A Review of the Milling Process to Fabricate a Dimple Structure

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ABSTRACT

Surface texture has become the main element in reducing friction on any moving surface. Dimple structure, is a surface texture that is produced through various processes like electrochemistry, electric-term, electrolysis, laser and machining. Vibration-assisted machining technique is the latest technique in the dimple structure fabrication. It has been proven to impact the roughness of the surface machined. Its application in the dimple structure fabrication is still at an experimental level as compared to the vehicle component surface. In this review, the dimple structure fabrication process via (turning milling) and vibration assisted technique are discussed to help the researchers understand the suitable dimple structure fabrication process to be applied on the vehicle lubrication system

Keywords: *Vibration Assisted Machining, Milling, Dimple Structure*

Introduction

The dimple structure acts as an oil reservoir on a moving engine component. Previous research showed that the dimple structure could reduce erosion of about 30-50% in the engine components. A manufacturing process and the dimple structure machining parameter are vital in determining the quality of

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each dimple [1]. A quality dimple structure is translated via its ability to reduce or increase the tribological attributes of the rubbing/sliding surfaces. There are two functions of a dimple structure; it acts as a reservoir, Fig. 1 and as a foreign item filter/trap in the lubricant [2][3] It helps in the formation of hydrodynamic lubrication during the lubricating process [4][5]. The dimple structure application depends on the shape, depth, arrangement and the surface roughness.

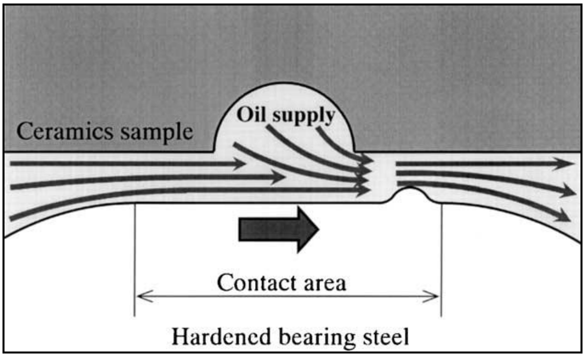


Figure 1: Application of dimple as oil reservoirs [6]

This is determined through the manufacturing process and the machining parameter. This parameter is still under research for its application in a real situation. There are two methods in the dimple structure fabrication via milling machining, vibration-assisted milling machining and conventional milling, Figs. 2 and 3. Both methods have significant impacts on the high production rate, time and low production costs [7].

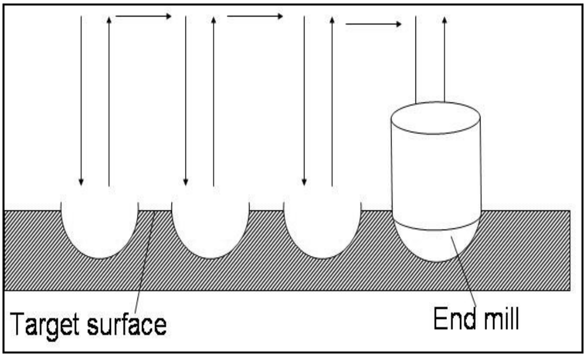


Figure 2: Conventional milling technique [8]

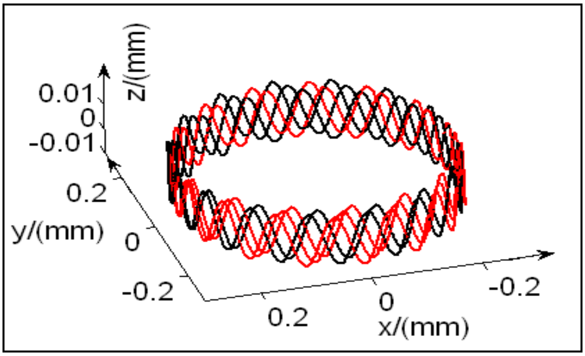


Figure 3: Vibration-assisted milling machining [9]

