A COMPARATIVE ANALYSIS OF ECH, PECH AND UVECH FOR SURFACE QUALITY IMPROVEMENT OF BEVEL GEARS

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Abstract: *Surface finishing of bevel gears is an main requirement in various machining shop floors. Variants of electrochemical honing (ECH) could be probable solutions for finishing such complex geometrical parts. This paper presents a comparative analysis of classical ECH, pulse-assisted ECH (PECH) and ultrasonic vibration assisted (UVECH) for tooth flank surface quality enhancement of bevel gears made of EN8 steel. The developed setups and the process has been compared with suitable illustrations. The tooth flank finish was analysed in terms of improvement in surface roughness, morphology of the finished surface and processing time. It was found that the UVECH finished gear exhibited better surface quality and lower processing time as compared to ECH and PECH finished gears. The PECH finished surface also gives better surface quality as compared with ECH, but the use of pulse-on and pulse-off time combination in PECH increases the time required to achieve the desired quality.*

Key words: *ECH, PECH, UVECH, Bevel Gears, Tooth Surface Finishing, Processing Time*

1. INTRODUCTION

The surface quality of a gear plays a major role in its performance and reliability. Bevel gears are widely used in all machinery, where the power and/or motion transmission between that non-parallel intersecting shafts [1]. The engineering applications are aerospace, construction machinery, cement and steel industries, marine, wind turbines, automobiles, oil and gas industries, etc. In gear manufacturing industries, the continued efforts are on to achieve a better surface finish of such gears irrespective of size and profiles. In general, gear grinding, gear shaving, gear honing and gear lapping process are popular in industries [2]. For finishing of bevel gears, gear grinding and gear lapping are mostly used, But these processes have their own inherent limitations such as expensive and slower process, workpiece surface burns and swell, grinding abrasive marks on finished surface, correct only small profile errors, etc. Therefore, there is a need for an alternate process which has super finishing at higher finishing rate. The process is expected to be effective for finishing intricate external profiles and advanced materials.

In the last few years, a non-conventional hybrid precision finishing process is developed and is termed as electrochemical honing (ECH), in which material is removed by combine action of electrochemical machining (ECM) and mechanical honing. The most of the material is removed at atomic scale by electrolytic dissolution, the hardness of the tool not act as determining factor and furthermore, the process experiences no tool wear. Although the concept of ECH of gear finishing was started in 1981 by Chen [3]. Wei et al. established an altering power supply system to continuously regulate anodic dissolution with the aim to generate field-controlled ECH to finish spur gears [4]. He et al. [5] developed a time control device for anodic dissolution to eliminate tooth profile errors from spur gear manufacture. In 2002, Yi et al. [6] presented an electrochemical tooth profile modification for carburized hypoid gears on a real-time control basis and developed a neural network based model. They mentioned that gear tooth profile modification is among the methods available for improving the load carrying capacity of gears. However, ECH of bevel gears was initiated in 2013 by Misra [7, 8]. The author studied the effect of electrolyte composition on percentage improvement in bearing ratio by experimental runs conducted using the mixture D-optimal design approach and found an aqueous solution containing 70% NaCl and 30% $NaNO_3$ as an optimum electrolyte composition for ECH of bevel gears. Shaikh et al. presents a theoretical models for tooth flank roughness and material removal rate (MRR) of a bevel gear by ECH and experimentally investigated them [9]. Ning et al. [10] applied PECF to separately finish one tooth of a bevel gear using a cathode cutter and

