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High Frequency and Amplitude Effects in Vibratory Media Finishing

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Abstract

The vibratory media finishing process is known for its long process time and there is an industrial need to speed up this process. Increasing frequency and amplitude of vibration, beyond the current process window commonly used, is an option to reduce process time. Using a laboratory scale electro-magnetic shaker setup, the effects of increasing frequency and amplitude of vibration is investigated. By monitoring the surface roughness with processing time it is shown that, while for a given amplitude frequency has a strong effect, amplitude in general has a stronger effect in quickening the time to saturation. Using high-speed camera measurements in a transparent bowl it is also shown that the average media speed increases with increase in frequency and this can partially explain the resulting shorter process time.

Keywords: Vibratory media finishing, high frequency, amplitude

1 Media finishing process, parameters and usual parameter window

Vibratory media finishing systems produce a polishing action on various industrial components that is very thorough. The process removes material from pockets and recesses and inside bores, a task not easily achievable by other processes, so it can be used for very delicate or intricate parts(Holzknecht 2009). Vibratory finishing media consists of bonded abrasive or non-abrasive materials in preformed shapes where the material is in granular form and held together by a proprietary mix of binders. Although a variety of shapes are used, the most common include pyramids, triangles, cones, cylinders and spheres with the maximum size normally limited to sides of 25 mm or less. As no standard classification schemes

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exist, media are loosely classified based on cutting action and referred to as ‘rough-cut’, ‘medium-cut’ or ‘finish-cut’. The key to the vibratory media finishing is pressure and speed. The higher the pressure exerted by the media on the parts, and the faster the media “rubs” on the parts, the faster the desired finishing results can be achieved.

There are several process parameters that influence the vibratory finishing process Gillespie (Gillespie 1975). Some of these parameters are inter-related as reported via detailed experimental investigation by Wang et al (Wang, Timsit et al. 2000). The changes in roughness were found to depend mostly on the lubrication condition, the media roughness, and the size of the media, since these influenced the interaction between the media and the work piece, and hence the extent of plastic surface deformation per impact. Sofranos and Taraman (Sofronas and Taraman 1979) experimented the effect of five variables of vibratory machining process such as work piece hardness, projection width, processing time, media size and vibration frequency on three responses such as projection height reduction, edge radius and surface finish reduction. They have used statistical approach known as response surface methodology to formulate a relationship between the above mentioned parameters. The examination showed that increasing the processing time, media size or vibratory frequency increases the effect on three responses. Their study revealed statistically that high frequency is important among all the processing variables considered. Baghbanan et al (Baghbanan, Yabuki et al. 2003) studied the tribological behavior of aluminum alloys in a vibratory finishing process. The nature of the normal and shear forces, and the variations in surface properties in a tub vibratory finisher were comparable to those in a smaller bowl finisher that had a much smaller amplitude and frequency as well as a completely different media bulk flow pattern (two-dimensional circulation in the tub and three-dimensional spiral flow in the bowl), which suggested that vibratory finishing data and observations can be generalized and are not specific to a particular machine, frequency or amplitude. Pradeep et al (Prakasam and Subbiah 2013) tried to understand the type of media motion and characterized the impact type and scratching type of media contact influencing wear mechanisms in vibratory finishing process by analyzing the acoustic emission signals. Work by Fraas(Fraas 1996) uncovered that by controlling the amplitude and frequency of the finisher, media particles can be fluidized and complex flow fields can be developed within the chamber. As a result, depending on the parameters of the process, this can produce a wide range of contact conditions involving varying degrees of rubbing, burnishing, ploughing, cutting and three-body abrasive wear. Work of Domblesky et al (Domblesky, Cariapa et al. 2003) reveals that material removal rate is directly proportional to the resultant bowl acceleration with higher accelerations giving increased material removal rates. Vibratory bowls in industries normally operate in a range of 30 Hertz to 50 Hertz and they vary in amplitude from 1.5 mm to 3 mm; these ranges represent the most common process window employed. The experimental findings reported in the literature tend to stay within this process window.

