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Product development with TRIZ: design evolution of deburring tools for intersecting holes†

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Abstract

In this work, an example of product development based on TRIZ is introduced. The products are deburring tools for drilled intersecting holes which have been developed in two steps of evolution. Each step of evolution has been derived in the framework of TRIZ. The first design had limited access to burr edges on surfaces with mild degrees of curvature. The second design was derived from the contradiction analysis of the first design. Tests on the second design revealed problems with excessive cutting and tool damage. A third design was obtained from the physical and technical contradiction analyses of the second design. Tests were performed on aluminum alloy Al6061-T6 for various diameter combinations, cutting speed, and axial feed rate to confirm the performance of the third design.

Keywords: TRIZ; Burr; Intersecting holes; Deburring tool; Design evolution

1. Introduction

There have been numerous studies on the mechanisms of burr formation and the conditions for burr minimization [1-2]. Studies show that burr minimization is possible even though complete suppression is not feasible. In practice, burr minimization has to be combined with a proper means of deburring. Removal of burrs on the edge of intersecting holes is especially difficult due to poor accessibility as well as the three-dimensional nature of the burr edge. The problem becomes more challenging when three or more holes intersect one another, and the diameter ratios are close to unity.

There are several methods and devices for removing burrs from intersecting holes, such as flexible rotary tools [3], spring-loaded cutters [4], abrasive jet [5], laser deburring [6], and other electrochemical processes [7], as well as conventional ball endmills. Most of these methods require time-consuming preparations or costly devices. They also inflict certain degrees of damage to the inner surfaces of the holes.

An ideal method and device will remove the burr in a short time simply and without damaging the holes. To this end, the authors have tried to develop a new deburring tool in two steps of design evolution in the framework of TRIZ.

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2. Design evolutions of deburring tools

Fig. 1 shows three designs of the deburring tool in its sequence of evolution. The first design [8] shows a deburring insert imbedded in a shaft. The second design [9] shows a cutter head mounted on a shaft which is pivoted and spring loaded in a grip. The third design [10] is essentially similar to the second design except for the hemispherical cutter head. With the hemispherical cutter head, the exposure of the cutting edge is limited, and the problem of excessive cutting can be overcome. The details of the two-step evolution are presented in the following.

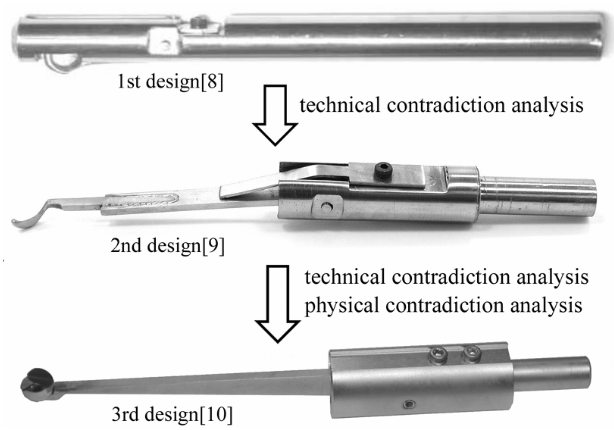


Fig. 1. Design evolution of deburring tools in two steps.

2.1 The first design

Fig. 2 shows the components, assembly, and deburring result of the first design. The deburring insert is pivoted and loaded by a spring in the shaft. To house the insert, a rectangular cavity is provided in the shaft. A close-up view of the deburring insert in Fig. 2(b) shows the cutter head protruding from the shaft. The cutter head is progressed up to the vicinity of the burr edge through the secondary hole and is rotated with retreat strokes until the cutter head passes through the burr zone. The planar cutting edge on the deburring insert has a certain degree of compatibility with the burr edges on surfaces with mild curvature. This is the case when the primary hole diameter is much larger than the secondary hole diameter and when the intersecting angle is close to 90^{o}. For conditions other than this, the cutting edge has limited access to a three-dimensional burr edge. If the cutting edge size is increased beyond a certain limit, the torsional strength of the shaft containing the deburring insert is reduced below a practical limit. This obvious problem with the first design can be described within the framework of TRIZ. The "ideality" of this problem is "Deburring without strength reduction of the shaft." and the corresponding technical contradiction can be stated as "If the size of the cutting edge is increased for efficient deburring, the durability of the shaft is reduced."