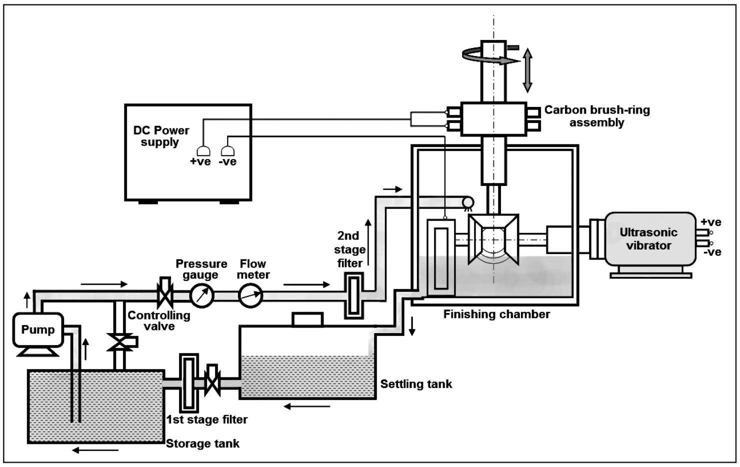


Fig 1. Schematic View of the UVECH Setup used for Finishing of Bevel

an indexing mechanism. The author reported that the improvement in both tooth flank finish and geometric accuracy. They developed a mathematical model for the total thickness of the material removed and surface roughness of tooth flank and validated it. From the available literature it can concluded that no work is reported on comparing the process performance of the variants of ECH of bevel gears to justified the monitored outputs.

Therefore, the aim of the present work are (a) to compare the process performance of UVECH and PECH to ECH using optimized input process parameters which provide the maximum values of monitored responses on the developed experimental setup and (b) to justify the use of recent variants of ECH which help to improving the working performance, transmission efficiency and service life of bevel gears. The process performance was compared in terms of percentage improvement achieved according to the input process parameters of micro geometry and tooth flank finish.

2. DESIGN METHODOLOGY

The experimental for the present work were conducted using the setup developed for bevel gear finishing by Misra et al. [7, 8], after modifying it as per requirements. A schematic view of experimental setup is shown in Fig. 1. The major components of the system are power supply system, electrolyte supply system, finishing chamber housing, and rotation system to the work-piece gear. A ultrasonic generator (made by Unitech Allied, India) has been assembled with the honing gear to perform the required ultrasonic vibrations within the honing zone. A comparison of the machining chamber arrangement was developed by Misra et al. and for the current work is shown in Fig. 2. The experiments were conducted for enhancing the tooth flank finish and micro geometry of the bevel gears by UVECH. The surface finish was evaluated in terms of percentage improvement in average roughness value (PIR_a) and maximum roughness value (PIR_t).

Roughness parameters (R_a, R_t) were evaluated before and after the process, is measured by a Wyko NT 1100 optical profilometer interfaced with Vision®32 software. Ten separate measurements on the flank face of one particular gear tooth are taken along the face width of the workpiece gear and the average value is used. The average surface roughness (R_a) and maximum surface roughness (R_t) values of the gear tooth profile are collected before and after the process and percentage improvement is calculated using the equation 1 and equation 2.

$$PIR_a = \frac{\text{Initial } R_a \text{ value - Final } R_a \text{ value}}{\text{Initial } R_a} \; 100\% \qquad \text{eq.1}$$

$$PIR_t = \frac{\text{Initial } R_t \text{ value - Final } R_t \text{ value}}{\text{Initial } R_t} \; 100\% \qquad \text{eq.2}$$

Higher values of PIR_a/PIR_t indicate the smaller value of final R_a/R_t. Misra et al. (2014) presented the optimum values of input process parameters of ECH of bevel gears in details and the value of input parameters were kept fixed at their optimum level for the present study. The list of these optimum parameters has been illustrated in table 1. The chemical composition of AISI 1040 bevel gear workpieces as presented in Table 2 were observed through a BAIRD made atomic absorption spectroscopy instrument. The ultrasonic frequency (kHz) is used as an input process variable to investigate its effect on finishing of gear tooth profile by analysing the surface roughness values before and after the process. The range of ultrasonic frequency from 20 to 50 kHz has been selected as per the machine constraint for the given study.

