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Fuzzy Knowledge Base Controller to Condensate The Roundness Error in the Cylindrical Plunge Grinding

استخدام المعلومات على أساس التحكم المشوش لتقدير خطأ الاستدارة فى عمليات التجليخ الاسطوانية

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الملخص العربى

يقدم هذا البحث دراسة نظرية لما يحدث أثناء تداخل حجر التجليخ مع الشغلة وبالتالى درجة تأثيره على استدارة المشغولات المشغلة بعملية التجليخ الاسطوانى الغاطس . تم استخدام نموذج رياضي يصف طبيعة هذا التداخل آخذا فى الاعتبار التآكل الحادث فى كل من حجر التجليخ والشغلة أثناء العملية ومعامل الكزازة لمنطقة التداخل بينهما. فى الدراسات السابقة افترض فيها أن سطح العينه الابتدائى قبل التجليخ كامل الاستدارة. فى هذا البحث تم تعديل هذا النموذج ليصبح عمليا أكثر وذلك باستخدام سطح عينة حقيقي يحتوى على بعض التموجات أى به عيوب استدارة. وبذلك تم دراسة تأثير مؤثر آخر على تداخل حجر التجليخ مع الشغلة وبالتالى على الحركة النسبية بينهما. وللسيطرة على عيوب الاستدارة تم فرض نظام تحكم مشوش Fuzzy وتم دراسة أثر استخدام هذا النظام على عيوب الاستدارة. وقد أجريت عدة تجارب عملية للتحقق من نتائج البحث النظرية.أوضحت نتائج الدراسات العمليه أن عدد وارتفاعات التموجات على سطح الشغلة الإبتدائى قبل التجليخ يؤثر على كل من:- قيم الاهتزازات المتولدة أثناء التجليخ والترددات السائدة للاهتزازات ، درجة استدارة العينات وعدد التموجات على أسطحها بعد التجليخ. وقد وضح ذلك جليا بدراسة المخطط البيانى لطيف الإستدارة لسطح كل عينه حيث وجد ترابط بين المخططين قبل وبعد التجليخ . وتم إستنتاج أيضا أن عدد التموجات على السطح الناتج من التجليخ لايعتمد فقط على نسبة دوران الحجر بالنسبة للشغلة كما أوضحت الدراسات السابقة، وإنما يعتمد أيضا على عدد التموجات على سطح الشغلة الابتدائى قبل التجليخ . ولقد تم تحليل النتائج باستخدام نظام التحكم المشوش لحساب قيمة تعويضية للحركة النسبية بين الشغلة والحجر كدالة فى عدد التموجات وارتفاعاتها. وقد أدى ذلك الى تحسين عيوب الاستدارة الناتجة من التموجات السابقة على سطح الشغلة بنسبة ٢٠%.

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ABSTRACT

The paper describes theoretical and experimental analysis of dynamics of system: grinding wheel- workpiece external cylindrical plunge grinding process to study the effect of workpiece previous profile on the ground workpiece roundness. The study has been carried out theoretical model taking contact stiffness of system (workpiece and machine), grinding wheel and workpiece wear into consideration. The results showed that mode shape vibration errors are strongly depends on amplitude of initial workpiece profiles. The mode shape vibration errors increases with the increase of initial workpiece profiles amplitudes and workpiece length.

Experiments had been carried out on identical specimens. These specimens were turned first with different cutting conditions to obtain different profiles. Then a cylindrical plunge grinding operation with the same cutting conditions was applied for the resulted specimens. The vibration signals existing during grinding were recorded. The resulted roundness error before and after grinding were compared for each specimens.

The results showed the root mean square (RMS) of vibration level, roundness error and undulation number of the ground workpiece are dependent on the initial workpiece profile. The comparison between theoretical and experimental results showed as good agreements.