In summary, while both academic and industrial research in mass finishing focused on process parameter effects, the process parameter windows investigated has largely been limited to a narrow window. There have not been any reports that describe the effect of the frequency individually on media particle motions, nor investigate material removal characteristics at very high frequencies and amplitudes beyond the usual process window and explore relationship of these parameters with the lead time to attain saturation surface roughness. This research attempts to fill this knowledge gap. The objective of this research is to find the effect of increasing the frequency above the typical frequency/amplitude ranges used conventionally in the existing vibratory media finishing process practiced in industries.

2 Lab Setup for High Frequency and Amplitude Application

The industrial vibratory media finishing machine setup and vibratory motor limits the possibility to increase the frequency/amplitude beyond the existing process window limits. The frequency can only be increased by using an alternative mechanism. An electro-magnetic shaker system shown in Figure 1 which is used for high frequency testing of structures was modified to provide the necessary frequency and amplitude.

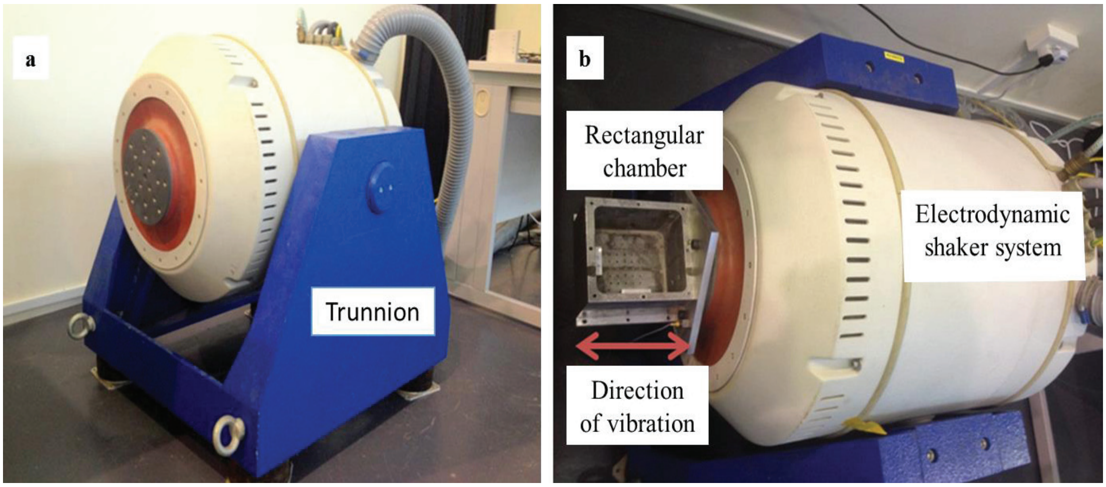

Figure 1. (a) Vibration exciter S 55240/LS-340 aligned horizontally to provide an ideal one-dimensional vibration (b) Experimental setup -Aluminium bowl attached to the shaker (view from top) .

2.1 Experimental Setup for High Frequency and Amplitude

The electro-magnetic shaker system is computer controlled and is capable of operating in the frequency range of 5 Hz to 3000 Hz. The shaker system has a feedback loop system comprising of an accelerometer which is attached to the vibrating bed of the shaker system to ensure that the system operates according to the input parameters given. Electro-magnetic shaker is mounted on a trunnion and aligned horizontally to provide a one-dimensional vibration. The vibratory motion is transferred to the media using a bowl which was attached to an armature via vibrating bed with load bearing capacity of 10kgs. It was ensured that the armature of the vibrational shaker was parallel to the horizontal axis of the shaker system by means of a 3-dimensional accelerometer.