Milling Dimple Structure Process

The dimple structure production process has been extensively used in several earlier reports. This has been due to the milling process being a flexible process, which uses a combination of various cutting techniques and cutting tool geometry that is able to produce various dimple structures on the working material [10]. In conventional industry, the dimple structure is produced on a large scale via the photolithographic technique, plastic formation process and milling [11][12][13]. According to Shinichi et al., [14] the conventional milling is a movement of the cutting tool in a vertical or a horizontal direction that produces the dimple structure. This technique is very time consuming. There are many factors that support the use of the milling process for the production of a dimple structure. Some of them are - a high disposal of the working material, accurate surface neatness and applications using various working materials [10]. Besides, the milling process can produce various dimple structures by simply changing the cutting techniques [10]. Takashi et al. have studied the effect of the slope of the cutting tool on the dimple structure surface via simulation and experimentation [15]. It was discovered that while the slope and the depth of the cutting tool were lesser than its radius, there was no cutting on the working material. Besides, a high feed rate could prevent overlapping of the dimple structure during the machining process [7]. The combination of the cutting tool movement in a vertical or a horizontal direction along with a high feeding rate during the milling process could produce a dimple structure on the working material surface [8]. A dimple structure fabrication process using the conventional milling is very time consuming. Moreover, a constant movement of the cutting tool will cause a deterioration of the cutting accuracy [8]. Hence, a new technique needs to be developed in order to produce a high-accuracy dimple structure

Table 1: Milling machining methods and their effect on the surface tribology.

RESEARCHER	YEAR	METHOD	FINDING
Taposh et al.	2015	Micro drilling	Dimple structure could reduce 22% friction and 53% erosion on the hip joint.
Taposh et al.	2014	Micro drilling	To investigate any mechanical change and the presence of wear particles during the dimple fabrication process using micro tooling. Micro dimple fabrication process succeeded without any damage on the mechanical attributes
Eldon et al.	2013	Micro milling	Surface texture produced on a bigger surface will be valued for its effectiveness on the tribological attributes. Machining method to produce a dimple was a viable method
Shinichi et al.	2008	Milling	Suggested the use of a machining centre to fabricate the dimple structure. Dimple structure could be fabricated on a metal surface using a sub-millimetre ball end mill.
Jiwang et al.	2010	Milling	Investigated the performance of a ball end mill cutting through the surface roughness and accurate machining of working material and cutting tool erosion attributes. Cutting performance depends on the direction of the cutting tool feeding rate.
Takashi et al.	2014	Milling	When the slope of the cutting tool and its depth was less than its radius, no cutting took place

			on the machining. No overlapping occurred at a high feeding rate.
Shinichi et al.	2015	Milling	New technique to fabricate a dimple via milling using the end mill tooling. Able to estimate a dimple geometry via the horizontal movement of a cutting tool
Takashi et al.	2013	Milling	New mechanistic model developed to control the form and dimple structure alignment. Develop an error model to estimate the machining accuracy. Testifying Error Model and mechanistic via simulation
Jesus et al.	2015	Milling	Effect of friction direction on textured aluminium surface. Sliding reaction does not depend on the friction direction from its coefficient friction

Table 1 showed the machining process by previous researchers focusing on cutting tool and machining parameters to produce a dimple structure on the working material surface. These two aspects are dominant in fabricating the dimple structure in order to improve the surface tribology attributes

Vibration-assisted Machining (VAM) Process

The VAM was a machining method that was first applied by the industry in 1950, in the micro scale metal-cutting applications [16][17]. However, its use was still limited, and research focused more towards an understanding of the VAM basic concept. In mid-1980, VAM was deeply researched on steel, glass and ceramic materials. As a result of using the VAM, the lifespan of the cutting tool and surface roughness could be increased [16]. It is a machining method where both the amplitude and the frequency are exposed to a cutting tool or the working table while the working material cutting process is taking place [18]. Low amplitude value and high frequency are used during the working material cutting process [16]. The combination of the cutting speed, amplitude and suitable frequency could reduce the machining force and this will result in accurate surface neatness, high accuracy approaching zero burrs as compared to the conventional machining [19]. The cutting tool life span could be increased with the use of the VAM process during fragile and ferrous working material cutting [19]. There are two types of VAM processes in fabricating the dimple structure; 1-Dimension and 2-Dimension, as mentioned in Fig. 4 [20][21].

