The Invention of Cam-Linkage Grinding Device with Double-Circle Grinding Traces

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Abstract. The double-circle grinding traces has 0% velocity deviation percentage ($V_{dp}=0\%$), which is the optimum polishing trace. This paper focuses on the invention of cam-linkage grinding devices with double-circle grinding traces. First, based on the modified Yan’s creative design methodology, 1st cam-linkage grinding device is synthesized. Then, according to Osborn’s Checklist Method, 2nd cam-linkage grinding device is synthesized. These two cam-linkage grinding devices can be designed to have optimum polishing traces and 0% velocity deviation percentage ($V_{dp}=0\%$). This paper provides a new creative design methodology for creating some or all possible design concepts that have the different topological characteristics as existing designs, e.g. with the different degrees of freedom. It can be said to create some or all possible design concepts from nothing (no existing design). The results of this paper can be used as the teaching material of innovative design course.

1. Introduction
In the past researches, the mechanisms of grinding devices can be planetary-type [1-6] and the link-type [7-9]. The link-type grinding devices, shown in Fig. 1(a), provide 8-shape grinding traces, shown in Fig. 1(b), and have velocity deviation percentages ($V_{dp}$) between 36.5520%~76.8652%. The mechanism, shown in Fig. 1(a), has two degrees of freedom and its links 2 and 6 are the two inputs (having the kinematic constraint “$\Delta \theta_{2}=2\Delta \theta_{1}$”) to get 8-shape grinding g trace. Fig. 1(b) shows the 8-shape grinding traces with 3 straight line segments, so the grinding qualities are not good. The link-type grinding devices cannot be designed to have zero velocity deviation percentages ($V_{dp}=0\%$). The ideal grinding traces, shown in Fig. 2, is grinding traces with double circles (∞-shape grinding traces). In 1997, Buzzetti [10] used the relatively high-cost PLC to control the link-type polishing device to get grinding traces with double circles. In order to reduce the manufacturing cost, other patents [11-13] of grinding devices are proposed.

![Kinematic skeleton and grinding traces](image)

(a) Kinematic skeleton (b) grinding traces

Figure 1. Link-type grinding device.
This paper focuses on the invention of cam-linkage grinding devices with ideal grinding traces (double-circle grinding traces). Yan’s creative design methodology is the method for creating some or all possible design concepts that have the same topological characteristics as existing designs, e.g. with the same degrees of freedom. First, based on the creative design of mechanical devices [14-17], the modified Yan’s creative design methodology is proposed to create some design concepts that have the different topological characteristics as existing designs, e.g. with the different degrees of freedom. Then, according to the modified Yan’s creative design methodology, 1st cam-linkage grinding device is generated. Finally, according to Osborn’s Checklist Method [18-23], 2nd cam-linkage grinding device is synthesized. These two cam-linkage polishing devices are designed to have ideal grinding traces (double-circle grinding traces).

2. First invention by modified Yan’s creative design methodology

Conceptual design is the initial stage of the engineering design process, which is the most difficult part. There is no existing mechanism (F=1) which can provide double-circle grinding traces, the Yan’s creative design methodology [15-18] must be modified. Fig. 3 shows the modified Yan’s creative design methodology, and its steps are:

Step 1. Based on the existing designs (F=2), conclude the topological characteristics and design requirements and constraints.

Step 2. According to the topological characteristics, synthesize the atlas of generalized chains (F=1) that can be used to design cam-linkage polishing devices.

Step 3. Based on the design requirements and constraints, synthesize the atlas of feasible specialized chains by assigning link types and joint types to each generalized chain.

Step 4. Particularize each feasible specialized chain into its corresponding kinematic skeleton, the atlas of cam-linkage polishing devices can be obtained.

