Study the Machining Accuracy in Hole Reaming of Medium Carbon Steel Using Ultrasonic Vibration Method

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ABSTRACT

The ultrasonic vibration reaming (UVR) cutting process is one types of non-Conventional machining process which was tested in this study to show whether its effective method or not. In this process, the tool is imposed on ultrasonic wave to produce vibration along the host cutting movement direction, formed the separation type of vibration process affected by waveform of pulse force. The effect of cutting speed, feed and ream allowance upon the surface roughness and circular degree in reaming a hole of C45 steel were studied in this paper. The results show that the surface quality and machining accuracy of the hole have been improved by using the technology of the present study. At the same time, the cutting force and cutting temperature has reduced correspondingly. In conclusion, it was noticed that the (UVR) is effective cutting techniques for high-precision "thin-hole" machining of the material under this study with respect to the conventional reaming process.

1. INTRODUCTION

Over the recent years, the development of science and technology is rapidly increased, especially in the aerospace, electronics, instruments and meters, precision machinery, automatic control and medical equipment, etc. To collect many parts in several industrial applications, it becomes necessary to product a bolt holes during machining of various materials. The demand for the machining of a precision holes in a structure was increased [1, 2]. Reaming is a machining process in which a light cut to improve the accuracy of around hole and enlarges an existing hole to the diameter of the tool that led to obtain accuracy holes, and this target can be reached after rotating an accuracy cutting tool called reamer into a hole sized slightly. There are several types of reamers and they may be prepared for use as a hand tool, or as in a drill press, etc. However, when ordinary reaming process is applied, the temperature at the cutting area, cutting torque and tool life are greatly affected upon the cut quality. Therefore, it becomes necessary to looking for an alternative reaming process to improve the cut quality and precision of hole size. Ultrasonic vibration reaming process, was adopted for this purpose. In this process, the piezoelectric transducer is used to generate a high frequency in the order of 16-21 kHz and low amplitude vibration in the order of 2-15 μm. These vibrations are superimposed in the drill with the help of a sonotrode in the longitudinal mode. This technology was put forward in 1950 by Japanese scholar Kumabe Junichiro. Then, the researchers of United States, Soviet Union, Britain and Germany did a lot of work on vibration cutting [3]. In the literatures, a little work was found on using ultrasonic vibration in reaming process. Zhang et al. [4] summarized the procedures of the (UVR)"thin-hole" in hardened steel. They concluded that the

(UVR) using reamer is of high excellent cutting technique for high-accuracy "thin-hole" machining of hardened material. Celaya et al. [5] investigated the effect of tool vibration upon the quality of surface for mild steels using the ultrasonic vibration assisted turning of mild steel. The researchers concluded that the ultrasonic vibration technology can improve the surface quality depending on the cutting conditions (cutting speed, feed and depth of cut). The effects of using ultrasonic vibration-facilitated milling technology on important sides of tool wear, cutting forces and surface integrity of Alloy 718, which is common use in high temp. applications has been investigated by Suárez et al. [6]. Their outcome be seen alterations in the sub- superficial part of the material which could affect the fatigue resistance of the material. Tool wear manner was observed also to be very comparable for both milling technologies. The principal analysis on (RUAD) of (CFRP) was presented by Li et al. [7] to explain the removal process of rod and chip. After that, the experiment analysis on (RUAD) of (CFRP) was execution it to observe the removal effects of rod & chip. The experimental outcome point to compared with the public drilling of core drill, when the vibration amplitude arrived 5.00 & 7.50 μm in (RUAD), the ability of cutting of core drill tool was quite reinforced, very good removal effects of rod & chip were obtained, which obviously reduced the, rod jamming, chip adhesion, cutting temp., thrust force, rod fragmentation, and surface roughness, improved rod diam. and the dimensional accuracy of machined hole, prolonged the tool life, in addition to acquired superior surface integrity of machined hole and flat fibers fracture surfaces, also the experimental outcomes proved the accuracy of the principal analysis. Kumar and Rameshkumar [8] used an ultrasonic assisted tool (UAT) made of Aluminium-7075-T6/HSS M2 as a first designed for a theoretical amplification

