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The Equivalent Variation and Optimization Design of the Operating Mechanism of the Harvester

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Abstract. In this paper, an equivalent mechanism is obtained by means of optimal design to overcome the drawbacks of an existing brake pedal operating mechanism in a harvester. After establishing the mathematical model, we obtain the optimal design model, including the objective and constraint functions. Consequently the local optimal solutions are worked out, resulting in a solution for the applied engineering problem.

Introduction

The brake pedal operating mechanism is an important part of the operating mechanisms of the harvester, which is used to brake or slow down the harvester and to control walking speed of the harvester [1]. So, the brake pedal operating mechanism plays a decisive role in the whole machine's braking performance. This paper adopted the method of equivalent and variation, by synthetically analyzing the mechanism, take the existed mechanism on as the object of the research, and redesigned it to gain a new mechanism that is different from the previous on its structure, but equivalent on its functions. And the new mechanism can satisfy the basic design requirements.

The original operating mechanism mainly consists of two planar mechanisms. As shown in Fig.1, when stamping down on the brake pedal, as long as the pin reaches to the lower endpoints of the two slot boards, the handle should be forced to its neutral position, and the whole mechanism is in the state of locking. As shown in Fig.2, releasing the brake pedal, the handle is able to rotate forward until one slot board's lower endpoint is blocked by the pin, or rotate backward until the other slot board's lower endpoint is blocked by the pin.

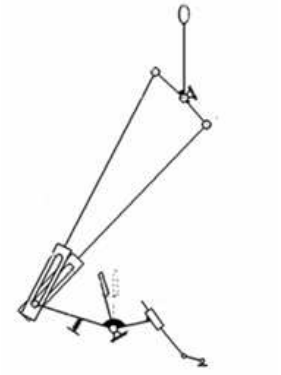

Fig. 1

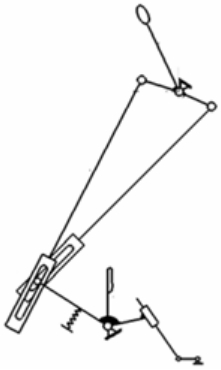

Fig. 2

The Innovative Operating Mechanism

The Configuration of the Operating Mechanism. As shown in Fig.3. The innovative operating mechanism can be classified to a planar six-bar mechanism, which consists of the brake pedal, the spring device, link L1, link L2, the handle, link L3, and link L4, where link L1 and L3 act as baffle-type links to reduce the DOF (degree of freedom) of the mechanism in certain positions.

