Structure Optimization of Excavator Bucket Mechanism Based on ADAMS

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Abstract **— In order to increase the maximum working capacity of an excavator, the basic design requirements of bucket mechanism was analyzed, and then with the overall gear ratio taken as optimization goal, ADAMS simulation software were used to optimize the structure of its parameters. The results demonstrates that the method using a bucket mechanism optimized can play greater digging forces and provides valuable reference for the future improvement of the structure of the excavator.**

Keywords-excavator; bucket institutions; optimal design; ADAMS

I. INTRODUCTION

Hydraulic excavator is widely utilized among water conservancy projects, highway construction, factory and other fields. Hydraulic excavator's shovel mechanism is the core part of functional performance. Whether reasonable or not, its structure will directly affect its performance. In recent years, in the optimization design of hydraulic excavator's linkage mechanism, various optimization methods are generally adopted to optimum seeking method, the composite method, the constraint scale method, Powell method, and so on [1-3]. All these optimization methods above mentioned need designers to analyze the system, establish the objective function, determine the design variables, and create a mathematical model. But, for complex mechanical systems, it is very complex to create a mathematical model. This paper optimizes the structure of excavator bucket mechanism by using ADAMS [4] [11].

II. THE DESIGN REQUIREMENT OF BUCKET MECHANISM

Backhoe bucket mechanism generally uses six link mechanism. In order to meet the requirements of excavation, unloading and transportation, the bucket's rotational angle is in 150°to 180°[5].When the bucket cylinder fully shrinks, tooth tip is required in the extending line of arm or at the top of the arm in 0°to 30°. Additionally, in order to meet the needs of special excavation, the design of the large elevation angle is used, such as groove digging and vertical sidewalls. To make bucket teeth contact with the soil prior to bucket bottom, it requires the bucket's angle of elevation in 25°to 45°.

Meanwhile, in order to make the bucket mechanism maximum theoretical digging force match the digging resistance, the following requirements of the bucket digging force are proposed. When the bucket begins to dig with 15°to 20°of elevation, the maximum digging force should be below the extension line of arm in 25 °to 35°. Consequently, That means, when the bucket digs to half stroke, soil thickness and digging resistance should reach maximum[6].

In addition, the full travel of the hydraulic cylinder, the bucket linkage should work well. Hydraulic cylinder 's locking force should ensure that the arm digging force could perform fully. In the condition of constant bucket cylinder locking force, the transmission ratio of bucket linkage mechanism is an important factor affecting the value of the link mechanism digging force [7]. Consequently, under the premise of ensuring normally performance of the arm digging force, bucket linkage mechanism should be improved to find the optimal transmission ratio of the system, to maximize the bucket digging force.

III. ANALYSIS OF THE BACKHOE WORKING DEVICE OF SHOVEL MECHANISM

The six link backhoe mechanism is shown in Figure 1. In this design, with the arm fixed, the bucket's movement relative to the arm is studied [8].

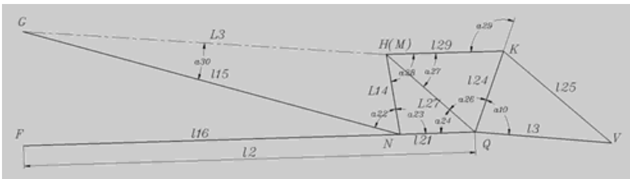

Figure 1. bucket mechanism analysis calculation diagram

Moment arm of cylinder to N:

$$r_1 = l_{14} \times \sin(\alpha_{22} + \alpha_{30}) \tag{1}$$

Moment arm of KH linkage to N:

$$r_2 = l_{14} \times \sin \alpha_{28} \tag{2}$$

Moment arm of KH linkage to Q:

$$r_3 = l_{24} \times \sin \alpha_{29} \tag{3}$$

Linkage overall gear ratio is:

$$i = \frac{r_1 \times r_3}{r_2 \times l_3} = \frac{l_{24} \times \sin(\alpha_{22} + \alpha_{30}) \times \sin\alpha_{29}}{\sin\alpha_{28} \times l_3} \quad (4)$$

A. Setting the Objective Function

In order to get the maximum digging force of bucket cylinder of backhoe working device , theoretically, digging force of bucket cylinder is the product of ratio i and theoretical thrust of bucket cylinder, which is determined by cylinder. Hence, transmission ratio of bucket linkage mechanism is the point influence on digging force of the bucket cylinder. Therefore, the objective function of this design is linkage mechanism total ratio i.

B. Determination of Constraint Conditions

Bucket mechanism parameter constraints include geometric constraints, motion characteristics of the requirements, the limitation of transmission angle and other restrictions.

1) Some geometric constraints

Bucket mechanism can be considered to be a crank rocker mechanism. In order to enable institutions to operate smoothly, the three points—M, N, G must maintain a stable shape of the triangle GMN. For the same reason, avoiding the alienation of triangular QKV and the quadrilateral HNQK is necessary in the full stroke of the L3. Besides, there requires that NH cannot interfere the Q point, cylinder projecting length L3 is in its range of travel, and the G point does not exceed the furthest point of the arm mechanism.