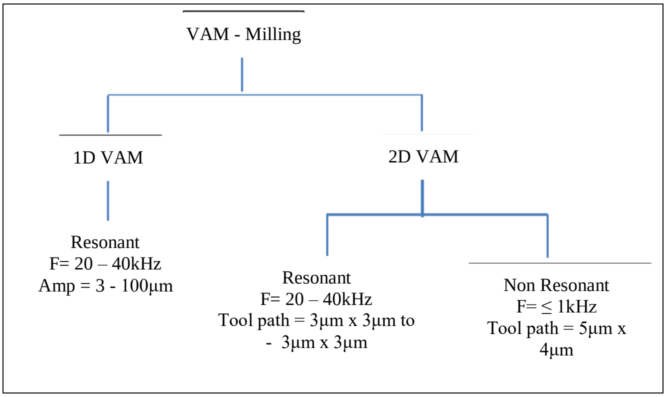


Figure 4: Type of VAM

Table 2: Vibration Assisted Machining Method and its Effect on the Tribology Surface

RESEARCHER	YEAR	METHOD	FINDING
Xuehui and Jianhua	2013	Ultrasonic Vibration assisted milling (UVAM)	Studied tribology attributes on the surface texture produced through UVAM method. Experimental results showed that the UVAM force could change morphology of the surface machined
Rendi Kurniawan and Tae Jo Ko	2014	Elliptical vibration machining	Design new tool holder for fabricating the dimple structure

		(EVM)	Micro dimples and grooves have been successfully built using a new tool holder
Hui Ding et al.	2010	Two dimensional Vibration Assisted Micro Enn Milling (2-D VAMEM)	2D VAMEM was produced for the hardened tool steel machining Researched vibration parameter effect on the surface roughness and cutting tool wear off 2DVAMEM could be used in making a mould or dice where it could increase the machining competency, surface quality and cutting tool life span
Xue and Guo	2015	Ultrasonic Vibration Assisted Milling (UVAM)	Two surfaces micro texture such as Micro Scale Texture (MST) and Micro Furrow Texture (MFT) were produced via the UVAM. The behaviour of MST and MFT were analysed with lubricant oil in the sliding position and compared to the non-texture surface. UVAM could increase the MST and MFT surface roughness as compared to the non-texture surface. MFT was better as compared to MST UVAM could increase the tribology attributes especially bearing capacity and resistance wear off.
Lian et al.	2013	Ultrasonic	UVAM investigated the

		Vibration Assisted Milling (UVAM)	surface roughness Al6061 with vibration and without vibration. Amplitude Ultrasonic vibration gave an optimum value on the Al6061 surface roughness.
Xue et al	2012	Ultrasonic Vibration Assisted Milling (UVAM)	Investigated the UVAM effect in micro end milling machining. Compared the cutting force effect, chip formation, surface topography and machining dimension accuracy. Chip formation with vibration in feeding direction, is small and consistent UVAM in feeding direction has negative effect on surface roughness and positive on dimension accuracy.
Xiaoling and Boyuan	2015	2D Vibration Assisted micro milling (2D VAMM)	Researched the vibration direction effect, vibration amplitude and frequency on the surface roughness. Vibration in the normal direction has great impact in increasing the surface quality.
Ding et al.	2010	2D Vibration Assisted micro end milling (2D VAMEM)	Model 3D cutting force by 2D VAMEM was analysed. Two models were taken to test the amplitude effect at the maximum level cutting force and average level cutting force

The cutting outcome using UAM has become the main focus in improving the surface tribology attributes as compared to the milling machining process to produce a dimple structure. The vibration and amplitude produced from the VAM process have a real impact on the working material surface.

