

Design Principles of Slotted Holes

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Abstract—Slotted holes are widely applied in mechanical design. But at the present time, there are few scattered document data to systematic conclude or sum up all various kinds of slotted holes' design principles and their application circumstances. By right of some experiences of perennial engineering design, we sum up some characters and functions of kinds of slotted holes. Combining with Matlab, we analyze these slotted holes' travel interval of slip distance accurately. These conclusions would be convenient for engineers to apply them with matching on different practical design purposes.

Index Terms—slotted hole, travel interval, nonlinear equation

I. INTRODUCTION

DIVERSE slotted holes are widely used in most sorts of mechanical design. Apply mainly in precisely fine tuning for uncontrollable dimension beforehand, alignment accuracy, fixation in certain direction meanwhile keeping slipping free in other directions [1], and so on. Such as tension device of belt pulley, thermal stress protection for slender bar structural parts or long spindle shafts, alignment accuracy in complex dimension chain, mechanism for enhancing tolerance and eliminating accumulated error.

In mechanical design, some principles and factors we should take into account include: the shape and travel of the slotted holes, the structural strength affected by the holes, and so on. In actual application, they can be classified into follow types: singleton slotted holes, coupled slotted holes.

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Coupled slotted holes can be also divided into parallel slotted holes and cross slotted holes between mating parts. They all have individual travels and differentiated usage scopes. Take an actual mechanical structure designing for example, we introduce and analysis application ranges of some classic types of slotted holes, appropriate usages, and other attentive matters.

II. SINGLETON SLOTTED HOLE

Singleton slotted holes are divided into straight slotted holes and curving slotted holes. Singleton slotted holes generally have short slip ranges in holes' length. They are normally used in these situations: 1. One of the connection parts is not allowed or not convenient to ream long holes. 2. Large travel scope is not necessary to remove displacement errors.

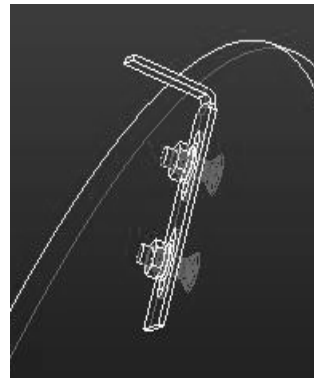


Fig. 1. Singleton straight slotted hole

In Fig. 1, There are two thru-holes of countersunk head screws drilled in the disc part, and two straight slotted holes perforated in L-shaped bend accessory. The disc part with thru-holes is not allowed to drill large-sized slotted holes because of its performance as surface reflecting microwave. The feature of overmuch protuberance things or gap areas is harmful to enhance the capability of smooth surface reflecting microwave. When the disc component is at revolving work state, aim to gain the angular speed and some position parameters, a L-shaped bend accessory extension jut is needed to pass through a small gap between two lugs of a photoelectric switch. To avoid bend accessory

extension jut interfering into two lugs of the photoelectric switch, but not passing through the little gap between them, mismachining tolerances of parts and assembly errors should be removed. Designing the mounting holes of L-shaped bend accessory into straight slotted hole form, is convenient for compensating the displacement errors in installation and trial run.



Fig. 2. Singleton curve slotted hole

In designing belt pulley transmission, the length of pulley belt is normally selected in standard series. That is usually not satisfying exactly a fixed actual mechanical dimension, and it can not be cut off extra section or connect up shortage part. In addition, the length of pulley belt will vary with the changes of ambient temperature and loads carried. Its work length is fluctuant in some ranges. So it needs an adjusting mechanism to keep the pulley belt tension. We call it tensioning device. In most of circumstances, using slotted holes as tensioning device is a simple and reliable method. For this consideration, a round thru-hole and two arc-shaped slotted holes are designed (in Fig. 2). The center to center distance can be adjusted by a mounting panel with two arc-shaped slotted holes and one round hole and one jack-up nut bolt. Mounting panel can rotate around the round hole. To keep rotating smoothly, the center of the arc-shape coincides with the round hole center. In this case, we could also design four straight slotted holes and two jack-up nut bolts to keep two sides translating synchronously. But for brief principle, the tensioning device with two arc-shaped slotted holes and one round hole and one jack-up nut bolt, is thought as more appropriate design according to simpleness, reliability and reasonability rules.