2.1. Topological characteristics.

The 1st step of this invention is to conclude the topological characteristics of existing grinding devices. The link-type grinding devices are the mechanisms with 2 degrees of freedom. The purpose of this paper is to invent mechanism with 1 degree of freedom (DOF) to provide double-circle grinding traces. For the
mechanism having double-circle grinding traces, it must have cam pairs. Eq. (1) shows the degrees of freedom of planar mechanical devices.

\[ F = 3(N - 1) - 2J_1 - J_2 \]  

(1)

Where: \( N \) is the number of links, \( J_1 \) is the number of joints with 1 degree of freedom, and \( J_2 \) is the number of joints with 2 degrees of freedom.

According to Eq. (1), if \( N=4 \), \( J_1=3 \), and \( J_2=2 \), the corresponding generalized chain \((4, 5)\) has 1 degree of freedom. Hence, the grinding device must have 2 cam pairs. The topological characteristics of grinding device with double-circle grinding traces are concluded as follows:

1. It is a mechanism with 4 links and 5 joints.
2. It has 4 links including a ground link (Gr), cam link (CA), 1st slider moving in X direction (S1), 2nd slider moving in Y direction (S2). The 2nd slider of grinding device can be also named as grinding disk.
3. It has 5 joints including 1 revolute joint (JR), 2 prismatic joints (JP), and 2 cam joints (JA).

2.2. Atlas generalized chain.

The 2nd step of this invention is to synthesize all possible generalized chains. According to above topological characteristics, Fig. 4 shows the generalized chain with 4 links and 5 joints.

![Figure 4. Generalized chain (4, 5).](image)

2.3. Design requirements and constraints.

Based on the topological characteristics, the design requirements and constraints of the cam-linkage grinding devices are:

1. There must be a ground link (Gr), cam link (CA), 1st slider moving in X direction (S1), 2nd slider moving in Y direction (S2).
2. The ground link (Gr) must be adjacent to cam link (CA) with revolute pair and adjacent to first slider (S1) with prismatic pair.
3. The ground link (Gr) cannot be incident to cam pair.
4. The cam link (CA) must at least have 1 revolute pair and 1 cam pair.
5. 1st slider (S1) must be adjacent to the ground link (Gr) with prismatic pair.
6. 1st slider (S1) must be adjacent to the second slider (S2) with prismatic pair.
7. 2nd slider (S2) can’t be adjacent to the frame.
8. There are 5 joints including 1 revolute pair (JR), 2 prismatic pairs (JP) and 2 cam pairs (JA).
9. There is at least 1 cam pair in 3-bar loop.

2.4. Specialization.

The 3rd step of this invention is to assign specific types of members and joints to each generalized chain, subject to design requirements and constraints to have specialized chains. The specializing steps for polishing devices are:

1. Identify the ground link (Gr) to each generalized chain for all possible cases. There are 2 possible identifications as shown in Figs. 5(a) and 5(b).
2. Identify the 2nd slider (S2) to each case obtained in Step 1. For the specialized chain shown in Fig. 5(b), based on the design requirements and constraints, there is no possible identification of 2nd slider (S2). So, there is only 1 possible identification, shown in Fig. 6.
3. Identify the cam link (CA) and 1st slider (S1) to each case obtained in Step 2. There is only 1 possible identification, shown in Fig. 7.
4. Identify the corresponding revolute pairs (denoted by ○), prismatic pairs (denoted by ●), and cam pairs (denoted by ♦) to each case obtained in Step 3. There is only 1 feasible specialized chain, shown in Fig. 8.
2.5. **Particularization.**

The last step of this invention is to particularize the feasible specialized chain into its corresponding kinematic skeleton. Particularization is the reverse process of generalization, and can be done by applying the generalizing rules in reverse order. Fig. 9 shows the corresponding kinematic skeleton of the feasible specialized chain as shown in Fig. 8. The mechanism, shown in Fig. 9, has 4 links and 5 joints ($J_1=3$ and $J_2=2$), its’ degrees of freedom can be calculated as:

$$ F = 3(4 - 1) - 2\times 3 - 1\times 2 = 9 - 8 = +1 $$  \hfill (2)

