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TRIZ APPROACH FOR ANALYZING METHOD OF DIMPLE STRUCTURE FABRICATION

Mohd Nor Azam bin Mohd Dali[1,2], Jaharah A. Ghani[2] and Che Hassan Che Haron[2]
[1]Politeknik Ungku Omar, Jalan Raja Musa Mahadi, Perak, Malaysia
[2]Department of Mechanical and Material Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan, Malaysia
E-Mail: azam310777@gmail.com

ABSTRACT

TRIZ is the Russian Theory of Inventive Problem Solving, an approach to come out with systematic approach from identifying the problem to engineering solution. This paper presents the TRIZ approach in selecting conventional and nonconventional machining method that meet the goal of study for dimple fracture fabrication. From the analysis using TRIZ approach, the fabrication method of turning process is selected for dimple fabrication. The selection is mainly due to the goal of study i.e. performance, reliable and cheapest dimple structure fabrication method.

Keywords: TRIZ, dimple structure, conventional and nonconventional machining method.

INTRODUCTION

TRIZ is the Russian Theory of Inventive Problem Solving (Altshuller, 1988), this paper present the use of function analysis to find and eliminate contradiction in analyzing method that commonly used to fabricate the dimple structure. In TRIZ, the main axiom is that the evolution of technological systems is governed by objective laws, which Altshuller called Laws of Technological System Evolution. System conflict and ideality principle are the two fundamental axiom of TRIZ. In system conflict, a problem requires creativity when attempts to improve some system attributes lead to deterioration of other system attributes. For ideality principle, it is referred to the technological systems toward increasing ideality. At the ultimate an ideal system is no energy to operate, costs nothing to produce, occupies no space, has no failure mode, etc.

They are more frequently applied to practical problems using three principle sub-systems of TRIZ as shown in Figure-1 (Fey and Rivin, 1996). One subsystem is the algorithm for Inventive-Problem Solving (Russian acronym ARIZ), which is a set of sequential, logical procedures aimed at eliminating the system conflict at the heart of the problem. A second sub-system, Standard Approaches to Inventive Problems (Standard) is a set of rules for problem solving based on the laws stating that many problems from different areas of technology can be solved by the same conceptual approaches. The third sub-system, the Knowledgebase of Physical, Chemical, and Geometric Effects, greatly facilitates problem solving by suggesting analogies from prior creative solutions.

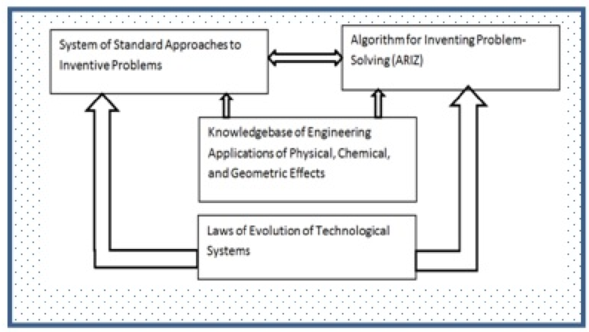

Figure-1. Three principal sub-systems of TRIZ.

Figure-2 shows the basic flow of problem reformulation using ARIZ. ARIZ is a set of successive logical procedures to reinterpret the initial problem through consecutive reformulations. Its structure consolidates two major ideas: System Conflict and the Ideality Principle. Since a technological problem becomes an inventive one when a System Conflict should be overcome, the problem for inventive-problem solving must include special subroutines to reveal and clarify these conflicts.

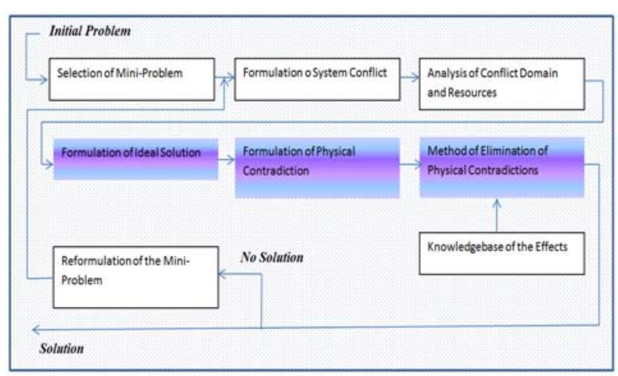

Figure-2. The basic flow of problem reformulation using ARIZ.