The bowl is fabricated with a single-piece aluminium block as the bowl would be subjected to vibration. The aluminium block had the provision of attaching it to one face of the fixture plate making it viable to be vibrated and attached to the vibrating bed of the shaker system. The chamber is filled with industrial grade ceramic abrasive media. The ceramic abrasive media used are angled and edge shaped and more aggressive than rounded shapes and they produce a fine finish. This formulation provides a high performance cutting action for de-burring and metal removal. The overall weight of the media filled aluminium bowl is around 2.2 kgs; this represents the moving mass in the shaker system. Milled work coupons of uniform surface roughness (Ra) of 1.5µm is fixed to the wall of the chamber which is parallel to the direction of vibration and the media motion using a double sided epoxy tape as shown in Figure 2. Surface roughness (Ra) of the work coupons is measured with a tactile probing Taly-scan.

Figure 2. Positioning of the work piece in the aluminium bowl

2.2 High Speed Camera Observation

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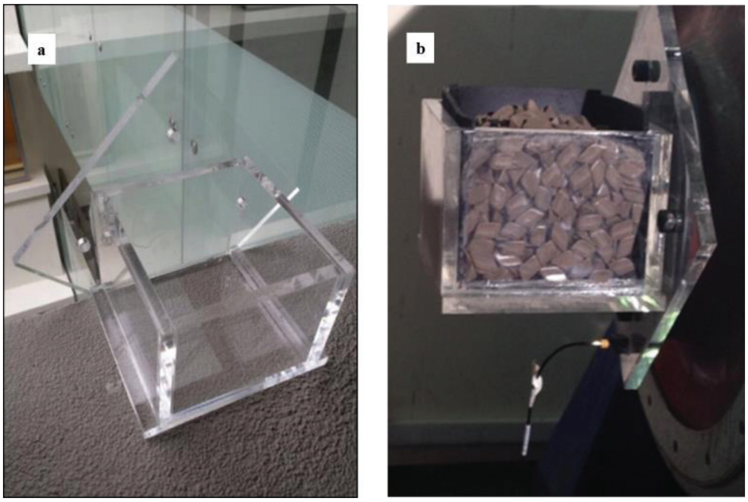

Figure 3. (a) Acrylic bowl fabricated (b) crylic bowl filled with tri-star ceramic abrasives

To visualize the media particles motion and to analyze the interaction between the work piece and abrasive particles a transparent work bowl was fabricated using Poly (methyl methacrylate-PMMA) see-through thermoplastic as shown in Figure 3. The acrylic bowl is of same dimensions of the aluminium work bowl to visualize and imitate the motion and velocity of the ceramic abrasive particles when subjected to higher frequencies and amplitude. The motion of the abrasive particles were videotaped with a high speed photron monochrome camera system capable of capturing motion at 100 frames per second as shown in Figure 4.The motion of the abrasive particles inside the bowl, as the result of the applied frequency and amplitude vibration, were captured. Recording was done at a rate of 60 frames per second with the high-speed camera.