ratio of 4. Then modal and harmonic analyses were carried out for six different dimensions of the UAT i.e., D10d5, D14d7, D16d8, D20d10, D24d12 and D30d15. Natural frequency and vibration amplitude at the tool end are determined. They concluded thatthe D16d8 UAT is the best suited dimension for the design criteria considered providing the required amplification of 4. Geng et al. [9] studied the feasibility "ultrasonic elliptical vibration assisted"(UEVA) reaming of carbon fiber reinforced plastics-titanium alloy stacks. In their study, they analyzed the compared between conventional reaming and the tool performance and hole quality in (UEVA). They found that the quality of holes was obviously enhance in (UEVR). This is proved by monitoring surface finish, cutting force, and hole geometric precision. Li et al. [10] introduced an 8-facet drill tool and combined the advantages of (RUAD) to carry out a study on the drilling of (Ti6Al4V) under no cooling condition. Their experimental outcome indicated that the thrust force, torque, cutting temp. near the drilled hole exit, expansion increment of hole diam., surface roughness of drilled hole, and burr height of drilled hole exit decreased by 16.79 to 20.2%, 31.5 to 33.6%, 18.54 to 21.68%, 24.87 to 25.36% , 46.75 to 57.63% , and 82.27 to 89.18% , respectively; compared with the common drilling of (Ti6Al4V), Furthermore, the experimental outcome also proved that the drilling technology of (RUAD) of (Ti6Al4V) using the 8-facet drill was practical and the cutting effects were excellent." There are many researches that dealt with thistopic, and the uses of different variables, and reached results of scientific interest on this topic [11-25]. Sharma et al. [26] studied the influence of cutting force and drilling temperature on glass hole surface integrity during rotary ultrasonic drilling. They investigated experimentally the surface roughness while drilling a hole in glass specimen using rotary ultrasonic machining (RUD). The authors were concluded that the best drilling condition to get the least value of average surface roughness (167.702 nm) is the usage of coolant with 5000 rpm of spindle speed.

In the present work, the ultrasonic vibration technique has been used to assess the effects of cutting speed, feed and ream allowance depth of reaming process upon the surface roughness and circular degree in hole making of C45 steel.

2. MECHANISM OF ULTRASONIC VIBRATION CUTTING

As presented in Figure 1. The cutting tool is imposing on the ultrasonic wave and vibrate at a certain vibration amplitude and frequency and form a separated type pulse force of vibration along the host cutting movement direction [27]. The chip formed by this type of cutting technology is regular in thickness, no difference in color and the cutting temp. is not different as the room temp. The tool life is highly improved with no clear abrasion in the cutting operation. The cutting operation is very stable, changed the extrusion of cutting-edge act on ablation zone of work piece into almost pure cutting process, cutting deformation is minimal shrinkage coefficient is approximation equal to one, cutting force is only 1/10-1/3 of the normal cutting; Graph of cutting zone temperature is pulse shape, so average cutting temperature is very low, producing little cutting heat, cutting process at room temperature, the tools rarely wear. Machine surface is composed of numerous tiny flat or curved forming a beautiful pattern [28-30].
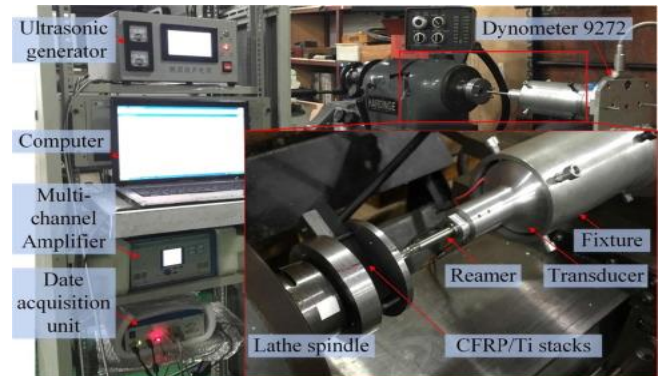