III. COUPLED SLOTTED HOLES

Coupled slotted holes mean there are both slotted holes on two bodies connecting each other. When at the same

slotted hole dimension, the travel scope of parallel slotted holes (Fig. 3) is twice the size of singleton slotted hole. Cross slotted holes (Fig. 4) can adjust parts' relative translational motion in two directions of x- and y-axis. In next content, a brief introduction of application about parallel slotted holes and cross slotted holes are given firstly, and then we focus our analysis on the travel scope of a component connected by four groups of cross slotted holes.

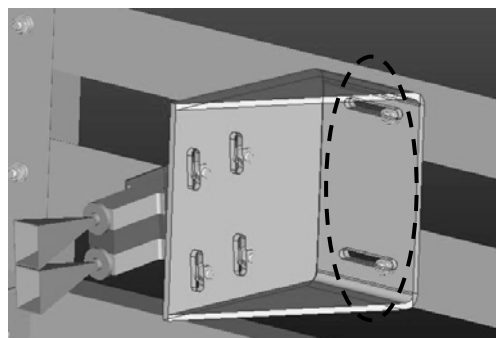


Fig. 3. Parallel slotted holes (marked in dash line scope)

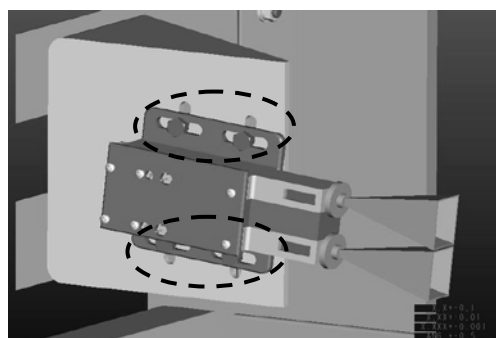


Fig. 4. Cross slotted holes (marked in dash line scope)

A. Parallel Slotted Holes

Overlong slotted hole normally has negative effects on both material strength of part and visual impression of product. So, that is not advocated to design overlong slender slotted hole unless it's absolutely necessary [2]. As a replacement solution to extend the travel length between two parts, we take the form of parallel straight slotted holes. It can double the travel length, with more permissive tolerances [3], as show in Fig. 5.

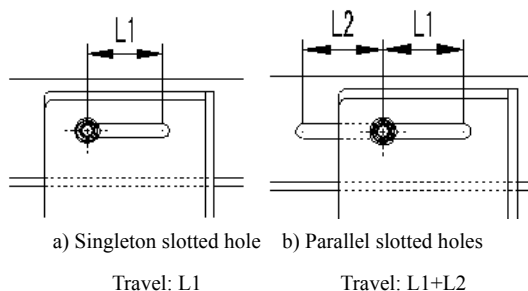


Fig. 5. Contrast travel

B. Cross Straight Slotted Holes

Cross straight slotted holes can adjust part relative translational motion at both two degrees of free in x- and y-axis directions. While being fixed by several points at the x-y plane, the part with groups of cross straight slotted holes has rotational freedom in z-axis direction. Above properties are exclusive, owned by only groups of cross straight slotted holes, and not shared with parallel straight slotted holes or others. Cross straight slotted holes are applied on some alignment adjustment mechanisms of microwave or optical transceivers. Offsetting scope and adjusting angle ability of a microwave receiver fixed with groups of cross straight slotted holes are analyzed as follows(Fig. 6).

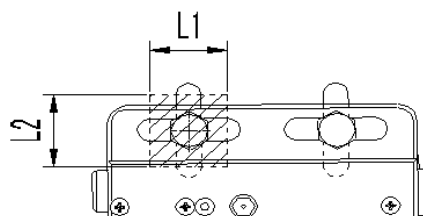


Fig. 6. Adjustable region of coupled square cross slotted holes: $L1 \times L2$

The microwave receiver with flange is fixed on mounting plate with four groups of cross straight slotted holes convenient for translation in x- and y-axis and angle rotation around z-axis. So it can aim at a certain receive direction.

