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THE RIGHT CHOICE OF CAMS FOR AUTOMATIC TOOL CHANGER (ATC)

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ABSTRACT
In this paper, the research target is interacting cams mechanism ATC. Maine work is done in designing with computer. All the design process is researched especially in dynamic property analysis and calculating. Some results and analysis method such as estimating the tool changing time accorded to the moment of inertia. Set up tool holder turnover dynamic model, etc., can be used in ATC's design to improve the ATC's working quality. Using CAD for ATC's design will increase the quality and speed in design especially in various types ATC and MC.
Keywords: automatic tool changer, dynamic analyzing, expert system.

1. ESTABLISHING THE WORKING CYCLE DIAGRAM OF INTERACTING CAMS MECHANISM

After tool storage finished tool choice, following actions are needed to perform sequencely for changing tools. To holder turn down; Mechanical hands grasp tools; Loosen tool; Pull out tool from spindle and tool holder, Exchange tools; Insert tools; Tighten tool in spindle; Mechanical hands turn back; Tool holder turn back.

In fig. 1 the rotation of mechanical hand is controlled by Ferguson cam, tool holder turn controlled by plane can pull out and insert tool controlled by another plane cam. Three cams interacting perform tools changing

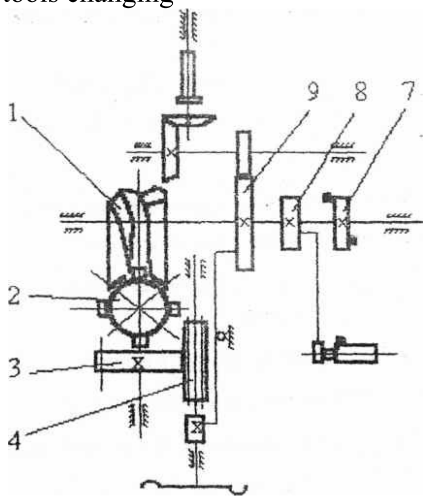

Figure 1. Kynematic scheme

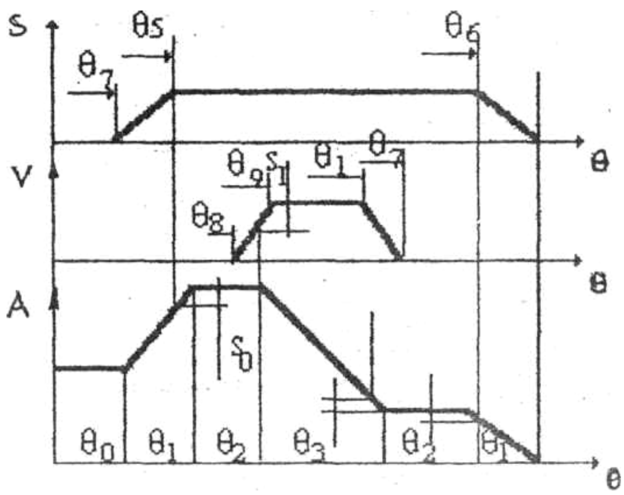

Figure 2 Working cycle diagram

1.1. Modified sine motion regular of cams

Modified sine curve may be used as cam's motion curve. The non-dimensional maximum velocity of modified sine curve V_{max} = 1.76 m/sec and non-dimensional max acceleration A_{max} = 5.53 m/sec^2. The both are smaller then other curves. For this reason, modified sine curve is suited to the cases of high speed and high load. In addition in the stage of beginning and finishing of modified sine curve, high frequency sine curve is used, which makes cam's curve.

1.2. Desired parameters of working cycle

1.2.1. Beginning rotation angle θ

When cam runs a round, ATC finishes a tool chancing cycle. Because some errors exit in cam and errors may affect the actions of ATC, the angle of beginning rotations θ_0 is needed to be designed.

1.2.2. Angle of pull and insert tools θ_2

θ_2 is used for designing plane cam which drives mechanical hand pull and insert tools. Working in θ_2, Ferguson cam doesn't perform graduation only plane cam acts to pull or insert tools.