Figure 1. Experimental setup

3. EXPERIMENTAL WORK

The control parameters were selected depending on the feed rate & spindle speed available on the machine. The control parameters during the reaming process were performed under the conditions of cutting speed (m/min), feed rate(mm/min) separately. Each test group for reaming included three test samples. The averages of three measurement values were obtained to get the mean value.

3.1 Material

For the empirical tests, a round bars of medium carbon steel (C45) produced by Ningbo Preah Vihear steel Industry Co., Ltd. / China was used. Medium carbon steel (C45) is usedwhen high strength and hardness is required such as in: building, automobile, shipbuilding, petrochemical, machinery,medicine, electric power, energy, space, building and decoration, etc. The chemical composition and mechanical properties for C45 steel can be shown in Table 1 and 2 [15].

Table 1. Chemical composition of C45 steel by weight%

Chemicalelements	C %	Si %	Mn %	Su %	Ph %	Fe %
Standardvalue, C40 Steel,[31]	0.37 - 0.44	0.4 max.	0.5 – 0.8	0.45 max.	0.045 max.	Rem.
Actualvalue	0.41	0.13	0.73	0.42	0.039	98.27

Table 2. Mechanical properties of C45 steel

Property	Tensile strength, MPa	Yield Strength, MPa	Impacting Energy, J	Poisson's ratio	Hardness, HBS	Elongation %
Standard value, C40 Steel, [30]	590 - 880	350 - 550	40 - 60	0.27 - 0.3	180 - 230	8 - 25
Actual, value	655	365	49	0.28	218	16

3.2 Experimental procedure for reaming

All the reaming tests were achieved by using the ultrasonic vibration reaming system (UVR). The UVR system consists of: ultrasonic generator with output power of 0-500w, ultrasonic transducer of (25 KHz, 500 watts made by Shenzhen yike ultrasonic company, China), horn which acts as tool holder in addition to an amplifier (The horn is of a length 100mm, made of aluminum material with natural frequency of 20, 527 Hz. and finally, the UVR system include the reamer tool. Schematic diagram for the ultrasonic vibration system used in the experiments can be shown in Figure 2. In ultrasonic transducer, piezoelectric material is used same as quartz. The ultrasonic vibration system giving ultrasonic sound in the form of vibration to the reamer tool at amplitude of 0.01 mm and frequency of 20 KHZ.
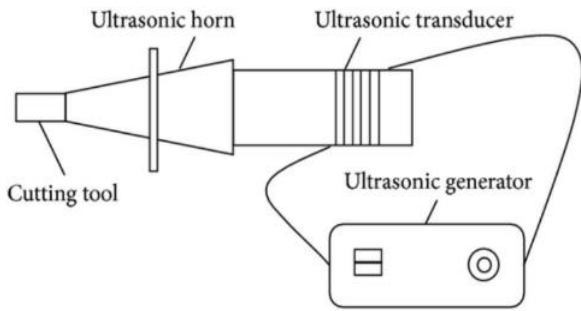

Figure 2. Structure sketch of ultrasonic vibration system

A reamer with 10.0 mm diam. was used through the experiments. The specification of reamer is illustrated in table The reamer diam. was calculated before and after every experiment employing a digital micrometer and the meanvalue of ten magnitudes on Table 3 pair of flutes was estimated. This value was invariable within a range of 1μm appearing thatno reduction in reamer diameter due to wear during the whole investigation. The vibration direction was along the diameter of the bar.

A set of three specimens were carried out to measure the average value of the response variables (surface roughness and circular degree). The dimensions of the specimen material of the material were ($\Phi 16mm \times 60mm$). The required bore diam. of the reamed hole is 10mm.