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Surface texturing for mechanical components is very important, especially towards enhancing the tribology properties. Tribology is closely associated to wear and friction which need to be minimized in order to ensure that the original function of a mechanical component moving in contact between the two or more surfaces of the working parts is correct and effective. Structured surfaces, alternatively termed textured surfaces or engineered surfaces, are becoming more and more important in advanced industrial technologies (Evans and Bryan, 1999). The ability to deterministically alter the topographic structure of a surface can have a profound effect on how that surface functions. According to Bruzzone *et al.* (2008), the function of a surface have led to the discovery of the distribution of micro dimples on the surface that act as a reservoir and provide lubrication to reduce friction by 30%.

DIMPLE STRUCTURE

Introduction to dimple structure

The ability to deterministically alter the topographic structure of a surface can have a profound effect on how that surface functions. As an application of the surface structures, the tribological properties have been associated with the surface structures. Because friction coefficient depends on the surface roughness, friction at the interfaces between substances is controlled by the surface structure (Yan *et al.* 2010). The mechanical, optical, tribological, and fluidic characteristics, as well as many other properties, can be altered by fabricating textures and micro-structures on a flat or curved surface. Typical surface structures are micro-dimples arrays, prism arrays, pyramid arrays, and micro-grooves (Yan *et al.* 2010).

According to Wang et al (2010), the patterns with micro-dimples are attracting more attentions since such closed texture cells are supposed to generate hydrodynamic pressure easier than micro-grooves. Use of dimples on the surface can significantly intensify the heat transfer enhancement (Patel and Borse, 2012) such as for turbine blade cooling, tube heat exchangers in chemical and textile industries, car radiators etc. Study done by Patel and Borse (2012), revealed that the thermal performance is increasing with Reynolds number. With the inline and staggered dimple arrangement, the heat transfer coefficients, Nusselt number and the thermal performance factors were higher for the staggered arrangement. The friction coefficient can be reduced by the micro dimples (Wakuda, 2003).

Meng *et al.* (2010) analyzed the effect of the micro dimples on friction coefficient. The micro dimples have also been used to maintain lubrication at the interface as found by Basnyat *et al*. 2008 and Voevodin and Zabinski (2006). They improved the tribological properties by micro reservoirs of solid lubrication. Aoki, Muto and Okanaga, (2009) investigated the relation between the drag and the flow pattern on the dimple structure (depth and shape of dimple) of a sphere from the experiments and the computation. They found that the critical region of a sphere with dimples shifts to the lower Reynolds number side compared to that of a smooth sphere. Then, the depth of dimple becomes deeper, the critical region shifts to the lower Reynolds number side.

As can be observed on lotus leaves, wettability also changes with the surface structure. The control of wettability has recently been required for the industrial uses. Wenzel (1936) reported the change in contact angle with surface roughness and presented a wetting model.

Fabrication of Dimple structure

Furthermore, the advanced manufacturing techniques provide precision and freedom for the fabrication of surface texture, which makes it possible to obtain better tribological performances by the optimization of dimple geometry and distribution. According to Wang, Yu, and Huang (2010), although circular dimples are low cost and easy for fabrication, modern micro manufacturing techniques are able to fabricate the dimples with other shapes. They found that, for the triangle dimple, the sliding direction that lubricant driven toward the base of the triangle was better than that toward the apex, and the elliptical dimple perpendicular to the sliding direction showed the better effect on the load carrying capacity than the cases of circular dimple and elliptical dimple parallel to the sliding direction.

The micro dimples were machined by abrasive jet or excimer laser beam (Wakuda, 2003). A single-crystalline diamond ball endmill has been used for generating micro-surface structures on two kinds of mold materials, oxygen-free copper and RB-SiC, respectively, and the cutting performance of the endmill was investigated experimentally by Yan *et al.* 2010. They found out that micro-dimple arrays, micro-grooves, and micro-pyramid arrays with extremely smooth surface and high-accuracy profile could be obtained on oxygen-free copper without remarkable tool wear. Matsumura and Takahashi (2012), investigated about micro dimple machining on a cylinder surface with a two-flute ball end mill. When the cutter axis is inclined and the depth of cut is less than the tool radius, non-cutting time, during which neither of the two cutting edges contacts the workpiece, appears in a rotation of the cutter.