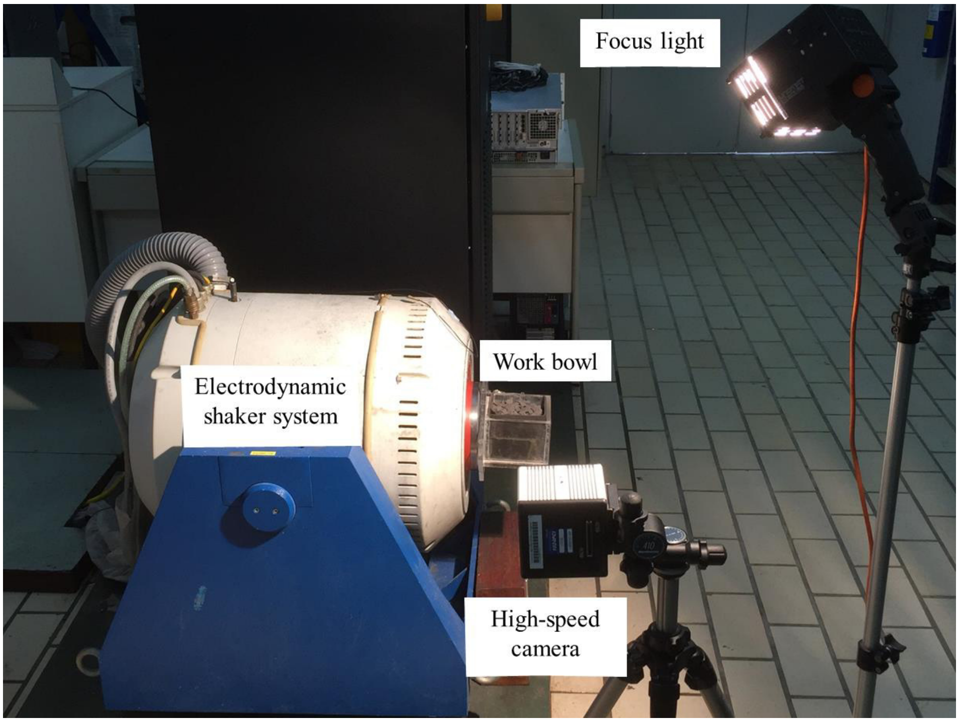

Figure 4. High-Speed Video system used to record the motion of the finishing media.

2.3 Design of Experiments with two levels of frequency and amplitude

Experiments are conducted using a basic Design of Experiments (DoE) approach varying the frequency and amplitude for different time intervals. Two-level full factorial experiments were planned in which the frequency and amplitude factors are investigated at two levels for both acrylic and aluminium chamber. Preliminary experiments at frequencies approaching 1000 Hz were attempted resulted in very small amplitudes of motion at which polishing action was hardly possible. Very high frequencies of 1000 Hz were imparted on the work bowl in preliminary experimental testing. As the frequency was higher the amplitude of the system was very small in order of 0.05 mm which did not have any effect on the motion of the abrasive particles. Very high amplitudes of 5mm were also attempted. As amplitude value increased the frequency decreased to around 15 Hz making the abrasive particle to be at rest and making the process inefficient. These observations revealed that an optimum frequency and amplitude combination window had to be found out with the electro-magnetic shaker system to ensure that process is effective in 1-dimensional vibration. Considering the maximum operational amplitude at different frequencies the following two levels of frequencies and amplitudes were considered: 50 Hz and 100 Hz for frequency and 0.7 mm and 1.4 mm for amplitude so that all factor combinations were possible to execute using the shaker system (summarized in Table 1).

Table 1 Parameters and levels used in DoE

Parameter	**Level 1**	**Level 2**
Frequency	50 Hz	100 Hz
Amplitude	0.7 mm	1.4 mm

The measured output of the experiments were in the form of progress of surface roughness (Ra) of the mounted workpiece with process time and the corresponding media motion (camera motion and velocity) for the various amplitude-frequency combinations. The surface roughness (Ra) of the work sample is measured at equal intervals of 15 minutes. The aluminium-alloy (6061) sample of dimension (30 mm x30 mm x10 mm) that are media finished at various frequency-amplitude combinations were taken out at equal intervals of 15 minutes and the roughness's were measured using a surface profiler. The measurements are taken from 15 different locations across the lay of the milled surface. After the measurements the samples are again placed in the center of wall parallel to the vibration and process is continued.

Experiments with the aluminum work pieces are carried out in the aluminium bowl. Following conditions are maintained constant.

- Position of the work piece (center of wall parallel to the vibration)
- Amount of the abrasive particles that are filled (90% of the bowl is filled with abrasives)
- Amount of time intervals between measurements (time interval of 15 minutes)
- Amount of compound added (50 ml of compound is added)
- Initial surface roughness (Ra) (work pieces should have initial Ra of 1.5 μm)