Geometric relationship to maintain a stable shape of the triangular GMN:

$$\begin{aligned}&\cos^{-1}\frac{l_{14}^2 + l_{15}^2 - L_{3\min}^2}{2l_{14}l_{15}} + \cos^{-1}\frac{l_{15}^2 + L_{3\min}^2 - l_{14}^2}{2l_{15}L_{3\min}} \\ &+ \cos^{-1}\frac{l_{14}^2 + L_{3\min}^2 - l_{15}^2}{2l_{14}L_{3\min}} - \pi = 0\end{aligned} \quad (5)$$

$$\begin{aligned}&\cos^{-1}\frac{l_{14}^2 + l_{15}^2 - L_{3\max}^2}{2l_{14}l_{15}} + \cos^{-1}\frac{l_{15}^2 + L_{3\max}^2 - l_{14}^2}{2l_{15}L_{3\max}} \\ &+ \cos^{-1}\frac{l_{14}^2 + L_{3\max}^2 - l_{15}^2}{2l_{14}L_{3\max}} - \pi = 0\end{aligned} \quad (6)$$

Geometric relationship to maintain a stable shape of the quadrilateral HNQK:

$$\alpha_{23} + \alpha_{24} + \alpha_{26} + \alpha_{28} + \pi - \alpha_{29} - 2\pi = 0 \quad (7)$$

2) Motion Characteristics Requirements

Link KQ and link KH rotate in the same direction in the whole process of digging. Moreover, the starting position of link KH cannot be in the extension of the KQ, nor on its right side.

Its constraint formula:

$$l_{24} - \sqrt{(l_{24} + l_{29})^2 + l_{21}^2 - 2l_{21}(l_{24} + l_{29})\cos\alpha_{10}} < 0 \quad (8)$$

α_{10} --- Angle between QH ' and the QN when link KH and link KQ is located on the same line.

In order to make K, N, H not on a same line, this formula must be established.

$$\sqrt{l_{29}^2 + l_{14}^2 - 2l_{14}l_{29}\cos\alpha_{28}} - (l_{24} + l_{21}) < 0 \quad (9)$$

3) Transmission angle restriction

In the proceed of backhoe digging, when external load of each position had no big difference, transmission angle does not have to be limited. However, when the external load maximum on the rod and stroke end position has one order of magnitude difference, and the transmission angle is very small, power transmission efficiency of lever will be worse. Therefore, it is necessary to restrict certain transmission angle to avoid the emergence of such phenomenon.

$$[\mu_{\min}] - \cos^{-1}\frac{l_{14}^2 + L_{3\max}^2 - l_{15}^2}{2l_{13}L_{3\max}} < 0 \quad (10)$$

$$[\mu_{\min}] - \cos^{-1}\frac{l_{14}^2 + L_{3\min}^2 - l_{15}^2}{2l_{13}L_{3\min}} < 0 \quad (11)$$

$$[\mu_{\min}] - \cos^{-1}\frac{l_{24}^2 + l_{29}^2 - l_{27}^2}{2l_{24}l_{29}} < 0 \quad (12)$$

IV. BUCKET MECHANISM PARAMETERS OPTIMIZATION

The bucket device was imported in ADAMS, to build virtual prototyping. Once imported, add drivers, constraints and loads.

A. Define Design Variables

L3, LMK, LMN, LNM, LGM, LQV, LMK etc, as design variables of bucket mechanism, which are set to real type, are set in Build-Design Variable-New of ADAMS. In order to visually reflect the influence of design variables on the design goals, limit value is set to absolute value in this design.

B. Define Objective Function

Preparing for the following test, r1, r2, r3 and i, as objective functions, are defined in the function editor.

C. Define Constraints

Establish measurement of□GMN, □QKM in ADAMS/view:

COMP_beta1_1_c=10-(180-MAX(.WJJCHDJGYOUHUA.MEA_ANGLE_GMN))

COMP_beta1_2_c=10-(180-MIN(.WJJCHDJGYOUHUA.MEA_ANGLE_ GMN))

COMP_beta2_1_c=30-(180-MAX(.WJJCHDJGYOUHU

A.MEA_ANGLE_QKM))

COMP_beta2_2_c=30-(180-MIN(.WJJCHDJGYOUHUA.MEA_ANGLE_QKM))

Furthermore, other constraints are presented by editing the definition function or measuring method.

D. Optimization Results

The objective function, design variables and constraints are set in the Design Evaluation Tools of ADMAS [9]. The optimization is carried out by choosing OPTODES-GRG algorithm. The optimization results are shown in Table 1.

Through the analysis of optimization results from ADAMS, optimized lever length effectively improved the transmission ratio of the backhoe lever mechanism.

In addition, by comparing bucket corner of the original value with optimized values, in the whole bucket cylinder working cycle of the bucket agency, the maximum rotation angle was 149°, the minimum rotation angle was 96°,thus, the rotation angle range was 53°[10]. Optimized corresponding values were 241°、102°、139°.That is, when the optimized bucket mechanism began digging, although the elevation was slightly smaller, excavation area was more than twice the original bucket mechanism, working range bucket agency greatly increased.

TABLE □. COMPARE ON LEVER LENGTH ABOUT OPTIMAL BUCKET DEVICE AND PRELIMINARY DESIGN (MM)

lever length	original design value(mm)	optimal value(mm)
NQ	300	329.60
NM	540	562.91
MQ	480	490.68
MK	430	493.75

V. CONCLUSIONS

In this paper, the excavator bucket mechanism is analyzed as a planar six-bar mechanism. The transmission ratio, which is confined by a series of constraints, is the optimization objective function. Based on ADAMS system, the structure of bucket mechanism is optimized. And the values of maximum, minimum rotation angle and rotation angle range of the optimized bucket mechanism are respectively compared with the original value. The results indicate that the optimized bucket mechanism can play greater digging forces and provide superior performance.

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