1.2.3. Angle of graduation θ_1 and θ_3

θ_1 and θ_3 are angle of mechanical hand rotation

$$\theta_3 = \frac{180}{\phi_1}\theta_1 \tag{1}$$

$Ø_1$ is the angle of mechanical hand rotation form primary plane.

From the equation : $\theta_0 + 2\theta_1 + 2\theta_2 + \theta_3 = 360°$ we get the solution:

$$\theta_1 = \frac{360^\circ - \theta_0 - 2\theta_2}{2 + 180/\phi_1} \tag{2}$$

1.2.4. Angle for safety overlapping rotation S_0 S_I

For the realizing of improving toot changing speed, some cams may overlapping rotate. S_0 is the overlapping angle of tool bolder turndown and mechanical hand running grasp tools. S_I is the overlapping angle of pull out tool and mechanical hand running for exchanging tools. Designing the overlapping angle must ensure that interfere doesn't take place in overlapping actions.

1.2.5. Angle of cam rotation at tool holder turnover θ_5

$$\theta_5 = \theta_0 + \frac{\phi_1 - S_0}{\phi_1/\theta_1} \tag{3}$$

1.2.6. Angle of cam rotation at tool holder turnback θ_6

$$\theta_6 = 360^\circ - (\theta_5 - \theta_4)$$

1.2.7. Angle of ferguson cam rotation at tool change of beginning θ_7

$\theta_7 = \theta_0 + \theta_1 + \theta_2 + \theta_3 - \phi_0$; in equation of $Ø_0$ is a safe angle before mechanical hand pull tools.

1.2.8. Angle of cam rotation at the position of tool pulled-out

From fig. 2 we have $\theta_8 = \theta_0 + \theta_1 + \theta_2 - \phi_0$

1.2.9. Angle of cam rotation at the position of tool inserts beginning θ_9

$$\theta_9 = \theta_0 + \theta_1 + \theta_2$$

1.2.10. Angle of cam rotation at the position of tool changing finished θ_{10}

$$\theta_{10} = \theta_0 + \theta_1 + \theta_2 + \theta_3$$

From above calculation, we have decided the working cycle diagram of interacting cam mechanism. See fig 2. To different tool types and MC types, w can calculate ATC working cycle following above method. And, that we can make program for calculating the different ATC working cycles hi CAD.

2. THE ESTIMATING FORMULA OF TOOL CHANGING TIME

How to choose suitable tool changing time in interacting cams ATC is another problem. At present, the choice of tool changing time is made by referring to some MC which have been used or estimating it. In this paper, on the basis of calculating moment of inertia, we have get a formula for choosing tool chancing time to different tool types.

For deciding tool changing time, theoretically, should consider the weakest link in three parts include (1) pull and insert tool: (2) tools exchanging; (3) tool holder turnover. According the weakest link no shuckness and vibration when distributing shaft nm a cycle at the shortest time, we can decide the tool change time

In real system, many factors may affect the tool changing time. We choose the tools exchanging link as a main factor to calculate moment of inertia because that maximum acceleration, appears in this action of all working cycle.

Following formula can be used to estimate the tool changing time t_h:

$$t_h = t_0\sqrt{k} \tag{4}$$

In the formula t_0, is a suitable tool changing time corresponding to a type of ATC, which has been got by experiments

$$k = \frac{T_1}{t_0} \tag{5}$$

T_1 is an equivalent moment of inertia of other tool type in the axle of mechanical hand.

3. DYNAMIC PROPERTY ANALYSING AND CALCULATING

Dynamic property analyzing is very important for interacting cams mechanism stabile working. Here as an example we do some dynamic calculating for tool holder turnover system because that the shockless and vibration will apply at tool holder with a bigger tool.

The mechanism of tool holder is in fig. 1, plane cam installed on distributing shaft drives tool holder turnover. For reason of analyzing conveniently, we simplify the real system to a model with following ways:

(1) Simple continuous system to separated system;
(2) Linearizing non linear system;
(3) Neglect some secondary factors.