It is a grinding device with 1 degree of freedom, and can be designed to have double-circle grinding traces (ideal grinding traces).
3. Second invention by checklist method

The checklist is the simplest method for problem solving. It is a method that provides hints by checking the items on a prepared list against the problem. In 1953, Alex Faickney Osborn published his book “Applied Imagination: Principles and Procedures of Creative Problem Solving” in which Osborn presented the technique of checklist. Professor Dior of Harvard University summarized Osborn’s 83 questions to 9 items. The 9 items are: 1. Reverse, 2. Transfer, 3. Combine, 4. Change, 5. Extend, 6. Enlarge, 7. Reduce, 8. Substitute, 9. Rearrange.

Here, based on the “change method”, the new invention could be realized. For the mechanism shown in Fig. 9, the 2nd cam pair is incident to cam link (CA) and first slider (S1). Here, we make a minor change “2nd cam pair is changed to be incident to cam link (CA) and 2nd slider (S2)”. Based on this minor change, the corresponding kinematic skeleton is shown in Fig. 10. The mechanism, shown in Fig. 10, has 4 links and 5 joints (J1=3 and J1=2), its’ degrees of freedom can be calculated as:

$$F = 3(4 − 1) − 2 	imes 3 − 1 	imes 2 = 9 − 8 = +1$$

It is a grinding device with 1 degree of freedom, and can be designed to have double-circle grinding traces (ideal grinding traces).

4. Cam profile design and dynamic simulation

The cam is a mechanical element with a special profile, and the follower will be driven to have the desired motion. It has the advantage of small size, compact construction, good dynamic performance, and easy designed to meet motion requirements. It is widely used in automated machinery, and plays an irreplaceable role. According to Fig.10, the schematic diagram of cam pairs can be redrawn as Fig.11. The cam link is a dual cam which is coupled by two disc cams.

![Figure 11. Schematic diagram of cam pairs.](image-url)
4.1. Cam profiles of x-cam and y-cam.
X-cam controls the displacement of grinding disk in X direction, and Y-cam controls the displacement of grinding disk in Y direction. By the special profiles of X-cam and Y-cam, grinding disk (S2) can provides the optimum grinding traces (double-circle grinding traces) as shown in Fig. 12.

![Figure 12. Optimum grinding traces(double-circle grinding traces).](image)

By analytical method, Chen [24] synthesized the cam profiles of X-cam and Y-cam, shown in Figs. 13(a) and 13(b). If the rotation speed of cam is 30rpm, Fig. 14(a), 14(b), and 14(c) show the corresponding speed in X-direction, Y-direction, and linear velocity of grinding disk. The linear velocities of grinding disk are constant value \( V = 47.12 \text{ mm/sec} \). According to Fig. 14(c), it is concluded that this invention “Cam-Linkage Grinding Device” has zero velocity deviation percentages \( V_{dp} = 0\% \). And, Fig. 15 shows its theoretical grinding traces.

![Figure 13. Cam profiles of X-disk and Y-disk (with conditions \( r = 7.5\text{mm} \) and \( r_{g} = 240\text{mm} \)).](image)

![Figure 14. Grinding velocity of grinding disk.](image)
5. Conclusions

Traditionally, for link-type polishers, the velocity deviation percentages ($V_{dp}$) are between 36.5520% - 76.8652%. It can’t be designed to have zero velocity deviation percentages ($V_{dp}$=0%). This paper provides a new creative design methodology of creating some or all possible design concepts that have the different topological characteristics as existing designs, e.g., with the different degrees of freedom. First, based on the modified Yan’s creative design methodology, 1st cam-linkage grinding device is synthesized. Then, according to Osborn’s Check-List Method, 2nd cam-linkage grinding device is synthesized. These two cam-linkage grinding devices can be designed to have optimum polishing traces and 0% velocity deviation percentage ($V_{dp}$=0%). The results of this paper can be used as the teaching material of innovative design course.

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