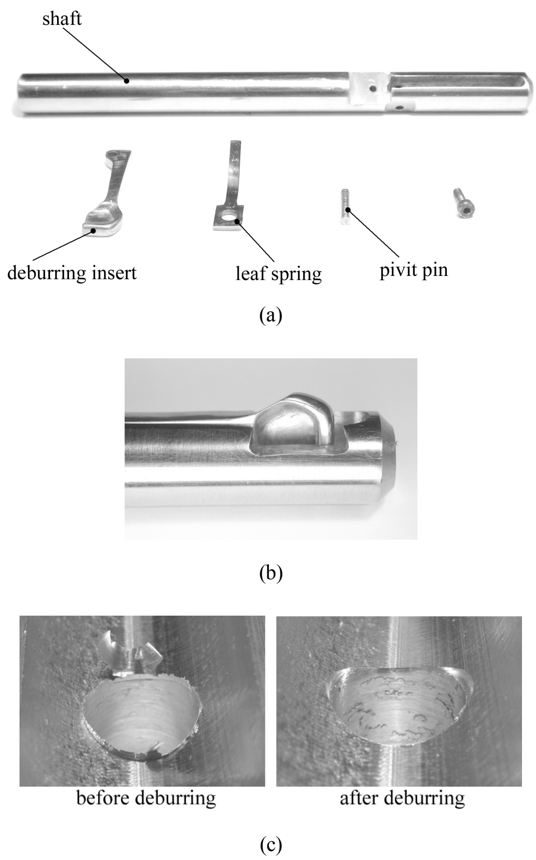


Fig. 2. The first design of the deburring tool [8]: (a) components, (b) assembly, (c) deburring of the intersecting edge of Al6061-T6: Primary hole dia. 18 mm; Secondary hole dia. 10 mm; Intersecting angle 90^{o}.

2.2 Design evolution from the first design

Technical contradiction analyses of the first design led to the solution guidelines from 40 inventive principles of TRIZ, which are summarized in Table 1. Different combinations of the inventive principles will lead to different designs. The "segmentation" in Table 1 suggests that the cutter head may be separated from the shaft. "Asymmetry" may pertain to cutter head geometry. Among the possible combinations, the second design of the deburring tool was reached after various conceptual experiments. The cutter head is separated from the shaft and is mounted on a slender member pivoted and loaded by a spring into the shaft. This way, the burr edge can be accessed with a greater flexibility of the cutter head geometry. The planar cutting edge in the first design is slanted toward the member such that it meets the burr edge in an oblique cutting condition. This "asymmetry" is useful for avoiding aligned encounters between the cutting edge and the burr edge. Protection of the inner surface of the secondary hole during access to and retreat from the burr zone can be provided by "the prior action" principle. In this case, the action will be the provision of a rounded edge at the end of the cutting edge, which contacts the inner surface of the access hole during access and retreat.

Fig. 3 shows the components and detailed view of the cutter head of the second design. The cutter head is inserted into the secondary hole up to the burr edge and is rotated counterclockwise with retreating strokes. Since the rotation of drill bits is usually clockwise, the counterclockwise rotation of the cutter head is expected to be more efficient for deburring.

With the second design, the length of the cutting edge can be increased with more freedom than the first design. The tool has wider ranges of operation than the first design in terms of the intersecting angle and diameter ratio between the intersecting holes. However, experiments show that when the intersecting angle is less than 45^{o} or the diameter ratio is close to unity, heavy engagements between the cutter head and the burr edge often lead to excessive cutting or tool damage. Fig. 4 shows examples of excessive cutting and tool damage for holes with d_1 = 12 mm and d_2 = 10 mm intersecting at a right angle. With the second design, the depth of cut cannot be controlled, and excessive cutting is unavoidable. The ideality of this problem is "Deburring without excessive cutting and tool damage." The physical contradiction for this problem can be stated as "The exposure of the cutting edge to the burr edge should be sufficiently large for efficient removal of the burr on a three-dimensional edge, but the exposure should be small enough to prevent excessive cutting."

Table 1. Frequency numbers of 40 principles for the first design.