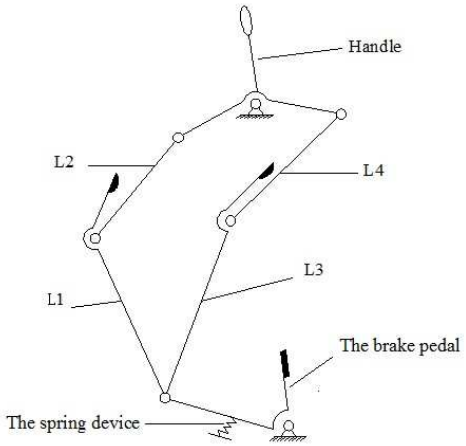

Fig. 3

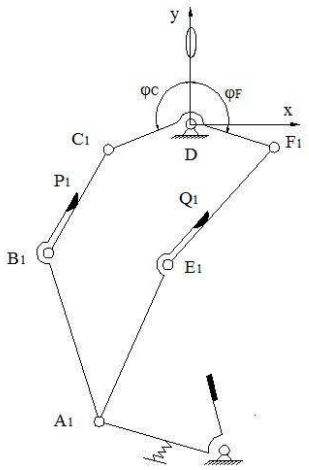

Fig. 4

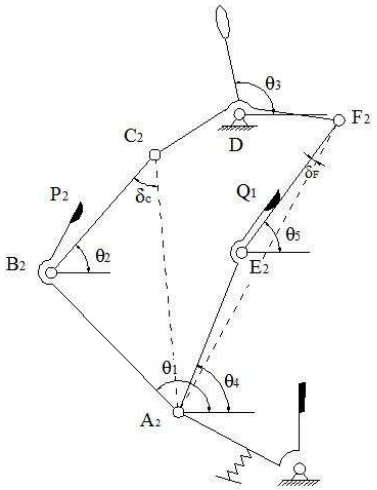

Fig. 5

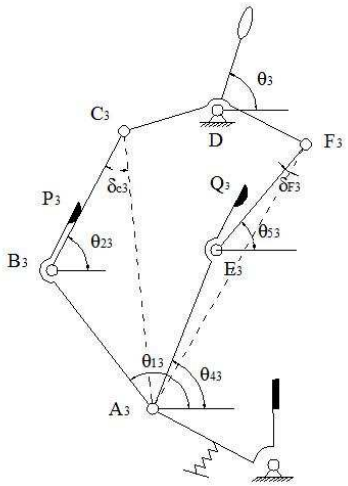

Fig. 6

The Functions of the Operating Mechanism. When stamping down on the brake pedal, L2 and L4 should be blocked by the corresponding baffles L1 and L3 respectively. At this moment, the degree of freedom of the mechanism should be zero, resulting in a rigid frame such that regardless of any position the operating handle is, the handle should be forced to its neutral position, the tilt angle of the oil pump swash plate is 0, without power output, the whole mechanism is in the state of locking. Releasing the brake pedal, the handle's freedom will recover by means of the spring device. As a result, the handle is able to rotate forward until link L4 is blocked by link L3, or rotate backward until link L2 is blocked by link L1. Apparently, it is the optimal design that can synthesize the operating mechanism to realize the preceding functions.

The Establishment of the Mathematical Model

The Selection of Design Variables. In mechanism optimal design, parameters consist of given and unknown ones that need to be optimized and the multiple design variables must be independent with each other. The more design variables there are, the more complex of the optimal design will be [2]. For a problem of parameters in optimal design, in order to simplify the problem, the number of design variables should as little as possible. So those independent parameters which have more significant impact on the objective function should be selected as the design variables in optimization. In this case, we selected six lengths as the design variables, that is l_{AB}, l_{BC}, l_{CD}, l_{AE}, l_{EF} and l_{DF}. They can be expressed as an array:

$$x=(x_1 \quad x_2 \quad x_3 \quad x_4 \quad x_5 \quad x_6)^T \tag{1}$$

The Establishment of the Objective Function. As an important criterion in the evaluation of optimal design of engineering, the objective function can be established from different perspectives, which are based on the considerations of mechanical kinematics(position or track deviation, etc.),dynamics(forces, vibration characteristics, etc.), mass, volume, efficiency, load capacity, cost, and life cycles, etc. In this specific design, we take the length of the links into consideration, leading to the objective function as follows:

$$\min f(x) = x(1) + x(2) + x(3) + x(4) + x(5) + x(6) \tag{2}$$

Therefore, our optimal design aims at minimizing the size, or the mass of the operating mechanism.

The Selection of Constraints. After analyzing three special positions of the mechanism by means of analytic method, we obtain the corresponding constraint conditions in order to avoid collisions between the links of the mechanism.

As is shown in figure 4, suppose the mechanism is in position 1, i.e. when stamping down on the brake pedal, link L2 and L4 are blocked by the corresponding baffles L1 and L3 respectively. Consequently, the degree of freedom of the whole mechanism is 0.The links should satisfy the following conditions:

The angle between link L1 and L2, in above-mentioned position 1 should equal to the angle of the baffle, saying 150. So is the angle between L3 and L4, the equality constraints h1(x) and h2(x) as follows.

$$\overrightarrow{C_1} = \overrightarrow{D} + l_{CD}\begin{pmatrix}\cos(\pi/2+\varphi_C)\\ \sin(\pi/2+\varphi_C)\end{pmatrix} \tag{3}$$

$$|\overrightarrow{A_1C_1}|^2 = (\overrightarrow{C_1} - \overrightarrow{A_1})^T(\overrightarrow{C_1} - \overrightarrow{A_1}) \tag{4}$$

$$h_1(x): \frac{l^2_{AB} + l^2_{BC} - |\overrightarrow{A_1C_1}|^2}{2l_{AB}l_{AC}} - \cos 150^\circ = 0 \tag{5}$$

$$\overrightarrow{F_1} = \overrightarrow{D} + l_{DF}\begin{pmatrix}\cos(5\pi/2-\varphi_F)\\ \sin(5\pi/2-\varphi_F)\end{pmatrix} \tag{6}$$

$$|\overrightarrow{A_1F_1}|^2 = (\overrightarrow{F_1} - \overrightarrow{A_1})^T(\overrightarrow{F_1} - \overrightarrow{A_1}) \tag{7}$$

$$h_2(x): \frac{l^2_{AE} + l^2_{EF} - |\overrightarrow{A_1F_1}|^2}{2l_{AE}l_{EF}} - \cos 150^\circ = 0 \tag{8}$$