We got up a system differential equation:

$$\ddot{x} + kx = kh(t) \tag{6}$$

In equation clearances and damp are neglected. h(t) is system in put here, that modified sine curve. The system primary condition is:

$$x(0) = \ddot{x}(0) = 0 \tag{7}$$

The system free period T_0 is:

$$T_0 = 2\pi\left(\frac{m}{k}\right)^{1/2} \tag{8}$$

Define non-dimensional parameters

$$\tau_0 = \frac{T_0}{t_m}, T = \frac{t}{t_m}, X = \frac{x}{h_m}, \ddot{X} = \frac{\ddot{x}t_m}{h_m} \tag{9}$$

In above equations: t_m is time of tool holder turnover; h_m is cam rise.

To modified sine curve, within $t > t_m$, $h(t) = h_m$ using primary condition $t = t_m$.

$$U = \frac{T_0^3}{\pi\left(1-4\tau_0^2\right)}\sin\left(\frac{2\pi}{\tau_0}\right)\cos\left(\frac{2\pi(2T-1)}{\tau_0}\right) \tag{10}$$

$$\ddot{U} = \frac{-T_0^3}{\pi\left(1-4\tau_0^2\right)}\sin\left(\frac{2\pi}{\tau_0}\right)\cos\left(\frac{2\pi(2T-1)}{\tau_0}\right) \tag{11}$$

Here, U is remain vibration error or call it relative error and $\ddot{U}$ is acceleration of remain.

$$U_0 = \frac{\tau_0^3}{\pi\left(1-\tau_0^2\right)}\left|\sin\left(\frac{\pi}{\tau_0}\right)\right| \tag{12}$$

$$\ddot{U}_0 = \frac{4\pi\tau_0}{\left(1-\tau_0^2\right)}\left|\sin\left(\frac{\pi}{\tau_0}\right)\right| \tag{13}$$

Form above equation, we know that U_{max} and $\ddot{U}_{max}$ relate τ_0, different U_{max} and $\ddot{U}_{max}$ with τ are give in table 1. In design, we can convert other parts mass to tool and get equivalent converting mass, in some way, can get equivalent converting rigidity. Form above equations, the free vibration cycle T_0 of mechanism can be calculated, and calculated too. Refer to the table 1, U_0 and $\ddot{U}_0$ can be found. In ATC, we hope U_0 and $\ddot{U}_0$ as little as possible.

Table 1

T[sec]	U[m]	$\ddot{U}_0$ [m/s^2]
0,105	$3{,}75 \times 10^{-5}$	1,34
0,222	$3{,}5 \times 10^{-4}$	2,65
0,286	$7{,}64 \times 10^{-4}$	3,91
0,4	$2{,}43 \times 10^{-3}$	5,98
0,86	$1{,}68 \times 10^{-2}$	15,2

4. ATC SCHEME DESIGN USING EXPERT SYSTEM

Different MC requires different ATC including different types, tool storage types, tool capacity and mechanical hand. Choosing and designing ATC must meet the need of MC's working. For this reason, we set up a knowledge base used to decide ATC's scheme.

ATC's scheme designing expert system include following parts:

- Set up a expert knowledge base by PCEST developing tool software;
- Knowledge is expressed by parameters, rules, frames and user defined function;
- Using inference to choose knowledge.

Set up a perfect knowledge base need to collect a lot of materials. In this respect, we are going to do more deep work at next step.

5. CONCLUSIONS

ATC is an important component of MC ATC made up of interacting cams mechanism is a king of advanced device. In this device, several cams are installed on one main controlling axle. In changing tools, each cam can drive mechanical hand performs some actions. Some actions may perform in same time. Suitable cam curves and interacting cams on one axle can make tools changing more quick and reliable. For this reason, many MC consider interacting cams mechanical ATC in design.

In this paper, we will discuss some problems about design ATC Using computer to analyze and calculate in design may gain better results for improve the acting property of ATC.

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