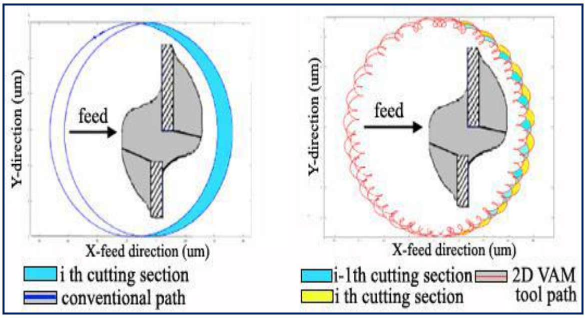


Figure 5: Mode of machining in the conventional and 2-D VAM milling [20]

Nowadays, the VAM method has been widely used in composite and optic glass and is hard to machine [9]. It is because the consistent overlapping route of the cutting tool will produce thin chips every time the cutting occurs and this will reduce the cutting force and heat. According to Masahiko et al., the heat generated during the cutting process could be reduced by using a vibration assisted technique. Fig. 5 showed the comparison between the conventional machining and 2D VAM milling process [20]. The effect of 2D VAM cutting technique could increase the material disposal rate and increase the machining competency from the production time, rate and cost aspects, Fig. 6.

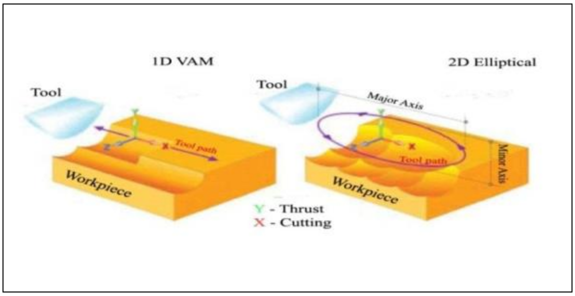


Figure 6: Types of VAM based on the modes of vibration (a) 1-Dimensional VAM, (b) 2-Dimensional VAM [20]

One Dimensional 1D Vibration Assisted Method

This is the first method used in machining to produce a dimple structure. This method consists of two types of cutting tool moves which are parallel to the Z-axis or the working table movement parallel to the Z-axis to produce a dimple structure, Fig 6

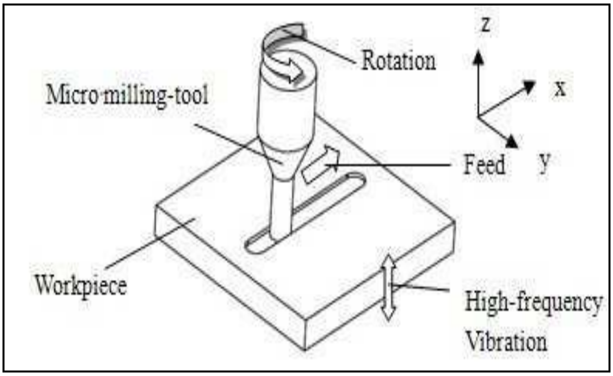
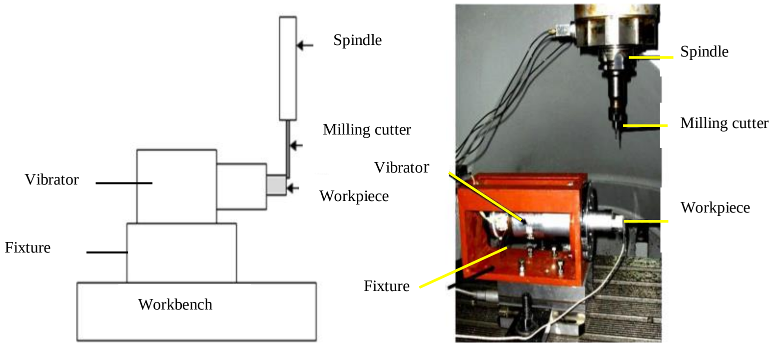


Figure 7: The principle schematic diagram of VAM [9]

The most studied method fabricates the dimples by moving the working table, Fig. 8. The working table is moved by a certain frequency value to produce dimples. However, the dimple structure accuracy also depends on the macro geometry angle of the cutting tool, feeding rate and axis movement speed ratio along with cutting speed [22].



