of attaching motive components has been taken to balance shaking moment of four-bar and six-bar linkages. But it usually makes the mechanism become very complex.

In this paper, a new method of synthesizing a dyad is taken to balance shaking moment of six-bar linkages, and good results are obtained with minimum number of attached components.

Angular Momentum of Mechanisms

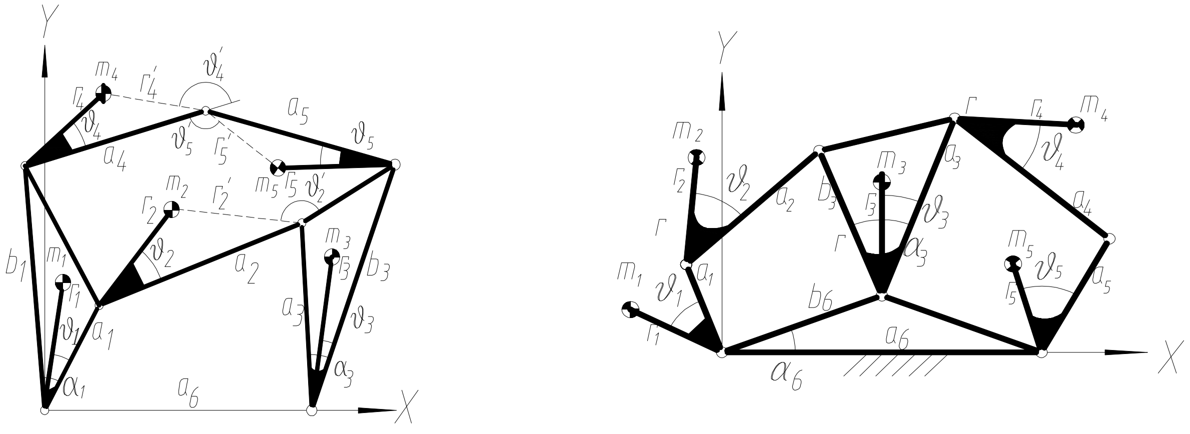
The shaking moment of a mechanism with one-DOF is equal to the derivative of the total angular momentum with respect to time, that is

$$M_s = -dH_o / dt \tag{1}$$

The angular momentum of the six-bar linkage is

$$H_o = \sum_{i=1}^{5} (m_i (x_i \dot{y}_i - y_i \dot{x}_i) + I_{si} \dot{\phi}_i) \tag{2}$$

Where M_s and H_o are shaking moment and angular momentum of a mechanism about origin point of the inertial reference system respectively. x_i and y_i are coordinates of the mass center of i th link with respect to the origin o. I_{si} is centered mass moment of inertia of the i th link. $\dot{\phi}_i$ is angular velocity of i th link.



(a) (b)

Fig. 1 Two original six-bar linkages

Six-bar linkages can be classified as Watt's and Stephenson's types. In both types of linkages a linkage is selected, respectively, Fig. 1. It is easy to get the condition of shaking force balance of the linkage in Fig.1(a) by means of the method of linearly independent mass vectors, that is

$$\begin{aligned} m_1 r_1 e^{j\theta_1} &= m_4 b_1 e^{j(\theta_4' - \alpha_1)}\, r_4'/a_4 + m_2 a_1 e^{j\theta_2'}\, r_2'/a_2 \\ m_3 r_3 e^{j\theta_3} &= m_5 b_3 e^{j\theta_5'}\, r_5'/a_5 + m_2 a_3 e^{j(\theta_2 + \alpha_2 + \pi)}\, r_2'/a_2 \\ m_5 r_5 e^{j\theta_5} &= m_4 a_5 e^{j(\theta_4 + \pi)}\, r_4/a_4 \end{aligned} \tag{3}$$

The dimensions and parameters given and determined by equation (3) are a listed in Table 1. Here, a11 are SI units. The symbols see Fig. 1.

Using the dimensions and parameters listed in Table 1 we calculated the angular momentums of the two linkages, during the input cranks rotate round 2π .