Table 3. Reamer specification

Material	HSS-E COBALT
Shank	DIN 212-8 NFE 660146
No. of flutes	6
Dimensions [mm]	
D	10.0
	10.1
L	133±1
l1	38±1
l2	99
D2	10.0
Tolerance	±0.003

4. EXPERIMENTAL RESULTS

The outcomes are presented in Table 4. The following is description of the response variables (surface roughness, dimensional accuracy):

1. The arithmetic average surface roughness (Ra), being the usually operated parameter in the industries for machining process was calculated using a contact-type stylus "(Mahr Perthometer)." The magnitudes were obtaining from (4) various positions along the cut hole depth surface– computed in (µm). The average value is described for investigation.

2. The dimensional accuracy of a specimen is of a critical importance in the production, especially for accuracy operation. In the production process, the designed section will be presented ina layout with all dimensions usually specific within a certain range of tolerances. The dimensional accuracy taken in terms of circular degree.

Table 4. Experimental results

No.	Cutting Speed (m/min)	Roughness (µm)	Feed Rate (mm/r)	Roughness (µm)	Depth of Reaming (mm)	Roughness (µm)
1	0	0	0	0	0	0
2	5	0.17	0.05	0.14	0.1	0.19
3	10	0.18	0.1	0.16	0.2	0.18
4	15	0.18	0.15	0.165	0.3	0.15
5	20	0.18	0.2	0.19	0.4	0.27

No.	Cutting Speed (m/min)	Circular degree (mm)	Feed Rate (mm/r)	Circular degree (mm)	Depth of Reaming (mm)	Circular degree (mm)
1	0	0	0	0	0	0
2	5	0.003	0.05	0.003	0.05	0.015
3	10	0.0028	0.1	0.0039	0.1	0.003
4	15	0.0029	0.15	0.0042	0.15	0.0035
5	20	0.0041	0.2	0.005	0.2	0.0035

5. RESULTS ANALYSIS

Figures 3, 4 & 5 show the effect of cutting speed, feed rate & depth of reaming separately upon the surface roughness & the circular degree respectively. The following are description of the effect for each input parameter upon the response variables (surface roughness & circular degree of the cutting surface.

5.1 The effect of cutting speed on the surface roughness & circular degree

Figure 3 illustrate the effect of cutting speed (v) upon the surface roughness (Ra) & circular degree under the test conditions. It was shown from the figure that, when the speed of cutting (v) is less than vibrating velocity (v_t), the surface roughness is almost nothing to do with speed of cutting. While, when speed of cutting is higher than vibrating velocity, surface roughness has no difference as common reaming. So, the significant effect of ultrasonic vibration reaming will be obtained only when the cutting speed is lower than vibrating velocity ($v_t=a\omega=2\pi af$) and $v\leq1/3$ v_t when dry type ultrasonic vibration reaming.
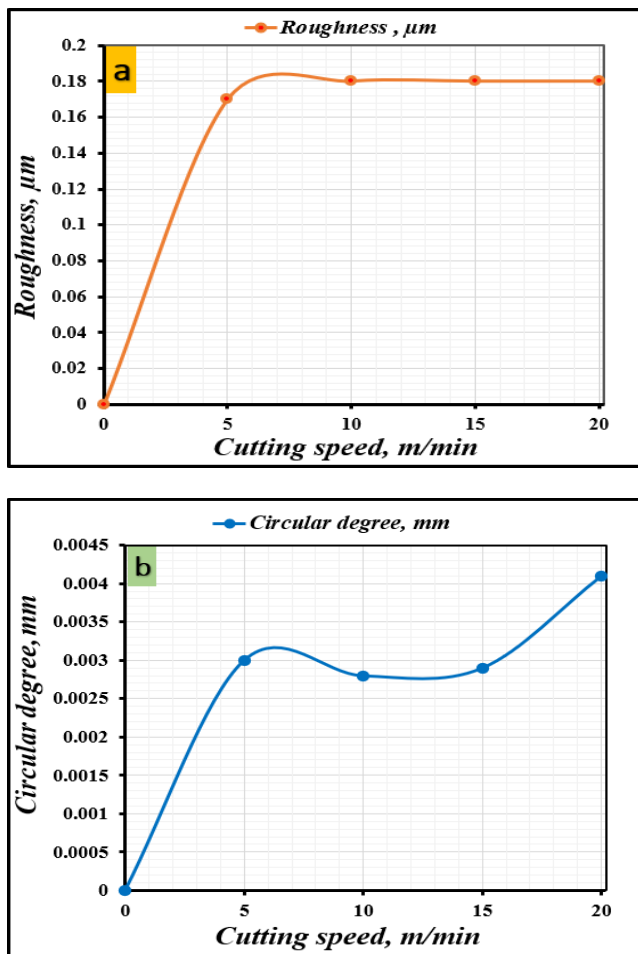
Figure 3. The influence of cutting speed upon: a- the surface roughness & b- Circular degree, where, a_p=0.1 mm; s=0.1 mm/r