The groups of cross straight slotted holes are brief sketched in Fig. 7. In which, the line RS indicates the straight slotted hole on the mounting plate, PQ indicates the straight slotted hole on microwave receiver's mounting flange, point D denotes the junction fixed with a screw. The rotational and translational ranges about the receiver component composed of these four groups of cross straight slotted holes are analyzed as follows.

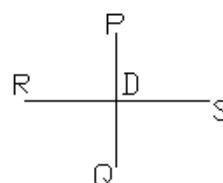


Fig. 7. Simplified representation of cross slotted holes

Details are expressed in Fig. 8. In which, C, D, E, F are the positions of the four mounting holes on the plate. U, V, W, Z are the positions after the microwave receiver anticlockwise rotating a $\alpha_{1/2}$ angle.

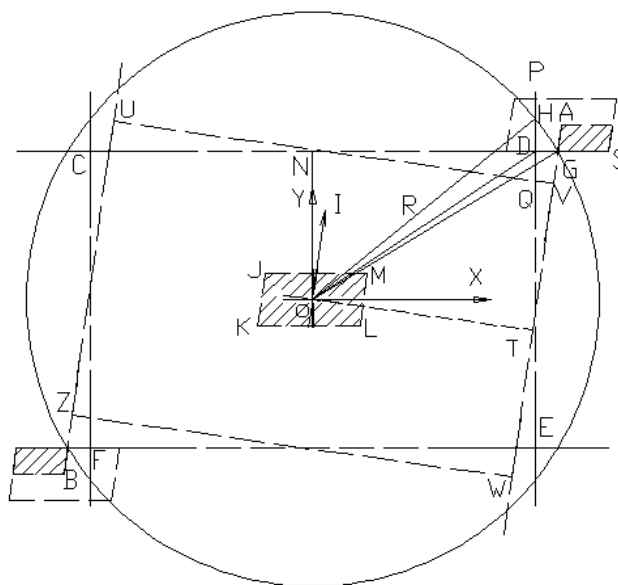


Fig. 8. Analysis of rotational and translational regions

In Fig. 8, the initial constraint condition set for calculation is: Preliminary center distance in x-axis direction $W = \overline{CD}$, the length of slotted hole in x-axis direction on mounting plate $L2 = \overline{RS}$; Preliminary center distance in y-axis direction $H = \overline{CF}$, the length of slotted hole in y-axis direction on receiver's mounting flange $L1 = \overline{PQ}$.

Suppose the rotational angle between the receiver and its mounting plate is $\alpha_{1/2}$. That means receiver's flange has clockwise rotated a $\alpha_{1/2}$ angle around negative z-axis direction. In those above conditions, we try to figure out the accurate slideable ranges of the receiver in x-axis and y-axis relative to the mounting plate.

From Fig. 8, it can be seen that the key points which limit the workpiece to move are focus on A and B locations after rotating. The illustration shows that work piece's movable area is now limited inside the parallelogram JMLK. In next content, it will be figure out about the numerical relationship of the edges of the parallelogram, which is exactly workpiece's slideable range after rotating $\alpha_{1/2}$ angle.

When rotating $\alpha_{1/2}$ angle, we have

$$\begin{aligned}\alpha_{1/2} &= \angle YOI \\ &= \angle DOV = \angle DOG + \angle GOV, \\ &= \angle DOG + \angle HOD = \angle HOG\end{aligned}$$

and from relation

$$\begin{aligned}\alpha_{1/2} &= \angle XOT = \angle YOG + \angle GOT - \pi/2, (\overline{OG} = R) \\ &= \arccos[(W/2)/R] + \arccos[(H/2)/R] - \pi/2\end{aligned}$$

it can be extrapolated and achieved the distance $R = \overline{OG}$ from rotating center O to current fixed cross point G after rotating(it is a nonlinear equation soluble within Matlab).