Inventive 40 principles	Frequency
Segmentation	12
Pneumatic or hydraulic construction	10
Asymmetry	9
Prior auction	8

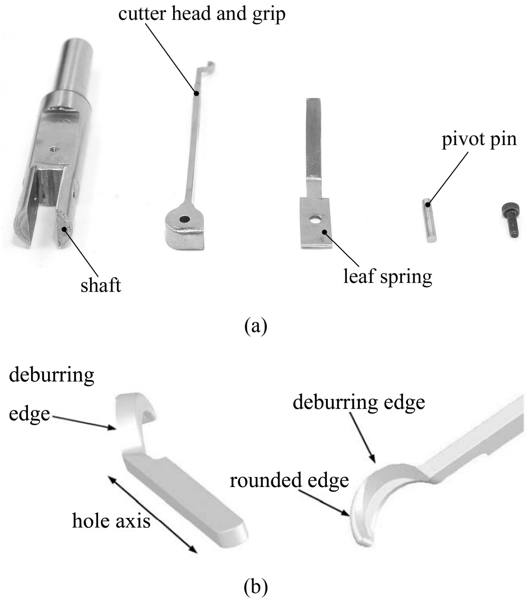


Fig. 3. The second design of the deburring tool [9]: (a) components, (b) details of the cutter head.

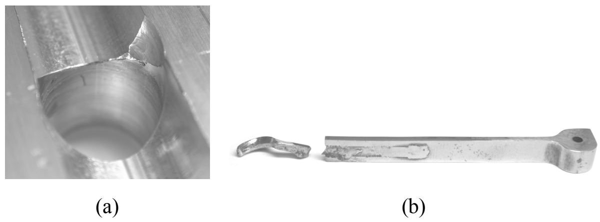


Fig. 4. Examples of excessive cutting and tool damage in the second design: (a) burr edge with excessive cutting, (b) damaged tool.

2.3 Design evolution from the second design

The third design was derived from the physical as well as technical contradiction analyses based on the second design. Among the separation principles as general solutions to physical contradictions, "Separation in space" suggests a cutting edge separate from the functional unit to limit the exposure of the cutting edge.

Technical contradiction analyses for the second design yields a list of solutions principles summarized in Table 2. A spherical cutter head can be suggested based on the "spheroidicity" principle. A rectangular slot on the hemisphere conforms to the "segmentation" principle. The slot generates two sharp edges. When this slot is slanted toward the axis of the secondary hole in accordance with the "asymmetry" principle, one of the two edges can be used as a cutting edge. The edge on the spherical surface opposite the cutting edge limits the exposure of the cutting edge and thus the cutter head is free from excessive engagement with the burr edge. By controlling the slot width and slot angle, proper combinations of rake and relief angles can be obtained. The "prior" action principle leads to a chamfer plane on the front end of the cutter head, which helps entry into the access hole. Fig. 5 shows the components and cutter head of the third design. Fig. 6 shows two cutter heads of the second and the third designs engaged with burr edges.

Table 2. The frequency numbers of 40 principles for the second design.

Inventive 40 principles	Frequency
Prior auction	15
Segmentation	12
Spheroidality	12
Asymmetry	10

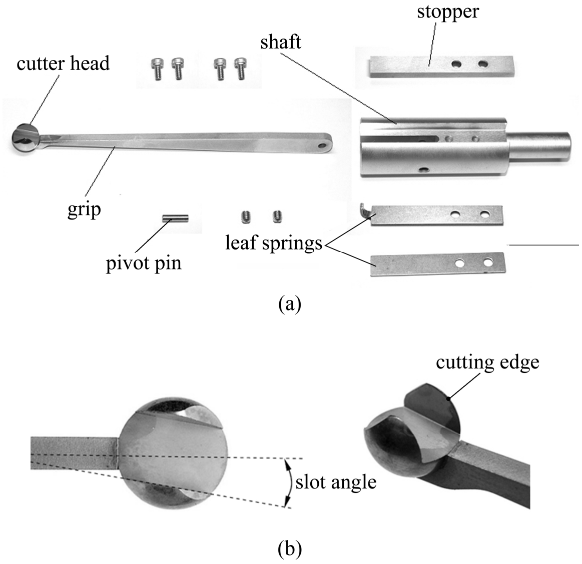


Fig. 5. The third design of the deburring tool [10]: (a) components, (b) cutter head with slot angle and cutting edge.