3 Results and Discussion

3.1 Time to Reach Target Surface Roughness

A target of surface roughness (Ra) of 0.4 μm was targeted and the process time taken by each amplitude and frequency combination was determined. The combination which takes less time to reach the target surface roughness is considered efficient and examining the frequency of such a combination will give an idea of the effect of frequency on the overall process. The progress in surface roughness for the various frequency-amplitude combinations are shown in Figure 5. The lowest frequency and lowest amplitude showed the highest process time to reach the target surface roughness. The other combinations showed considerably lower time to reach the target .At the combination of highest frequency and highest amplitude of 100 Hz and 1.4 mm amplitude showed the lowest process time of 30 minutes. It is noted here that this time of 30 minutes is comparable to that achieved at a typically similar frequency and few millimeters of amplitude seen in an industrial vibratory finisher for the same work and media materials (Prakasam 2015). Experimental trial data also revealed that when higher amplitude was coupled with a smaller frequency the results produced in terms of surface roughness (Ra) to lead time were better compared to combined effect of higher frequency and lower amplitude as shown in Figure 6. The combination of higher frequency and higher amplitude were effective as the lead time in reaching to the roughness value of 0.4 µm of aluminium surface was lesser compared to the other combinations.

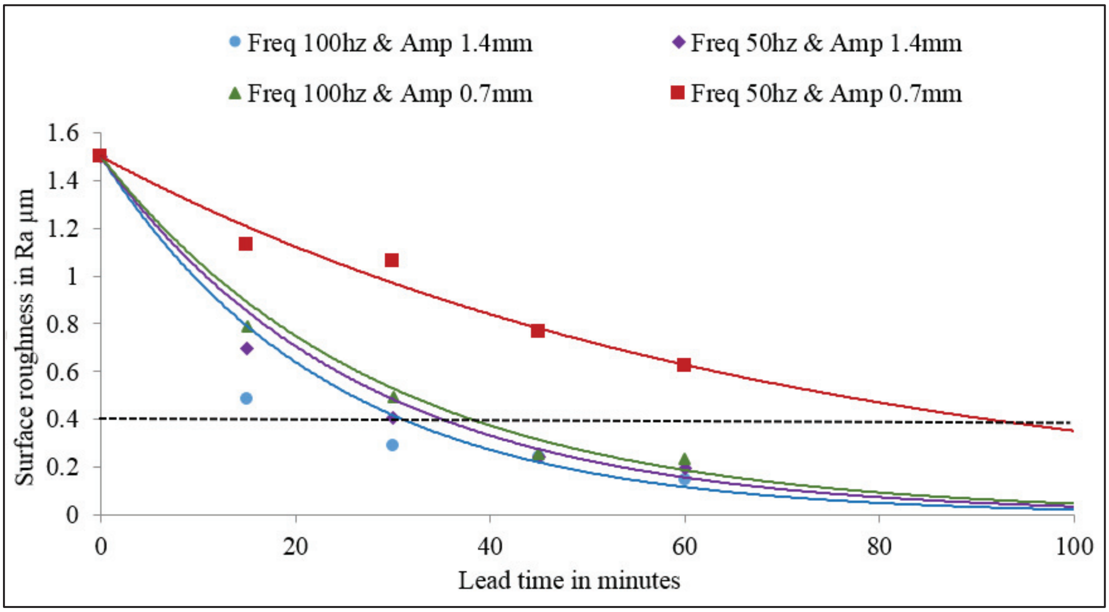

Figure 5. Comparison of the time taken to reach a target surface roughness (Ra) of 0.4 µm (black horizontal line) by various frequency and amplitude combinations.