5.2 The relationship between surfaceroughness and the feed rate

The relationship between the feed rate (s) & the surface roughness (Ra) under the test conditions is shown in Figure 4. It was shown from the figure that when the feed rate increases, the surface roughness increases slightly. This is because the reamer vibration along the main cutting direction in the cutting process, rather than along the feed motion synthesis direction vibration, feeding the greater the impact, the more prominent. Feed movement of the cutting is not fully pulse.

5.3 The relationship between surface roughness & the depth of the reaming

The relationship between the reaming depth and the surface roughness is illustrated in Figure 5. It can be shown from the figure that the depth of cut has slight effect upon the surface roughness of when the reaming depth less than 0.10mm While, when reaming depth is more than 0.10mm, the values of roughness increase clearly with the increasing the depth of the reaming. This is because of the increases in the cutting force with the increase in cutting depth, ultrasonic power cannot meet the requirement. Simultaneously, the increase in the radial interference is larger when the tool is disengaged. The max. interference value along the radial is equivalent to the reaming depth and as a result of this, the (UVR) is affected by the flank interference with the cutting surface when the reaming depth is large. Therefore; (UVR) should be used for small reaming depth.
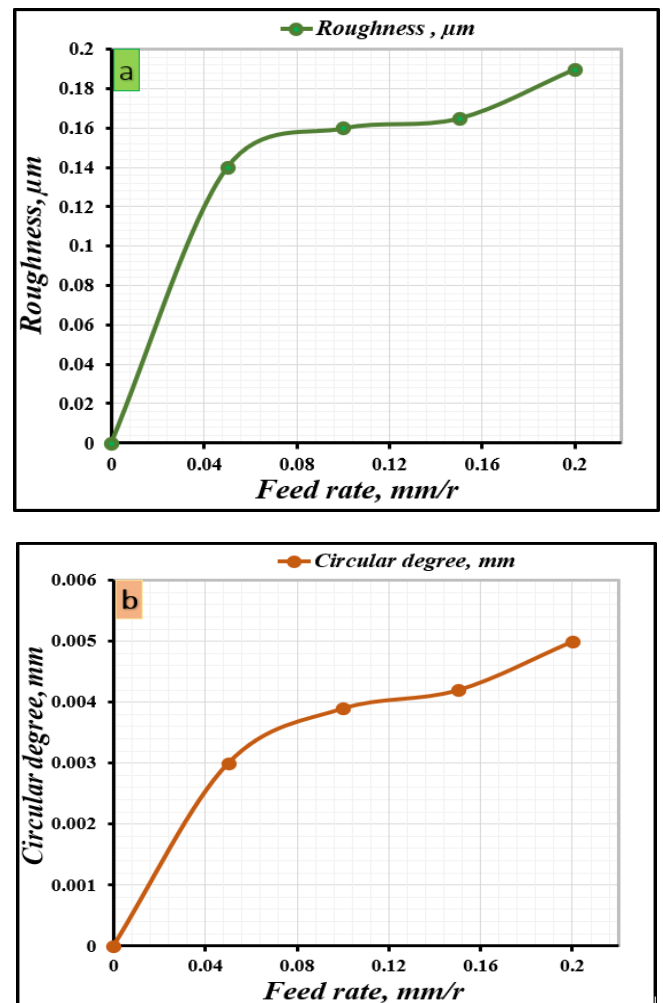
Figure 4. The influence of feed rate upon: a- the surface roughness & b- Circular degree, where, a_p=0.1 mm; s=0.1 mm/r
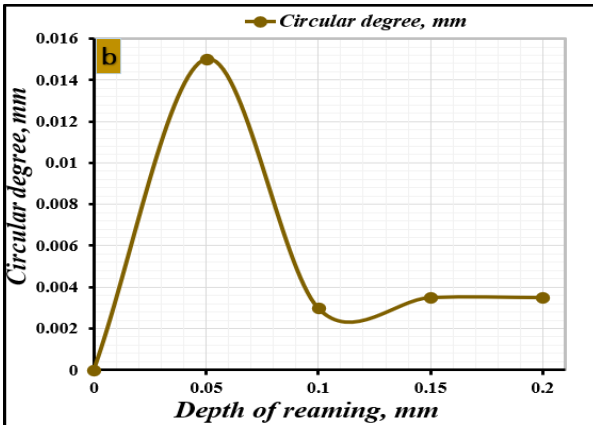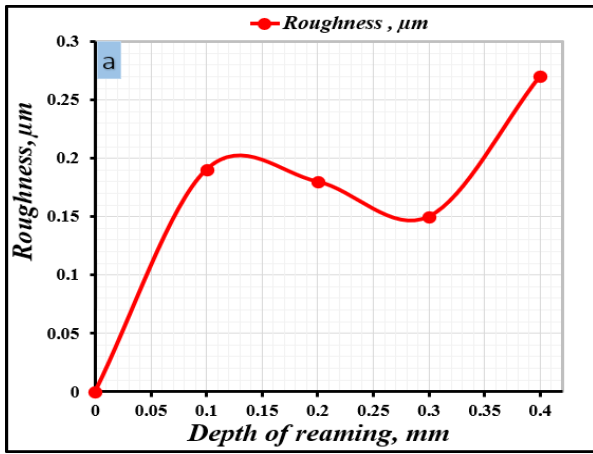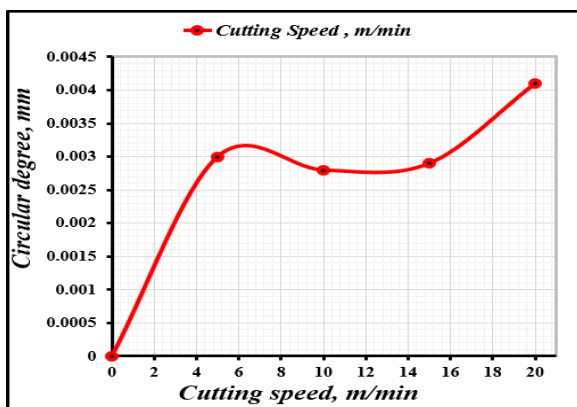
Figure 5. The influence of depth of reaming upon: a- the surface roughness & b- Circular degree, where, a_p=0.1 mm; s=0.1 mm/r
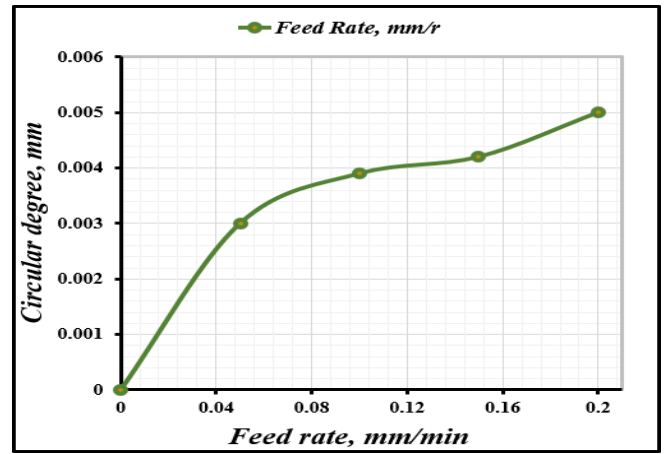
5.4 Circular degree