According to figure 5, position 2, involves the configuration where link L4 is blocked by the baffle of link L3 when the handle rotates forward to the maximum angle, resulting in the inequality constraint g1(x) as follows.

$$g_1(x): \pi/6 - \theta_1 + \theta_2 \le 0 \tag{9}$$

$$\overrightarrow{C_2} = \overrightarrow{D} + l_{CD}\begin{pmatrix}\cos(\theta_3+\varphi_C)\\ \sin(\theta_3+\varphi_C)\end{pmatrix} \tag{10}$$

$$\delta_C = \arccos\frac{(\overrightarrow{C_2} - \overrightarrow{A_2})^T(\overrightarrow{C_2} - \overrightarrow{A_2}) + l^2_{BC} - l^2_{AB}}{2l_{BC}\sqrt{(\overrightarrow{C_2} - \overrightarrow{A_2})^T(\overrightarrow{C_2} - \overrightarrow{A_2})}} \tag{11}$$

$$\theta_2 = arc\tan(\frac{y_{C2} - y_{A2}}{x_{C2} - x_{A2}}) - \delta_C \tag{12}$$

$$\overrightarrow{B_2} = \overrightarrow{C} + l_{BC}\begin{pmatrix}\cos(\theta_2+\pi)\\ \sin(\theta_2+\pi)\end{pmatrix} \tag{13}$$

$$\theta_1 = arc\tan(\frac{y_{B2} - y_{A2}}{x_{B2} - x_{A2}}) \tag{14}$$

Similarly, in case of the inequality constraint g2(x), we have

$$g_2(x): \theta_5 - \theta_4 + \pi/6 \le 0 \tag{15}$$

$$\overrightarrow{F_2} = \overrightarrow{D} + l_{DF}\begin{pmatrix}\cos(\theta_3-\varphi_F+2\pi)\\ \sin(\theta_3-\varphi_F+2\pi)\end{pmatrix} \tag{16}$$

$$\delta_F = \arccos\frac{(\overrightarrow{A_2} - \overrightarrow{F_2})^T(\overrightarrow{A_2} - \overrightarrow{F_2}) + l^2_{EF} - l^2_{AE}}{2l_{EF}\sqrt{(\overrightarrow{A_2} - \overrightarrow{F_2})^T(\overrightarrow{A_2} - \overrightarrow{F_2})}} \tag{17}$$

$$\theta_5 = arc\tan(\frac{y_{A2} - y_{F2}}{x_{A2} - x_{F2}}) - \delta_F \tag{18}$$

$$\overrightarrow{E_2} = \overrightarrow{F_2} + l_{EF}\begin{pmatrix}\cos(\theta_5+\pi)\\ \sin(\theta_5+\pi)\end{pmatrix} \tag{19}$$

$$\theta_4 = arc\tan(\frac{y_{E2}-y_{A2}}{x_{E2}-x_{A2}}) \tag{20}$$

Since the interference between Link L1 and L3 may occur, the inequality constraint g3(x) should be included.

$$g_3(x): \theta_4 - \theta_1 + \pi/4 \le 0 \tag{21}$$

With figure 6, the mechanism's position 3 can be defined as the configuration where link L2 is blocked by the baffle of link L1 when the handle rotates backward to the maximum angle. The corresponding inequality constraint g4(x) yields

$$g_4(x): \theta_{23} - \theta_{13} + \pi/6 \le 0 \tag{22}$$

$$\overrightarrow{C_3} = \overrightarrow{D} + l_{CD}\begin{pmatrix}\cos(\theta_3+\varphi_C)\\ \sin(\theta_3+\varphi_C)\end{pmatrix} \tag{23}$$