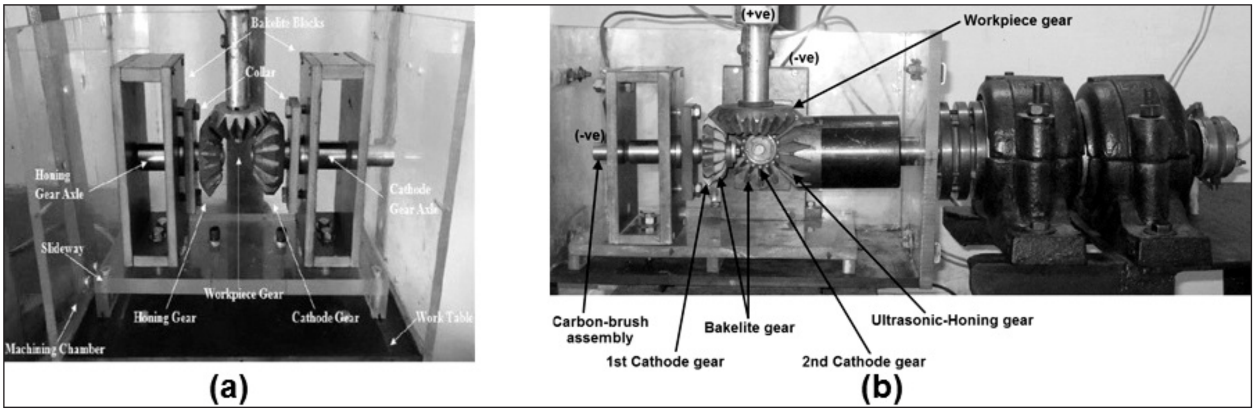


Fig 2. Arrangement of Workpiece, Cathode, and Honing Gears for Bevel Gear Finishing using (a) ECH/PECH [7], (b) UVECH in the Present Work

Table 1: List of Optimum Input Parameters of ECH of Bevel Gear (Misra et al., 2014) [8]

Power supply based	
Current	30A
Voltage	30V
Duty cycle	50
Pulse-on time	1 ms
Pulse-off time	1 ms
IEG	0.25 mm
Processing time	10 min
Electrolyte based	
Composition	75% NaCl +25% Na NO_3
Concentration	10 %
Temperature	35^0C
Flow	15 lpm
Honing based	
Honing material	NiCr
Rotating speed	80 rpm
Abrasive size	50-75 µm
Abrasive layer thickness	100-200 µm
Workpiece & Tool based	
Workpiece material	AISI 1040
Cathode material	Copper and Bakelite

Table 2: Chemical Composition of the Workpiece Gear

Element	C	Mn	Si	S	P	Fe
Weight (%)	0.38	0.72	0.67	0.71	0.75	balanced

3. RESULTS AND DISCUSSION

The experimental results have been presented in the following sections. Table 3 shows a comparison of optimized responses (surface topography and material removal rate) and corresponding optimized input parameters for bevel gears finishing by different variants of ECH process. It will be seen from Table 3 that UVECH gives a significantly higher percentage improvement in the surface topography (PIR_a and PIR_t) and material removal rate (processing time) than about Misra using ECH/PECH. The maximum values of percentage improvement in the parameters of tooth flank finish for a duration of 8 min by UVECH. The obtained results can be followed by the following:

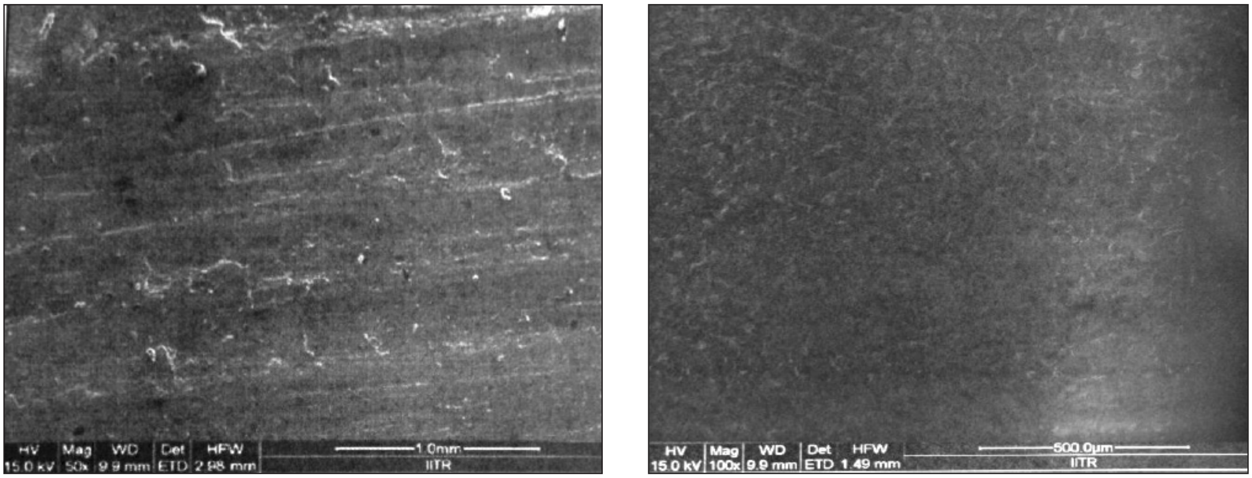
In ECH of bevel gears, material is removed by the combination of ECM and honing process coordination. During ECM action, the generation of the oxide layer in the workpiece surface does not effectively removed by honing tool, because of the nonexistence of required honing pressure on the workpiece surface.

In PECH, material removal is relatively smaller as current is applied in a combination of pulse-on and pulse-off period, causing smaller anodic dissolution of workpiece gear. Since there is pulse-off period available for effective flushing of sludge products during the entire processing time and , this leads to generation of controlled and uniform anodic dissolution. At the same time, this leads to higher honing abrasion time between the workpiece surface and honing tool surface.

In UVECH, introduction of the ultrasonic vibrations plays a vital role in finishing the gears. During the finishing process, the generation of oxide layer by an ECM process on the workpiece surface

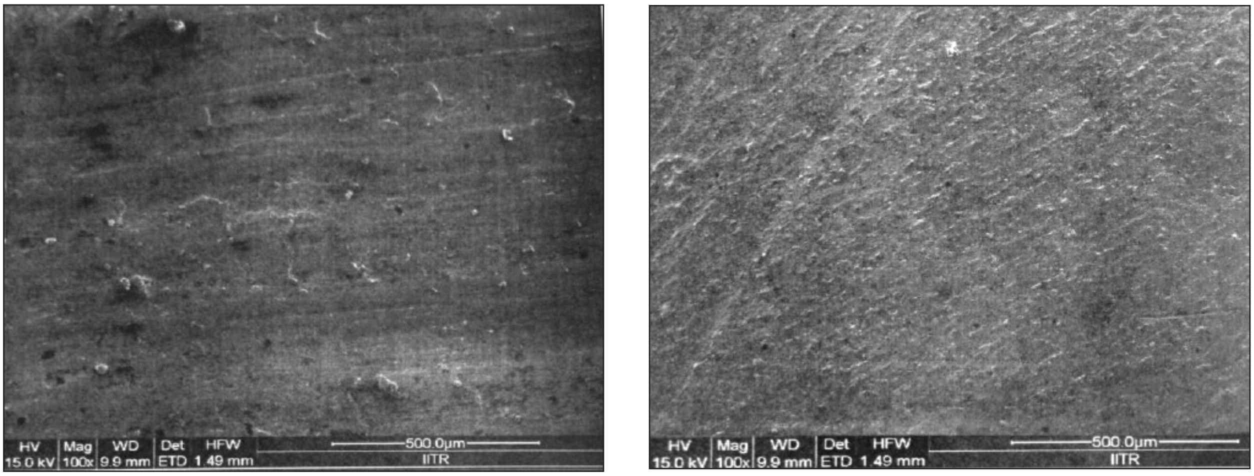
Table 3: Comparison of Process Performance of ECH, PECH and UVECH for Finishing of Bevel Gear