To compensate roundness error within an acceptable range, fuzzy knowledge base controller (FKBC) was proposed. The proposed fuzzy controller predicts the work piece shape error more accurately, and reduces it by about 20%

KEYWORDS

Plunge grinding, vibration, roundness, initial profile, undulation, flexibility, fuzzy controller.

1- INTRODUCTION

Grinding is a high specific energy finish machining process that is used widely in the manufacturing of components requiring fine tolerances and smooth finish [1].

As it is known, out of roundness is a complex error resulting during grinding process. It refers to deviation from a perfect circle. In a conventional plunge grinding operation, the grinding wheel is fed radially into a rotating workpiece by a wheel head system as shown in figure 1. Since the wheel head and the workpiece supports are not infinitely rigid, the deflection takes place as soon as the wheel contacts the workpiece and the normal force is developed. This will result in grinding wheel position to falls behind the nominal position of the wheel head system. Due to the variation in the deflection of the system during a grinding cycle, a relative motion between workpiece and grinding wheel is initiated.

The previous publication (e.g. [2]) in this field reported that, the roundness of the workpiece depends on the motion of the wheel relative to the workpiece which is called vibration. Vibration in the system: grinding wheel-workpiece changes the local cutting conditions which can result in non-homogeneous characteristics of mechanical properties of machined surface. These disadvantages are the reason of searching the way of avoiding of harmful phenomenon of vibration. It can be performed in two ways [3]:

- Identifying and removing vibration sources from the grinder,
- Minimization the influence of vibration on grinding workpiece.

This relative motion (vibration) originates from many sources such as wheel imbalance, self excited vibration, etc. The major source of roundness error during grinding is the spindle radial error motion (SREM) [4]. Hyum-seumg C. [5] presented a machining error compensation system for cylindrical grinding based on genetic algorithm

The present paper discusses another source which affects the roundness error during grinding. The study puts importance to the effect of previous workpiece profile on the wheel motion relative to the workpiece during grinding. The vibration signals existing during grinding are used to describe this relative motion. Fuzzy knowledge base controller was proposed to compensate the roundness error.

2-MATHEMATICAL MODEL AND SIMULATION

In the external cylindrical plunge grinding process the wheel is fed radially into the workpiece. The cutting process takes place along the interference between the wheel and the workpiece by a number of abrasive grains on the wheel surface.

To study the effect of workpiece previous profile on the ground workpiece roundness; a grinding process model will be used. Liao and Shiang [6] derived a model, which includes grinding wheel and workpiece regenerative effects. The model takes contact stiffness, grinding wheel and workpiece wear into consideration. Since this model can describe the grinding process more completely than others [2, 7], it is adopted for simulation and modified for our purpose in this research.

As shown in Figure 2 the total infeed of the grinding wheel at the time instant t, denoted by $U_o(t)$ is equal to the sum of the wear of the grinding wheel, wear of the workpiece and the elastic deformation at the contact area and the machine tool structure That is,

$$U_o(t) = W_w(t) + W_g(t) + X_{cm} \qquad (1)$$

$$X_{cm} = X_c(t) + X_m(t)$$

Where $W_w(t)$ is the total amount of wear of the workpiece,
$W_g(t)$ is the total amount of wear of the grinding wheel,
$X_{cm}(t)$ is the elastic deformation at contact area, and elastic deformation of machine tool structure.

The effect of forced vibration on the system must be taken into consideration. Let us consider one case of process forced vibrations when the workpiece surface is not smooth. This happens when the workpiece initial contour has waviness. This would result in a periodic force F_P. Now for a well trued and balanced grinding wheel the grinding force F(t) is the sum of the static force F_S and periodic force F_P. The static force component is a function of grinding conditions such as infeed, wheel speed and width of cut. Consider the number of waves on workpiece surface is n with amplitude a_n. Because the workpiece is rotating with angular velocity ω the increase in the total infeed of the wheel due to the periodic force F_P can be written as:

$$Xp = a_n \cos n\omega t \qquad (2)$$

Based on the discussion given above, eq. (1) should be modified as follow:

$$U_o(t) + a_n \cos n\omega t = W_w(t) + W_g(t) + X_{cm} \qquad (3)$$

As depicted in figure (3), the elastic deformations Xcm are dependent on the grinding force F (t), workpiece geometry, and machine stiffness especially head and tail stock. This can be modeled and represent different cases