There are many methods for producing a dimple structure. Table-1 shows a comparison of the various methods that have been reviewed.

ARPN Journal of Engineering and Applied Sciences

Table-1. Comparison of various methods reviewed for the production of micro dimples.

No	Method	Pattern	Dimple Specification	Researcher
1		Triangle Ellipse Circle	100 – 300 µm (diameter)	Wang, Yu, and Huang 2010
2	Electrochemical Micromachining		4 to 10 µm (depth)	Zhu et al. 2009
3	Milling		200 µm & 282 µm (diameter) 5 µm, 10 µm & 15 µm (depth) Distance between dimples 500 µm	Yan *et al.* 2010
4	Ultrasonic Nanocrystalline Surface Modification (UNSM)	Spherical	1.25 µm (diameter) 0.07 µm (depth)	Amanov *et al.* 2012
5	YAG laser	Circle Groove Groove (Triangular)	100 µm (diameter) 10 µm (depth) Diameter ratio = 0.4 50 µm (width) 100 µm (depth) 50 µm (width) 100 µm (depth)	Shum, Zhou, and Li 2013 Wu *et al.* 2012 Wu *et al.* 2014
6	Electrox Laser Marking Machine	Ellipse Circle		Qiu and Khonsari 2011.
7	Micro Tooling		400 µm (diameter) 20 µm (depth)	Taposh *et al.* 2014
8	Photochemical Machining	Circle Triangle	20 µm (diameter) 20 µm (length)	Zhang and Meng 2012
9	Miniature Engraving Machine	Cylindrical	300, 500, 700 µm (diameter) 50 µm (depth)	Tang *et al.* 2013
10	Laser Textured Surface	Circle Triangle Square	500 µm (diameter) 250 µm (diameter) 250 µm (diameter) 5.5 µm (depth) side length	Segu *et al.* 2013
11	Femtosecond laser	Circle	70 µm (diameter) 200 µm (diameter)	Lei *et al.* 2009

Solution using abridged ARIZ process

Solving a problem using ARIZ starts with a transition from a vaguely defined initial problem into a mini-problem that is formulated by "everything in the system remains unchanged, but the required function is realized' (Fey and Rivin, 1996). The steps of the process focus on the core of each problem and lead toward an Ideal System solution are as follows:

Problem statement

For this study the problem definition is to identify the reliable and cheapest dimple structure fabrication method among all the methods listed in Table-1. Capabilities to fabricate various shapes of dimple structure, conventional and nonconventional method are the issues that need to consider. For instances, various method of nonconventional method are commonly used compared to only one method of conventional method in fabricating the dimple structure. Attempts to use fabrication method that are commonly available, environmental friendly, cheap, easy to operate the machine, produce high quality and according to the specification dimples.

Mini-Problem

It is important to investigate the performance, reliability and cheapest dimple structure fabrication method.

System Conflict

Comparison of fabrication method performances is shown in Table-2.

Table-2. Performance of various dimple fabrication methods.

Methods	Shape of dimple	Size of dimple	Remarks
Electrochemical Micromachining		4 to 10 µm (depth)	Costly disposable of waste, high cost process due to long fabrication time, small size of dimple
Milling		200 µm & 282 µm (diameter) 5 µm, 10 µm & 15 µm (depth) Distance between dimples 500 µm	Cheaper process, big size of dimple
Ultrasonic Nan crystalline Surface Modification (UNSM)	Spherical	1.25 µm (diameter) 0.07 µm (depth)	Expensive process, very small size of dimple, limited shape of dimple
YAG laser	Circle Groove Groove (Triangular)	100 µm (diameter) 10 µm (depth) Diameter ratio = 0.4 50 µm (width) 100 µm (depth) 50 µm (width) 100 µm (depth)	Expensive process, hazardous (has to follow strict precaution), various shape of dimple, big size of dimple
Electrox Laser Marking Machine	Ellipse Circle		Expensive process, hazardous (has to follow strict precaution), various shape of dimple
Micro Tooling		400 µm (diameter) 20 µm (depth)	Intermediate process cost, various shape of dimple
Photochemical Machining	Circle Triangle	20 µm (diameter) 20 µm (length)	Costly disposable of waste, high cost process due to long fabrication time, medium size of dimple, various shape of dimple
Miniature Engraving Machine	Cylindrical	300, 500, 700 µm (diameter) 50 µm (depth)	Cheaper process, big size of dimple, limited shape of dimple
Laser Textured Surface	Circle Triangle Square	500 µm (diameter) 250 µm (diameter) 250 µm (diameter) 5.5 µm (depth) side length	Expensive process, hazardous (has to follow strict precaution), various shape of dimple, big size of dimple
Femtosecond laser	Circle	70 µm (diameter) 200 µm (diameter)	Expensive process, hazardous (has to follow strict precaution), limited shape of dimple, intermediate to big size of dimple