(a) Illustration (b) Photo

Figure 8: Fabricating setup a: Illustration b Photo [18]

Two Dimensional (2D) Vibration Assisted Method

This method was developed after the 1-D VAM process had been widely used to produce the dimple structure. A 2-D VAM concept was first introduced in 1990, with the objective to reduce the force and the lifespan of the cutting tool surpassing the performance of 1-D VAM process [16][23][24]. In this method, the cutting tool moves along the X-axis and Z-axis while cutting the working material. It is also known as elliptical motion cutting [21], based on the movement while the cutting occurs. Most of the assisted tooling was focused on the cutting tool movement rather than the working table. According to Chang et al., the 2-D cutting technique could decrease the cutting performance where the cutting tool wear-off could be

reduced and the machining accuracy could be increased during alloy machining Al 6061 [25]. Ding et al., discovered that during the HRC 55 and HRC58 hardened tool steel machining, the 2-D technique could reduce 5 - 20% of the tool wear as compared to the conventional method [26]. The use of the 2-D cutting technique can reduce the cutting force, improve surface neatness, prolong the cutting tool lifespan and is able to cut fragile and hard machine materials [27][28][29]. The research carried out by Rendi et al., found that a correct plane surface and low surface roughness were produced by using the 2-D vibration assisted tool that was developed [30].Ding et al., [26] discovered the HRC tool steel (without vibration) roughness value of 0.53 μm, as compared to 0.15 μm with vibration. Besides, the frequency and amplitude also affects the material surface roughness. The research by Xioling and Boyuan found that by reducing the waviness on the machined surface, the surface roughness could be reduced [31]. Their research found that the vibration assisted in a normal direction was the main factor in increasing the quality of surface machined. The 2-D machining was used mainly for the development of a cutting tool holder in order to generate a 2-dimensional movement in the working material cutting. The Piezoactuator was the main component to generate a 2D movement. This movement is sent to the cutting tool while the milling process is taking place. However, a high dynamic movement during the operation can cause a generation of heat on the actuator ring [22]. The heat effect will result in the deterioration of the machining accuracy.

Cutting Process in the Vibration Assisted Milling

The phenomenon of controlling the vibration during machining is an approach to increase the machining efficiency. The cutting tool vibration along the elliptical trajectory will form a dimple structure on the working material surface [32], Fig. 9. According to Shen et al., the vibration parameter and machining were controlled in order to form a geometry morphology scale during the machining process [33]. Ping et al., stated that the surface form and the texture pattern depend on the vibration trajectory form, cutting speed, feeding rate and the cutting tool geometry.

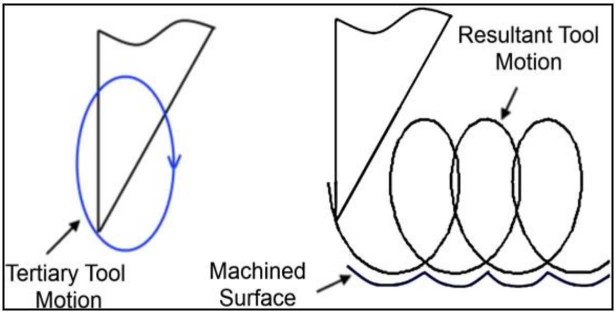


Figure 9: A Schematic representation of the elliptical vibration texturing process [32]

By applying the vibration on the cutting tool during the machining process, the quality of the surface machined is increased. The quality of the machining can be upgraded by applying a high-frequency vibration during the cutting process [34]. During the 2-D cutting process, the loss of the cutting tool consistent touch on the working material surface will reduce the cutting force, vibration and the cutting zone temperature [25][34]. Lian et al., [9], stated that the Hammer effect existed during the UVAM process when the cutting tooth constantly hit the working material at high frequencies. This would cause a thin chip formation and could avoid the formation of micro cracks on the working material surface and cutting

edge [34]. Takashi et al., found that the dimple machining occurred at a certain slope of the cutting tool with a high feeding rate. No material cutting occurred when the cutting tool slope and its depth were less than its radius during a cutting circuit [35].

Application on Flat Surface

The global demand for cost saving and high-performance vehicles has recently become the main issue for all the car manufacturers. Almost 2/3rd of the engine performance loss was caused by vibration and wear off, Fig 10 and Fig 11

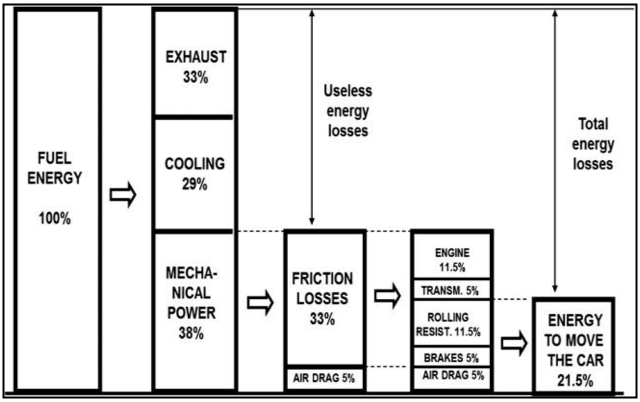


Figure 10: Mechanical losses distribution in an internal combustion engine [36].