And then, we can get the workpiece's maximal translational distance along x-axis direction:

$$\overline{GS} = (W + L2)/2 - \sqrt{R^2 - (H/2)^2};$$

and maximal translational distance in \overline{OI} direction:

$$\overline{GA} = (H + L1)/2 - \sqrt{R^2 - (W/2)^2}.$$

Finally, we get the workpiece's slideable range interval in \mathbf{i} direction (relative to positive direction of x-axis): $[-\overline{GS}, \overline{GS}]$; and interval in $(\sin \alpha_{1/2})\mathbf{i} + (\cos \alpha_{1/2})\mathbf{j}$ direction: $[-\overline{GA}, \overline{GA}]$.

C. Numerical Computation

The numerical computation codes calculating slideable ranges of the cross slotted holes within Matlab are provided in latter appendix. They can be copied directly into Matlab and run without any modifications except the data of input parameters matching with actual situation.

IV. CONCLUSION

About slotted holes, besides these kinds of singleton straight slotted holes, singleton arc-shaped slotted holes [4], parallel slotted holes and cross slotted holes, there are still many other types. Like as parallel arc-shaped slotted holes, coupled square cross arc-shaped slotted holes, coupled slant cross arc-shaped slotted holes, and so on. Those usages are

not showed one by one in this paper. Nevertheless you can combine actual application conditions and consult the methods introduced above to use them optionally.

APPENDIX

Matlab codes for calculating slideable ranges of the cross slotted holes are shown as follows.

Main function codes:

function main()

W=38; % Center distance in x axis

L2=20; % The slotted holes' length on mounting plate in x axis

H=66; % Center distance in y axis

L1=20; % The slotted holes' length on the workpiece in y axis

a120=10; % Rotating angle between the workpiece and mounting plate.

a12=a120*pi/180;

R0=sqrt((W/2)^2+((H/2)^2);

R1max=sqrt((W/2)^2+((H+L1)/2)^2);

R2max=sqrt((H/2)^2+((W+L2)/2)^2);

Rmax=min(R1max,R2max);

a12max=acos((W/2)/Rmax)+acos((H/2)/Rmax)-pi/2;

a120max=a12max*180/pi;

if (a12<=a12max) && (a12>=0)

R=fzero(@a12R,[R0,Rmax],optimset,W,H,a12);

TRx12=(W+L2)/2-sqrt(R^2-(H/2)^2);

TRa12=(H+L1)/2-sqrt(R^2-(W/2)^2);

fprintf(['Rotating angle between workpiece and mounting plate a120=' num2str(a120) '°']);fprintf('\n');

fprintf(['Maximum Rotating angle allowed

a120max=' num2str(a120max) '°']);fprintf('\n');

fprintf(['Workpiece's slideable interval in i direction:

['...

num2str(-TRx12,'%5.2f')

num2str(TRx12,'%5.2f') ']mm']);fprintf('\n');

fprintf(['Workpiece's slideable interval in (' num2str(sin(a12)) ')i+(' num2str(cos(a12)) ')j direction: ['...

num2str(-TRa12,'%5.2f')

num2str(TRa12,'%5.2f') ']mm']);fprintf('\n');

else

fprintf(['Rotating angle a120(=' num2str(a120) '°) should be greater than 0°and less than a120max(='...

num2str(a120max) '°), Please reset the value of a120.']); fprintf('\n');

end

end

Subfunction codes:

function y=a12R(R,W,H,a12) %Function of relation
between the cross points' circumradius R and the rotating
angle a12

$$y=\text{acos}((W/2)/R)+\text{acos}((H/2)/R)-(\pi/2)-a12;$$

end

REFERENCE

- [1] Abdul Malik, "Length of slotted holes and kidney-shape slots," *Steel Construction Institute*, Ascot, UK, 2008, pp. 20-35.
- [2] Man, C. Y. Jack, Driver, G. Robert, Grondin, and Y. Gilbert, "Behaviour of slotted hole angle connections," *Annual Conference - Canadian Society for Civil Engineering 2005*, pp. GC-293-1-10.
- [3] Aguilera, Eduardo, Rusek, Piotr, Rodríguez, and Rafael A, "Development of stack-up tolerances for bolted flange Pairs," *Informacion Tecnologica*, vol. 17, no. 6, 2006.
- [4] Xu Ming and Liu Tao, "Design of the comprehensive test instrument based on the position accuracy requirement of waist type hole," *Technology Development*, vol. 30, no. 17, pp. 82-83, Sep. 2011.