The circular degree of the processing part is one of the important indexes of machining accuracy. The outcome displays that the circular degree of the (UVR) is relatively higher than that obtained by the conventional method. Figures 6-8 show the influence of the cutting parameters upon the circular degree.
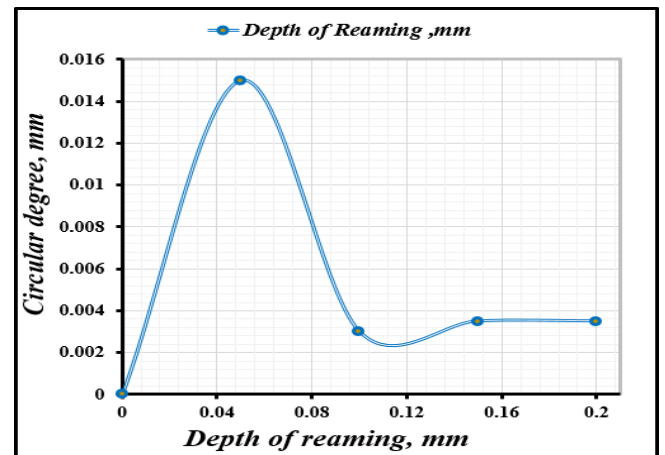
It was shown from the figures that with the increase of the cutting speed and feed, the circular degree of the work piece increased slightly, while with the increase of depth of reaming, the circular degree of the work piece gradually reduces and it tends to be stable when the ream allowance is 0.1mm.

Figure 6. The influence of cutting speed upon thecircular degree, where, a_p=0.1 mm (unilateral); s=0.1 mm/r

Figure 7. The influence of cutting feed on the circular degree, where, a_p=0.1 mm (unilateral); v=9.1 m/min

Figure 8. The influence of depth of reaming on the circular degree, where, v=9.1 m/min; s=0.1 mm/r

6. CONCLUSIONS

The surface quality and circularity degree of the hole have been improved dramatically by ultrasonic vibration reaming processing technology due its vibro-impact. It was shown from the Figures 6, 7 & 8 that with the increase of the cutting speed and feed, the circular degree of the work piece increased slightly, while with the increase of depth of reaming, the circular degree of the work piece gradually reduces and it tends to be stable when the ream allowance is 0. 1mmThe following conclusions can be drawn based on the results of the experimental study on reaming of carbon steel by ultrasonic vibration reaming process:

(1) The surface roughness was decreased clearly and this is because of the removal of plastic deformation in machining operation which reduce the effect of micro elastic vibration & physical factors of the experimental system. Simultaneously, cutting force and cutting temperature has reduced correspondingly.

(2) The comparison made with the results obtained for the circular degree by using the conventional method with that obtained by the present study of the (UVR) is relatively higher than that obtained by the conventional method due to the axial vibration, which will contribute to reducing the cutting forces and improving the heat dissipation. Meanwhile, a friction effect was generated by the peripheral cutting edge which can

improve the micro-scale surface roughness.

(3) It was shown from Figures 5 & 8 that (UVR) should be used for small reaming depth because it gives low roughness and good circular degree.

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NOMENCLATURE

Ra	Arithmetic surface roughness
v	Cutting speed
vt	Vibrating velocity
a	Amplitude of vibration
f	Frequency of vibration
s	Feed rate
ap	Depth of the ream