Table 1 Parameters of the six-bar linkages

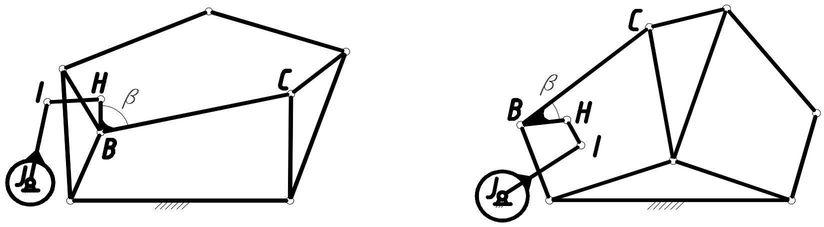
	a_1	a_2	a_3	a_4	a_5	a_6	r_1	r_2	r_3	r_4	r_5
1st	.02	.16	.09	.10	.15	.13	.062	.08	.09	.071	.074
2nd	.02	.16	.06	.06	.08	.19	.10	.06	.037	.069	.069
	θ_1	θ_2	θ_3	θ_4	θ_5	m_1	m_2	m_3	m_4	m_5	
1st	π	0	3.33	0.79	3.9	.001	.008	.0045	.005	.0075	
2nd	π	0	$3\pi/2$	$-\pi/6$	$-\pi/6$	.001	.008	.010	.003	.008	
	I_{s1}	I_{s2}	I_{s3}	I_{s4}	I_{s5}	b		α			
1st	.018	.14	.12	.08	.135	$b_1 = .03$	$b_3 = .12$	$\alpha_1 = .79$	$\alpha_3 = .19$		
2nd	.018	.14	.16	.07	.07	$b_3 = .09$	$b_6 = .12$	$\alpha_3 = \pi/2$	$\alpha_6 = \pi/12$		

Method of Shaking Moment Balance

From equation (1) we know that the shaking moment equals or approximates zero if the angular momentum equals or approximates a constant. So we may attach a rotating roll to the mechanism, the fluctuation of the angular momentum of which can offset the fluctuation of that of the original mechanism, that is

$$H_o + H_r = C_o \tag{4}$$

where H_o is the angular momentum of the original mechanism, H_r is the angular momentum of the attached component, C_0 is an appropriately selected constant.



(a) (b)

Fig.2 Mechanisms attached with dyads

A added dyad HIJ with a roll IJ which is housed to the ground in a revolute pair may be used to balance the shaking moment, Fig.2. Point H is connected to the coupler.

If the mass centre of link IJ is at the point J, the angular momentum of IJ is

$$H_r = I_r \dot{\phi}_r \tag{5}$$

where H_r is the required angular momentum of link IJ, I_r is the centered mass moment of inertia of IJ, $\dot{\phi}_r$ is the angular velocity of IJ.

When the link HI is short enough and its mass is much smaller than that of IJ, the error existing as neglecting the angular momentum of HI is very small. When a dyad synthesized appropriately is attached to a six-bar linkage, the total angular momentum of the linkage can approximate invariable, so that the shaking moment of the linkage can approximate zero. H_o in equation (4) may be written as

$$H_o = I_o \dot{\phi}_1 \tag{6}$$

Where $\dot{\phi}_1$ is angular velocity of input crank I_0 is equivalent mass moment of inertia obtained from the total original mechanism. From equation (2), H_o is a position function of mechanism with constant input angular velocity $\dot{\phi}_1$ so Io is a position function of the mechanism as well. The dyad HIJ does not affect the balance of shaking force, as the centre of mass of IJ is fixed. Substituting equations (5) and (6) into (4) yield

$$\dot{\phi}_r I_r = C_o - I_o \dot{\phi}_1 \quad (7)$$

Equation (7) may be rewritten as

$$\dot{\phi}_r / \dot{\phi}_1 = (C - I_o)/I_r \quad (8)$$

The influence coefficient G_r is

$$G_r = \dot{\phi}_r / \dot{\phi}_1 = (C - I_o)/I_r \quad (9)$$

From equation (9)

$$\phi_r = \int_0^{\phi_1} \frac{C - I_o}{I_r} d\phi_1 \quad (10)$$

I_r can not be chosen free after the constant C is selected, if we want the input crank rotates 2π while the roll rotates 2π also, thus