$$\delta_{C3} = \arccos\frac{(\overrightarrow{C_3}-\overrightarrow{A_3})^T(\overrightarrow{C_3}-\overrightarrow{A_3}) + l_{BC}^2 - l_{AB}^2}{2l_{BC}\sqrt{(\overrightarrow{C_3}-\overrightarrow{A_3})^T(\overrightarrow{C_3}-\overrightarrow{A_3})}} \tag{24}$$

$$\theta_{23} = arc\tan\frac{y_{C3}-y_{A3}}{x_{C3}-x_{A3}} - \delta_{C3} \tag{25}$$

$$\overrightarrow{B_3} = \overrightarrow{C_3} + l_{BC}\begin{pmatrix}\cos(\theta_{23}+\pi)\\ \sin(\theta_{23}+\pi)\end{pmatrix} \tag{26}$$

$$\theta_{13} = arc\tan(\frac{y_{B3}-y_{A3}}{x_{B3}-x_{A3}}) \tag{27}$$

The same analysis leads to

$$g_5(x): \theta_{53} - \theta_{43} + \pi/6 \le 0 \tag{28}$$

$$\overrightarrow{F_3} = \overrightarrow{D} + l_{DF}\begin{pmatrix}\cos(\theta_3-\varphi_F+2\pi)\\ \sin(\theta_3-\varphi_F+2\pi)\end{pmatrix} \tag{29}$$

$$\delta_{F3} = \arccos\frac{(\overrightarrow{A_3}-\overrightarrow{F_3})^T(\overrightarrow{A_3}-\overrightarrow{F_3}) + l_{EF}^2 - l_{AE}^2}{2l_{EF}\sqrt{(\overrightarrow{A_3}-\overrightarrow{F_3})^T(\overrightarrow{A_3}-\overrightarrow{F_3})}} \tag{30}$$

$$\theta_{53} = arc\tan(\frac{y_{A3}-y_{F3}}{x_{A3}-x_{F3}}) - \delta_{F3} \tag{31}$$

$$\overrightarrow{E_3} = \overrightarrow{F_3} + l_{EF}\begin{pmatrix}\cos(\theta_{53}+\pi)\\ \sin(\theta_{53}+\pi)\end{pmatrix} \tag{32}$$

$$\theta_{43} = arc\tan(\frac{y_{E3}-y_{A3}}{x_{E3}-x_{A3}}) \tag{33}$$

Realization of the Optimization by Means of MATLAB. The optimal design of machine is built on the basis of theoretical analysis. Firstly, take all aspects into consideration, select the appropriate optimization ideas and methods [3], then given the initial position and the necessary data, and solve a reasonable and appropriate solution with the help of computer program language to achieve optimum design requirements. The datum of Japan's Kubota PRO208 harvester is summarized as follows:

$A_1 = \begin{pmatrix}120.11\\ -308.32\end{pmatrix}$ $A_2 = A_3 = \begin{pmatrix}111.85\\ -323.47\end{pmatrix}$ $D = \begin{pmatrix}0\\ 0\end{pmatrix}$ $\theta_{3\min} = \pi/4$ $\theta_{3\max} = 2\pi/3$ $\varphi_C = \varphi_F = 2\pi/3$

In order to obtain the minimal solution of the objective function 2.2, we used fmincon(a optimization function of MATLAB) to deal with the optimization problem. Multivariable constrained optimization is a method to solve the problem of nonlinear multivariable constrained. The constraints include equation and inequality constraints, and there are one or more nonlinear functions between the objective function and constraints [4]. The results of optimization are related to the initial values of the design variables, and we obtained a set of optimal solutions:

l_{AB}=241.3183 l_{BC}=287.9138 l_{CD}=56.3348 l_{AE}=69.9649 l_{EF}=200.3341 l_{DF}=95.4692

Conclusions

This paper takes the existing mechanism on as the object of the research, after redesigning, ultimately, the new mechanism can satisfy the basic design requirements.

The revolving pair that connect the connecting rods is lower pair, and the contact form of the kinematical pair elements is surface contact, therefore, the contact stress and abrasion are smaller relative to the point contact, and ultimately to ensure the motion accuracy.

In optimal design of planar linkage, the reasonable and appropriate solution can be obtained with the help of the optimization toolbox of MATLAB. Thus, it can improve the efficiency of design without writing a lot of algorithm.

The method of equivalent and variation can provide a technical support in avoiding patent infringement. What's more, it would be a guideline to some extent for innovation design.

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