	Responses at optimized input parameters		
	ECH From Misra et al. [8]	PECH From Misra et al. [8]	UVECH [Present work]
PIR_a (%)	70.51	80.29	91.55
PIR_t (%)	74.93	81.67	81.78
Processing Time (min)	10	30	8
MRR (mg/min)	170.99	73.44	173.59



(a) (b)

Fig 3. SEM Images (Misra et al.) of the Bevel Gear Tooth Flank (a) Before Finishing and (b) After Finishing by ECH using Selected Optimum Input Parameters

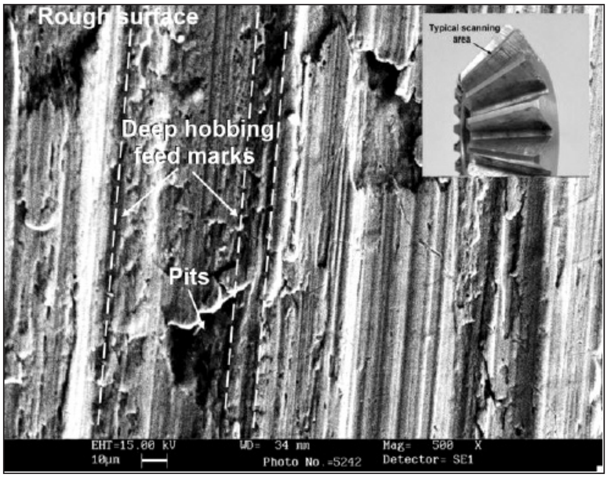


(a) (b)

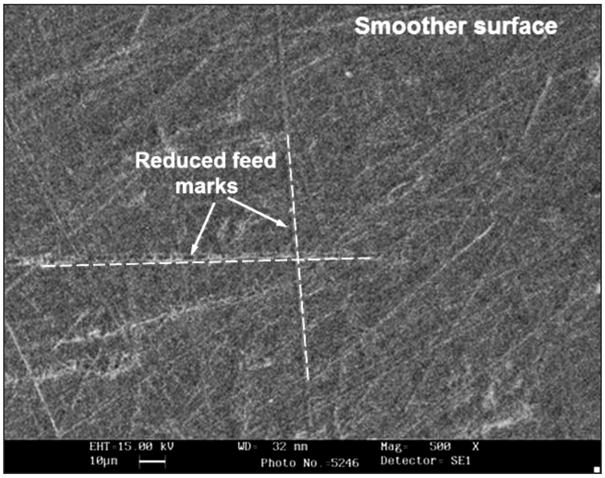
Fig. 4 SEM Images (Misra et al.) of the Bevel Gear Tooth Flank (a) Before Finishing and (b) After Finishing by PECH Using Selected Optimum Input Parameters

is significantly removed by the ultrasonic vibrations assisted honing tool. The ultrasonic vibrations in the honing zone of the system acts as a performance multiplier. This does not allow for any insulating layer between the anode and cathode, which may result of continuously anodic dissolution of the workpiece gear.

Figure 3 (a) and 3 (b) show SEM images of the microstructure of the tooth flank surface before and after finishing by ECH process of bevel gears and Fig 4 (a) and 4 (b) show the almost same SEM



(a)