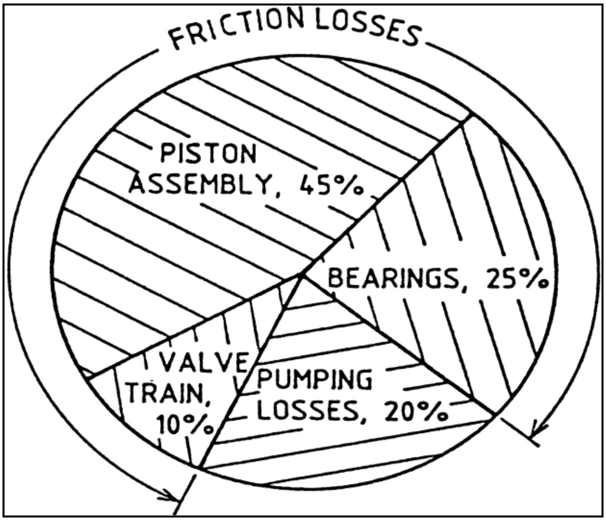


Figure 11: Breakdown of the passenger car energy consumption [37]

To meet the global demand, the vibration source and wear-off need to be minimised primarily. A surface structure like dimple has been identified as one of the solutions [36][38]. According to Ryk et al., [39], it was discovered that the micro dimple on the piston ring surface could reduce the friction by 25%. According to Sapawe et al.,[40] , the main issue in the mechanical system is to reduce wear and friction are the main focus of researchers. The reduction of wear and friction will be an impact on the fuel consumption and energy competency of the vehicles. In other words, billions of dollars per year could be saved if the component life can be enhanced by understanding the characteristics and the ability to reduce and control the wear and friction. These two aspects have become the main focus in the global automotive industry where the manufacturing technique and the surface geometry need specific attention [41]. According to Lawes et al., [38], an increase in the engine competency played a main role in the reduction of the CO_2 global disposal through better fuel saving for the customers. According to Eldon and Jesus [41][42], the value of the friction coefficient on the non-dimple surface is higher when compared to the surface with a dimple in both the cases, with or without lubrication. The application of the dimple structure in real-life situations is limited. So far, studies are still at their experimental level. Research on the flat surface was done using the fabricating machine guide ways. Yukeng et al., discovered that a dimple structure acted as an oil reservoir on the guideways and had effectively reduced the maximum pressure touch during sliding [43]. The dimple structure could also generate a hydrodynamic pressure in the surrounding environment and this would widen the hydrodynamic lubrication regime of the guideways surface [44][45][46]. The research in the automotive industry is mainly focused on the cylindrical surface component rather than the flat component. Shim surface on the valve train is a flat surface that contributes to 10% of the friction losses. The Fig. 10 is still not fully explored with respect to the surface texture aspect. Components like 'shim' have an impact on the vehicle engine performance in the case of a wear off.

Conclusion

The machining process via a VAM for fabrication of the dimple is still at the research level and needs to be studied and applied in the real situations of friction and wear off. Its objective is to observe the effectiveness of dimple structure, acting as a reservoir and a foreign item filter in the lubricant. Generally, a dimple structure can be produced by using this process. Most studies on the production of a dimple were mainly focused on the table movement and comparatively fewer studies focused on the cutting tool. The complication in applying the VAM process on the cutting tool needs further study. The surface roughness resulting due to the dimple structure needs to be upgraded since surface roughness is a main aspect in tribology. This is vital in upgrading the material tribology attributes based on its application in the automotive industry which is more challenging along with meeting the global demand. Besides, a low-frequency machining for producing the dimple structure needs to be explored further to determine the effect of its use on the dimple structure.

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