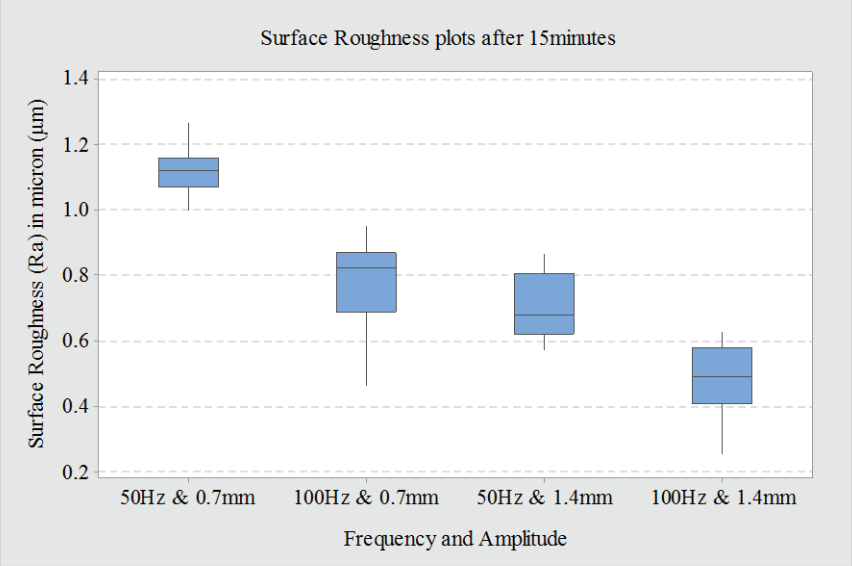

Figure 6. Effect of identified frequency and amplitude combinations on surface roughness from DOE for a processing time of 15 minutes

3.2 Direction of Motion of the media in the work bowl

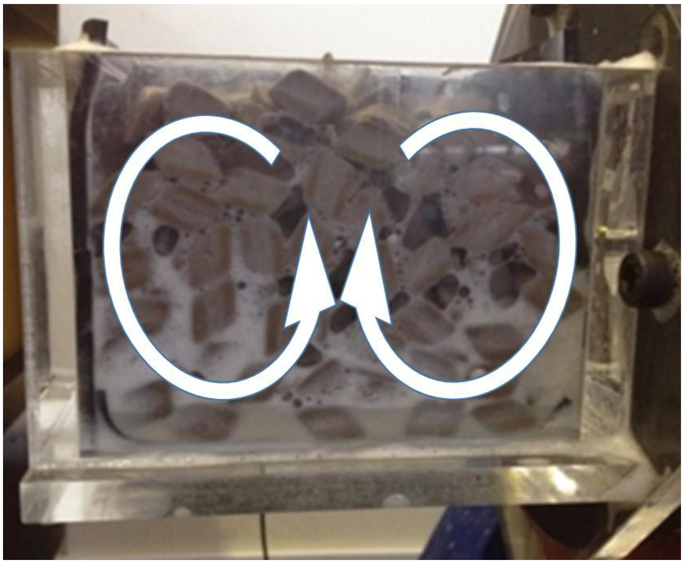

Figure 7. Media motion in clockwise direction and anti-clock wise direction as seen through acrylic bowl

Examination of motion of ceramic abrasive particles in the acrylic transparent bowl reveals that media circulated in two circular patterns in one-dimensional vibration, one in clockwise direction and another in anti-clock wise direction as shown in Figure 7.

3.3 Media Velocity Observation

The media velocity at different frequency and amplitude combinations, using High-Speed video system, were found and were compared to analyze the effect of frequency. The high-speed video has to be processed in order to determine the velocity of the each individual particle. With the video recorded frame by frame the velocity of the abrasive particles can be calculated by identifying the distance travelled by an identified individual particle and the frame number difference between the initial frames to the final frame under consideration. The only reference in the video was the dimension of the bowl and a scale image was overlaid on the video with the help of Sony Vegas video editing software. The overlaid scale image had dimensions same as the actual dimension of the bowl (Figure 8).