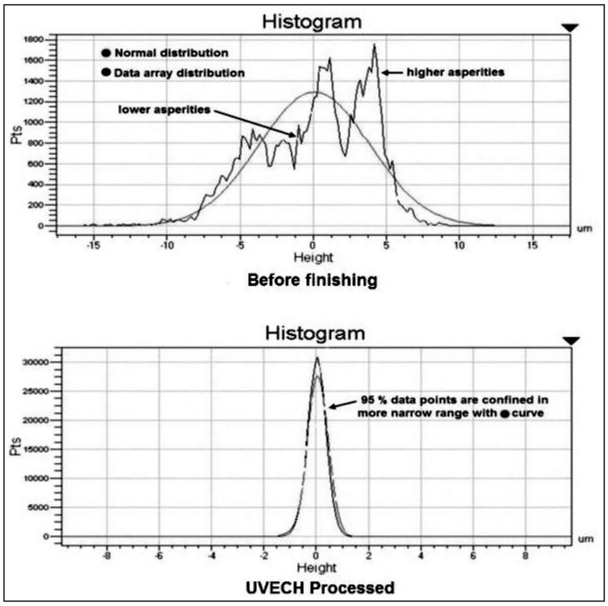


(b)

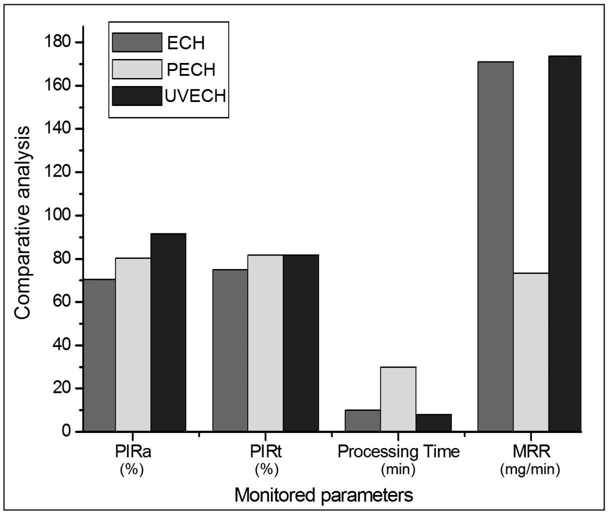
Fig 5. SEM Images (Present Work) of the Bevel Gear Tooth Flank (a) Before Finishing and (b) After Finishing by UVECH using selected Optimum Input Parameters

images by PECH process as reported by Misra, et al [8]. It is clear that the surface roughness and feed marks generated on the tooth flank during hobbing operation are still visible on the tooth flank surface of the workpiece. Figures 5 (a) and 5 (b) depict SEM micrographs of bevel gears before and after finishing by UVECH. It will be seen from Fig. 5 (b) that the surface obtained after finishing by UVECH is very smooth and there are no feed marks, pitting, scratches visible on the finished tooth

flank surface. The efficient and superior finishing has resulted from uniform anodic dissolution of tooth flank surface, due to proper scrubbing of workpiece surface by ultrasonic assisted honing gear. Figure 6 (a) presents a distribution plot of the work surface before UECH and after UECH obtained through optical profilometer and 6 (b)



(a)



(b)

Fig 6. (a) Distribution Plot of the work surface before UECH and after UECH, (b) a bar graph of comparison analysis of monitoring parameters

describes a comparison analysis of monitoring parameters (i.e., PIR_a, PIR_t, Processing time and MRR) of ECH, PECH and UVECH. Smoother surface profile contributes to enhance working performance and service life of bevel gears.

4. CONCLUSIONS

In the present work, the process performance of ECH, PECH and UVECH was compared in terms of enhancement of tooth flank surface finish and material removal rate of bevel gears. The following conclusions could be drawn from the study.

1. This study shows that the application of an ultrasonic vibrations in ECH process improves the aspects of surface quality of bevel gear, thus improving their service life and working performance.
2. The reported improvement in PIR_a/PIR_t by UVECH is 21.04/8.85 percent greater than ECH and 11.26/0.11 percent greater than PECH of bevel gear.
3. In the same experimental conditions, UVECH process gives higher precision finish at the processing time of 8 minutes, which is far better that achieved by Misra et al. [8].
4. It is observed that the improvement of tooth flank finish and microstructure increases with the increase of ultrasonic frequency.
5. It is established that the enhancement in tooth flank finish and material removal rate due to the existence of ultrasonic vibration in the honing zone.

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