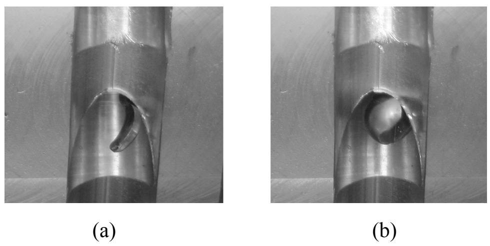


Fig. 6. Comparison of the cutter heads: (a) the second design [9] in excessive engagement with the burr edge, (b) the third design [10] with limited exposure of the cutting edge.

As shown in Fig. 5, the third design employs a hemispherical cutter head mounted on a slender member which is pivoted and loaded by leaf springs in a circular cylindrical grip. The displacement of the cutter head in the radial direction with respect to the axis of the access hole is limited by the stopper in Fig. 5(a). The cutting force is controlled by the preload and stiffness of the spring. The exposure of the cutting edge is dependent on the position along the cutting edge, as well as the slot width and slot angle as shown in Fig. 7. Experiments show that the cutting edge exposure below 0.3 mm gives reasonable results without excessive cutting. Fig. 8 shows the

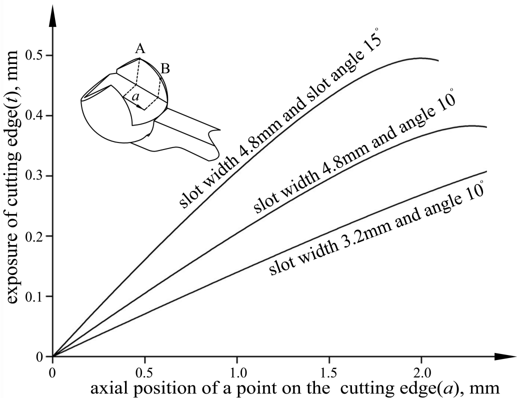
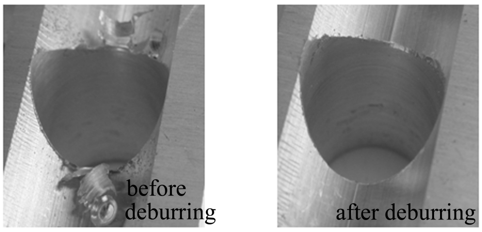
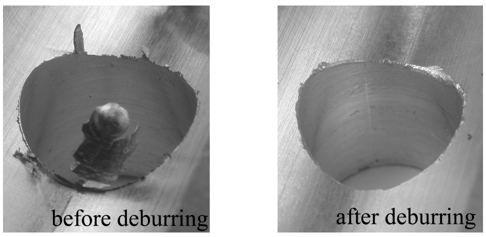


Fig. 7. Cutting edge exposure vs. the axial position of a point on the cutting edge for different combinations of slot widths and slot angles (Cutter head diameter is 8 mm).



(a)



(b)

Fig. 8. Burr edges before and after deburring Al6061-T6 at a spindle speed of 350rev/min and an axial feed rate of 20 mm/min: (a) Primary hole dia. 13 mm; Secondary hole dia. 13 mm; Intersecting angle 90°, (b) Primary hole dia. 20 mm; Secondary hole dia. 13 mm, Intersecting angle 90°. The cutter head diameter is 8 mm, and the slot width and slot angle are 4.8 mm and 10°, respectively.

deburring test results on AL6061-T6 for several diameter ratios and intersecting angles. For some combinations of spindle speed and diameter ratios, irregular cutting was observed (see Fig. 8(b)). Tool vibration is supposed to be the main cause of such a phenomenon. Further study is necessary for the improvement of irregular cutting.

3. Conclusions

The design evolution of a deburring tool for intersecting holes has been achieved within the framework of TRIZ. Two steps of evolution with three designs have been achieved by contradiction analyses in TRIZ. The second design was derived from the first design along the inventive principles of TRIZ such as "Segmentation," "Asymmetry," and "Prior action." The third design was reached by the principles "Separation in space," "Spheroidicity," "Asymmetry," and "Prior action." Deburring tests on AL6061-T6 show that the problem of excessive cutting of burr edges was successfully overcome by the third design. Tool vibrations leading to the irregular cutting of burr edges is a problem which needs to be addressed.

As shown in this case of deburring tool design, TRIZ can be a powerful tool for engineering design problems. Based on the authors' experience, even though TRIZ gives useful clues to solve engineering problems, the experiences, skills, and intuition of the engineer using TRIZ remain to be the most important factors governing the success of the solution process.

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