$$I_r = \frac{1}{2\pi} \int_0^{2\pi} (C - I_o) d\phi_1 \quad (11)$$

Hence, the problem of shaking moment balance has been transformed into a problem of mechanism synthesis. To mechanism attaches a roll, which rotates around a fixed shaft and is driven by the original mechanism. The motion of the roll should satisfy equation (9). From equation (9)

$$G_{r\max} = (C - I_{o\min})/I_r \quad (12)$$

$$G_{r\min} = (C - I_{o\max})/I_r \quad (13)$$

Solving the system of simultaneous equations, yields

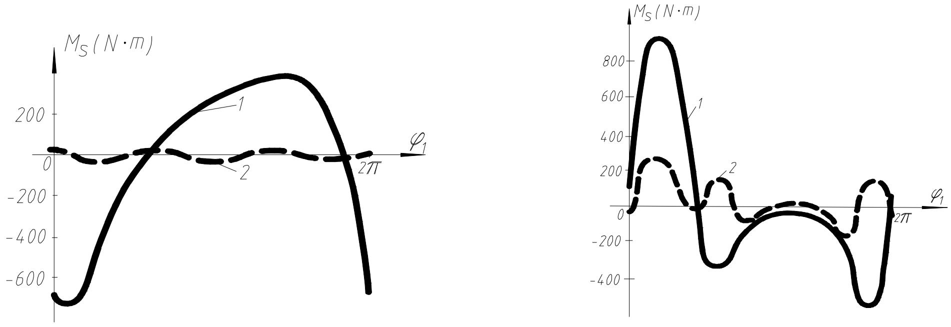
$$C = (G_{r\max} I_{o\max} - G_{r\min} I_{o\min})/(G_{r\max} - G_{r\min}) \quad (14)$$

Constant C can be calculated by equation (14) after selecting appropriate $G_{r\max}$ and $G_{r\min}$.

Two Examples

Shaking moment balances of the six-bar linkages in Fig.1 are taken for examples. The curve 1 and curve 2 are shaking moments of the two linkages before and after balancing respectively, Fig. 3. In table 2, M_{smb} and M_{sma} are maximum absolute values of M_s before and after balancing respectively. $\Delta M = (M_{sma} - M_{smb})/M_{smb}$. $\Delta F = (M_{afa} - M_{afb})/M_{sfb}$. M_{sfb} and M_{sfa} are fluctuation values of M_s before and after balancing respectively. The fluctuation value of shaking moment is the difference of the maximum value and the minimum value. The others are parameters of the dyad HIJ. All are SI units. Type of the dyad HIJ is +1 or -1 depending on the order HIJ to be counterclockwise or clockwise respectively. β is the angle HBC.

The results show that the maximum absolute values of shaking moment are decreased by more than 75％ and the fluctuation values of which are reduced by more than 68％.



(a) (b)

Fig. 3 The shaking moment curves before and after balancing

Table 2 Shaking moments of mechanisms and parameters of dyads

	M_{smb}	M_{sma}	$\Delta M\%$	M_{sfb}	M_{sfa}	$\Delta F\%$	BH	HI	IJ	β	x_j	y_j	I_r	*type*
1st	74.54	3.46	-95.4	115.2	6.3	-94.5	.0028	.0231	.0135	0.28	.0086	-0.0001	2.43	+1
2nd	93.43	22.35	-76.1	151.7	48.5	-64.3	.0063	.0026	.0198	-1.4	.0037	-0.0016	4.31	-1

Conclusion

The method synthesizing a two-link dyad to compensate the fluctuation of angular momentum of the original mechanism and make it approach all invariable is feasible for shaking moment balance. A good result has already achieved，a large percentage has been cut down. From the analysis we know that even more complex mechanisms can also be balance using this method.

The balance method of synthesis a dyad has some advantages such as，it is good in effect of balance and simple in construction of the balance attachment. No matter how complex the original mechanism may be，the only necessary is two-link dyad to attach with. The more complex the original mechanism，the more evident the advantage is.

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