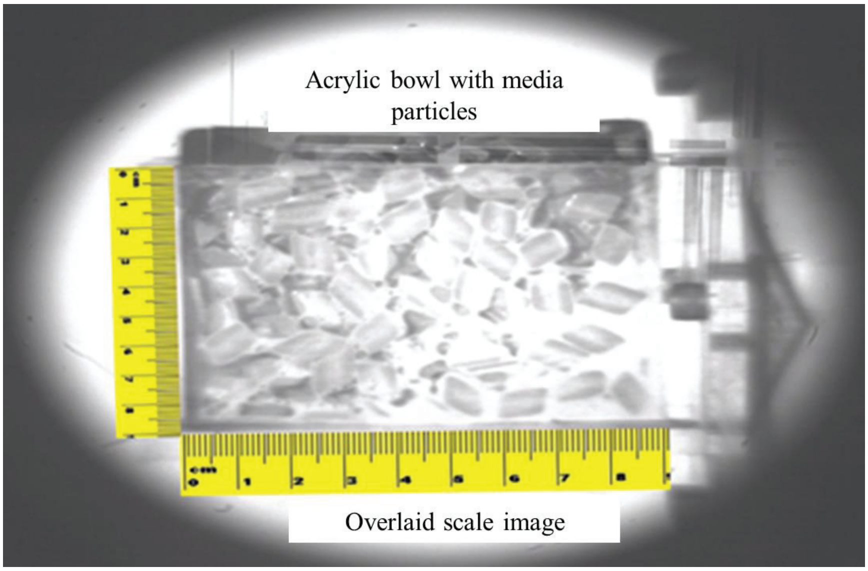

Figure 8. Scale image overlaid on the bowl with actual dimensions of 9 cm and 11 cm.

In order to get a distinct view of the individual abrasive particles the video with the overlaid scale is zoomed till the abrasive particles are clearly seen as shown in Figure 9. The video is zoomed and then processed using Kinovea software which helps to break the video frame by frame. A visible point in the abrasive particle is taken. Normally the sharp corner end of the Tri-Star media is taken as the reference point. It is also ensured that the media particle that moved in contact with acrylic side of the bowl and followed a straight path is taken as a reference.

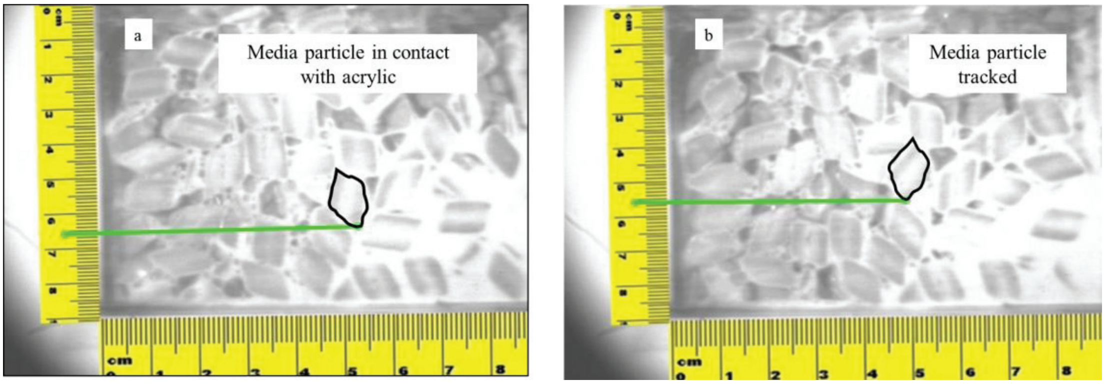

Figure 9. (a) Left side shows the abrasive in initial position (b) At the right side is the same abrasive at a different position.

As the initial frame and final frame numbers are known and frame rate is constant at 60 frames/second the time the particle has moved can be calculated. With drawing horizontal line from initial frame on the visible reference point and horizontal line on the final frame the distance travelled could be calculated. As the distance and time is known the average velocity can be easily calculated.

The average velocities of media at various frequency-amplitude combinations are shown in Figure 10. Ranges in observed media velocity for higher frequencies and amplitude combination were larger due to more vigorous media interactions as shown in Figure 10.