1- Workpiece with rigid head and tail stoke

$$X_{cm} = \frac{f(L-x)^2 x^2}{3ELI} \qquad (4)$$

where

f is the grinding force
L is the workpiece length
E is the modulus elasticity
I is the second moment of area

2- workpiece with flexible head and tail stoke

$$X_{cm} = \frac{f(L-x)^2 x^2}{3ELI} + f\left[\frac{\left(1-\frac{x}{L}\right)^2}{K_{head}} + \frac{\left(\frac{x}{L}\right)^2}{K_{tail}}\right] \qquad (5)$$

where

K_{head} stiffness of the head stock
K_{tail} stiffness of the tail stock

Eq.(3) shows that the total infeed of the grinding wheel at any time depends on dynamic displacement which is produced by the previous waves on the workpiece contour.

The dynamic displacement in the left hand side of eq. (3) will produce a dynamic component of the grinding force which affects the quantities in the right hand side of the equation. The grinding force F(t) is assumed to be related to the instantaneous amount of wear of the wheel $\Delta W_g(t)$ and that for workpiece $\Delta W_w(t)$ by the following equations:

$$F(t) = k_g \, \Delta W_g(t) \qquad (6)$$

$$F(t) = k_w \, \Delta W_w(t) \qquad (7)$$

Where k_g, k_w are the grinding wheel and workpiece wear stiffness, respectively.

Eqs. (4) and (5) with eq. (3) show that the instantaneous wear of both grinding wheel and workpiece will be varied with the variation of the grinding force or in other words variation of total infeed which vary periodically. Because the wear of the grinding wheel is far smaller than that of the workpiece, so it can be neglected for this study. It is noted that the wear rate of the workpiece depends on the wearing stiffness k_w. The elastic deformation at contact area $X_c(t)$ and the elastic deformation of machine tool structure $X_m(t)$ will be varied also periodically according to eq. (3).

The amount of this variation depends on the contact stiffness and static stiffness of the machine tool structure.

Since the vibration of the grinding wheel relative to workpiece depends on the depth of cut, the dynamic displacement which adds to the total infeed in eq. (3) will cause the grinding wheel to move away from or to the workpiece according to the displacement sign. Then relative vibration between the workpiece and grinding wheel occurs.

Figure 4 shows how the workpiece previous waviness influences the dynamic normal force. The component F_{ng} appears when over grinding a smooth workpiece surface, a component F_{nw} which from real wavy surface and the resultant dynamic normal force F_n. As shown in the figure, the previous waves on the workpiece surface cause the grinding wheel to be subjected to varying force. This force itself produces vibration in the system. The vibration causes a new wave to be produced on the workpiece surface.

The wave left on the workpiece surface is neither sinusoidal in form nor having the same amplitude as the vibration. This is due to the effect of the wheel removing material from the workpiece over an arc of contact rather at a single point [9].

Figure5 shows the workpiece shape error using rigid head and tail stock at different initial profiles. The workpiece material is steel and length is 100 mm while workpiece diameter is 50 mm. The applied grinding force is 200 N. Figure 6 shows the shape error for the same workpiece using flexible head and tail stock. The results show that the ground workpiece profile and shape error depends on workpiece rigidity and workpiece initial profile. Introducing the flexibility of head and tail stock improved the shape error

The above analysis of the grinding wheel workpiece motion during cylindrical plunge grinding indicates that: the vibration existing during the operation depends on the workpiece initial profile which results from the underlying process. This vibration will have a considerable effect on the final ground workpiece profile and shape error.