Reformulated problem: only two methods are identified as reliable and cheapest dimple structure fabrication method i.e. milling and miniature engraving machine. Normally miniature engraving machine is only suitable for soft materials fabrication. Therefore milling process is chosen.

Model of the Problem

Milling process is only suitable for fabrication of spherical shape of dimple. Other cheaper process is needed to consider that is able to produce various shape of dimple.

Analysis of the Conflict Domain and resources

The Conflict Domain is the principle of milling operation, i.e. the prismatic or rectangular block of work piece is stationary, and the cutter is rotating on the spindle head and move to in the direction of *x*, *y* and *z* as programmed using the G Code. The only resource is the shape of the cutter that will determine the shape and size of the dimple fabricated. To change the shape of the cutter will requires substantial time and cost (RND is required).

Ideal Final result (IFR)

The machining process should able to produce various shape and size of dimple structure. Therefore turning process is suggested. Special form tool can be mounted of the turning machine tool holder without further analysis of machine process stability.

Physical Contradiction

Physical contradiction presents in this study is such as cost of the machine, the skilled operator and the limited function of nonconventional machine that cause the limited machine availability. Milling process is suitable for a prismatic or rectangular block of workpiece, whereas turning process is for cylindrical shape part.

Elimination of the Physical Contradiction

The study will focus on the cylindrical shape part.

Engineering Solution

Develop the suitable form tools that can fabricate various shape and size of dimple structure. Investigate the range of turning parameters that suitable for dimple structure fabrication. In addition special assisted tool is required imitate the milling process i.e. the turning is behaved like intermittent instead of continuous cutting.

CONCLUSIONS

TRIZ provides simple solution by providing a systematic approach from identifying the problem to engineering solution. From the case study presented, the selection is justified using TRIZ approach, and found that the turning process is the most appropriate for dimple fabrication due to its low cost and ease of method.

REFERENCES

[1] Altshuller G. 1988. Creativity as an Exact Science, New York, Gordon and Breach.

[2] Fey V. and Rivin E. 1996. TRIZ : A New Approach to Innovative Engineering & Problem Solving, Traget (Periodical of Association for Manufacturing Excellence), Vol. 2, No. 4, pp. 7--13.

[3] Evans C. and Bryan J. 1999. “Structured” “textured” or “engineered” surfaces. CIRP Ann, Vol. 48, pp. 541—556

[4] Bruzzone A.A.G., Costa H.L., Lonardo P.M. and Lucca D.A. 2008. Advances in engineering surfaces for functional performance. CIRP Annals: Manufacturing Technology, Vol. 57, pp.750--769.

[5] Yan J., Zhang Z., Kuriyagawa T. and Gonda H. 2010. Fabricating micro-structured surface by using single-crystalline diamond end mill, Int J Adv Manuf Technol, Vol. 51, pp. 957--964.

[6] Wang X., Yu H. and Huang W. 2010. Surface Texture Design For Different Circumstances, TriboBR, First International Brazilian Conference on Tribology, 24-26 November 2010, Copacabana, Rio de Janeiro, Brazil.

[7] Patel H.I. and Borse l.S. 2012. Experimental Investigation of Heat Transfer Enhancement Over The Dimpled Surface, International Journal of Engineering Science and Technology (IJEST), ISSN : 0975-5462, Vol. 4, No. 8, pp. 3666--3672.

[8] Wakuda M., Yamauchi Y., Kanzaki S. and Yasuda Y. 2003. Effect of surface texturing on friction reduction between ceramic and steel materials under lubricated sliding contact. Wear, Vol. 254, pp 356--63.