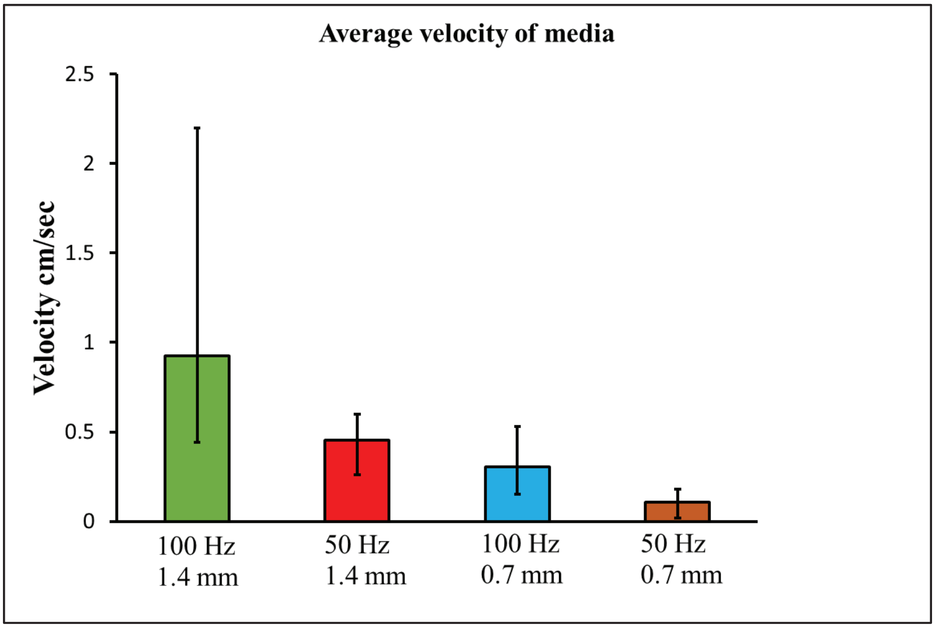

Figure 10. Error plot for velocities of abrasive particles subjected to identified frequency and amplitude combinations from DOE.

The frequency of 50 Hz and 1.4 mm amplitude, frequency of 100 Hz and 0.7 mm amplitude and frequency of 50 Hz and 0.7 mm amplitude imparted lesser velocity on the abrasive particles compared to frequency of 100 Hz and 1.4 mm amplitude.

At higher amplitude of 1.4 mm when the frequency is doubled the velocity of the particles are doubled and at amplitude of 0.7 mm when the frequency is doubled the velocity of the particles are Tripled. Fast speeds of the abrasives produce the best surface finishes and should be used for lowering process time. Increasing the frequency of the vibrator improves circulation of the media and thereby creating more abrasive action to speed up the time to reach surface roughness saturation.

4 Conclusions

An electro-magnetic shaker system was modified to carry out media finishing process at higher frequencies not normally practiced in industries with the idea of improving process time needed to achieve a certain target surface roughness value

- Experiments carried out from identified frequency and amplitude combinations from DOE revealed that combination of higher frequency of 100 Hz and higher amplitude of 1.4 mm were effective as the lead time in reaching to the roughness saturation of 0.4 μm of aluminum surface was lesser compared to the other combinations. Experimental data also reveals that when higher amplitude was coupled with a lesser frequency the results produced in terms of surface roughness (Ra) to lead time were better compared to combined effect of higher frequency and lower amplitude stating that among two factors amplitude effect is dominant.

- Examination of motion of ceramic abrasive particles in the acrylic transparent bowl reveals that media circulated in two circular patterns, one in clockwise direction and another in anti-clock wise direction in one-dimensional vibration. Videotaped observation revealed that increasing the frequency influenced the interaction between the media and the work piece. With the bowl vibrating at higher frequencies velocity of the abrasive particles increased supporting fact that increasing the frequency of the vibrator improves circulation of the media and thereby creating more abrasive action

Imparting higher frequency results in better material removal rate. However subsurface evolution and residual stresses generated should also be studied for the better understanding of the process at high frequency. Media particles come with different sizes and shapes. Their interaction with the work piece at higher frequencies will give a better idea on material removal mechanism. Effect of media geometry with high frequency vibrations can be explored.

Acknowledgements

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