[9] Meng F., Zhou R. Davis T., Cao J., Jane Q.W. and Diann H. 2010. Study on effect of dimples on friction of parallel surfaces under different sliding conditions. Applied Surface Science, Vol. 256, pp. 2863--75.

[10] Basnyat P., Luster B., Muratore C., Voevodin A.A., Haasch R. and Zakeri R. 2008. Surface texturing for adaptive solid lubrication. Surface & Coatings Technology, Vol. 203, pp.73--9.

[11] Voevodin A.A. and Zabinski J.S. 2006. Laser surface texturing for adaptive solid lubrication. Wear, Vol. 261, pp. 1285--92.

[12] Aoki K., Muto K., Okanaga H. and Nakayama Y. 2009. Aerodynamic Characteristic And Flow Pattern On Dimples Structure Of A Sphere, FLUCOME 2009, 10th International Conference on Fluid Control, Measurements, and Visualization, August pp. 17-21, 2009, Moscow, Russia.

[13] Wenzel R.N. 1936. Resistance of solid surfaces to wetting by water. Industrial and Engineering Chemistry, Vol. 28, pp.988--94.

[14] Matsumura T. and Takahashi S. 2012. Micro dimple milling on cylinder surfaces, Journal of Manufacturing Processes, Vol. 14, pp. 135--140.

[15] Wang X., Yu H. and Huang W. 2010. Surface Texture Design For Different Circumstances. First International Brazilian Conference Tribology 2010. ISSN pp. 2179-3956

[16] Zhu D., Qu N.S., Li H.S., Zeng Y.B., Li D.L. and Qian S.Q. 2009. Electrochemical Micromachining of Microstructures of Micro Hole and Dimple Array. CIRP Annals - Manufacturing Technology, Vol. 58, pp. 177--180

[17] Yan J., Zhang Z., Kuriyagawa T. and Gonda H. 2010. Fabricating micro-structured surface by using single-crystalline diamond endmill. Int J Adv Manuf Technol, Vol. 51, pp. 957—964.

[18] Amanov A., Cho I.S., Pyoun Y.S., Lee C.S. and Park. I.G. 2012. Micro Dimpled Surface by Ultrasonic Nanocrystal Surface Modification and its tribological effect. Wear, Vol. 286–287, pp.136—144.

[19] Shum P.W., Zhou Z.F. Li. 2013. Investigation of the tribological properties of the different textured DLC coatings under reciprocating lubricated conditions. Tribology Internationa, Vol. 65, pp. 259--264 .

[20] Wu Z., Deng J., Zhang H., Lian Y. and Zhao J. 2012. Tribological behavior of textured cemented carbide filled with solod lubricants in dry sliding with titanium alloys. Wear, 292-293. pp. 135--143.

[21] Wu Z., Deng J., Su C., Luo C., Xia D. 2014. Performance of the micro texture self-lubricating and pulsating heat pipe self cooling tools in dry cutting process. Int. Journal of Refractory Metal and Hard Materials, Vol. 45, pp. 238—248.

[22] Qiu Y. and Khonsari M.M. 2011. Experimental investigation of tribological performance of laser textured stainless steel rings. Tribology International, Vol. 44, pp. 635—644.

[23] Taposh R., Choudhurya R., Azuddin. and M, Murphy B.P. 2014. Fabrication and characterization of micro-dimple array on Al_2O_3 surfaces by using a micro-tooling. Ceramics International, Vol. 40, pp. 2381—2388.

[24] Zhang J. and Meng, Y. 2012. A Study of Surface texturing of carbon steel by photochemical machining. Journal of Materials Processing Technology, Vol. 212, pp. 2133--2140.

[25] Tang W., Zhoua Y., Zhua H. and Yanga H. 2013. The effect of surface texturing on reducing the friction and wear of steel under lubricated sliding contact. Applied Surface Science, Vol. 273 pp. 199-204.

[26] Segu D.Z., Kim J.H., Choi S.G., Jung Y.S., Kim S.S. 2013. Application of Taguchi Techniques To Study Friction and Wear Properties of MoS_2 Coating Deposited on Laser Textured Surface. Surface & Coating Technology, Vol. 232, pp. 504--514.

[27] Lei S., Devarajan S. and Chang Z. 2009. A Study of Micropool Lubricated Cutting Tool in Machining of Mild Steel. Journal of Materials Processing Technology, Vol. 209, pp. 1612—1620.