3 -EXPERIMENTAL WORK AND RESULTS

The experimental work was carried out to study the effect of initial workpiece profile on the cylindrical plunge grinding process. The study related the previous roundness error to the variation of the actual interference between the wheel and workpiece. The effect of this variation on the final workpiece profile was also studied.

First a turning operation was carried out using different conditions to produce specimens from the rolled steel bar of 50mm diameter. The composition of this steel is 0.48%C, 0.25%Si, 0.8%Mn and 0.018%S. The roundness of the machined specimens was measured and the roundness profile was plotted on polar graph.

A plunge cut grinding test was conducted on four specimens selected from the turned specimens. These specimens are chosen such that, they had different roundness profiles as shown in figure 7. A cylindrical grinding machine type Jones & shipman model 1300 was used for the grinding test.

The grinding wheel used for the test was A60KV7 with 400 mm outside diameter, 127mm bore and 25mm thickness. The dressing operation was applied to the wheel before grinding each specimen with 20μm depth of dresser and 0.125mm/rev. feed rate, with four passes.

The grinding conditions were constant for all specimens as follow:

wheel speed	1600 r.p.m.
workpiece speed	140 r.p.m.
infeed	0.025 mm /rev.
width of grinding	20 mm

The specimens were mounted between two centers and each workpiece was machined for 8 Sec.

The variation of the actual interference between the workpiece and the grinding wheel surface was monitored by means of vibration. The portable vibration analyzer B & K 2515 was used to measure the vibration signals exists during grinding. Because of the workpiece form errors determined by the relative displacements of the grinding wheel in direction normal to the ground surface, the vibration accelerometer is to be fixed on a horizontal plan on the workpiece head [8]. The vibration was monitored through the analyzer in frequency domain and the root mean square (RMS) in acceleration of the signal for each workpiece was recorded.

The root mean square (RMS) of vibration signals existed during grinding was used as a vibration measuring parameter so it relates the overall intensity of vibration signal. The (RMS) values recorded during grinding are given in table (1).

Table (1) Root mean square of vibration level during grinding

Workpiece No.	1	2	3	4
RMS (m/sec^2)	2.195	2.360	2.961	3.761

Measurement of out-of-roundness was carried out for each workpiece after it had been ground on a precision roundness measurement instrument (Talyround 250). The polar plot of the roundness profile are shown in Figure 7

As it is known, out of roundness is a complex periodic error which can be resolved by Fourier's sinusoidal harmonics. The amplitude spectra of roundness profile are calculated for all workpeices and plotted for different harmonics as shown in figure8. The undulation number on the workpieces profile is calculated. The results are given for each workpiece in figure 7.

4 -FUZZY CONTROLLER

Fuzzy proportional integral (PI) controller is proposed to compensate the grinding error this controller is based on fuzzy knowledge base controller (FNBC). The equation of PI controller is

$$U = K_p + \frac{K_p}{T_i}\int edt \qquad (8)$$

hence

$$\Delta U = K_p \Delta e + \frac{K_p}{T_i} e$$

This PI controller is inference to the following fuzzy logic approximate reasoning

IF e is (premise) and Δe is (premise)
THEN ΔU is (conclusion)

Table (2) illustrates the rule base of such PI fuzzy controller in tabular form, the cell defined by the intersection of row and column represents a rule such as

IF e(k) is Zo and Δe(k) is Zo
THEN ΔU(k) is Zo

The member ship function of the error signal is shown in figure (9)

Table (2) Rule Base of Fuzzy Knowledge Base Controller (FNBC)

	NB	NM	NS	ZO	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZO
NM	NB	NB	NB	NM	NS	ZO	PS
NS	NB	NB	NM	NS	ZO	PS	PM
ZO	NB	NM	NS	ZO	PS	PM	PB
PS	NM	NS	ZO	PS	PM	PB	PB
PM	NS	ZO	PS	PM	PB	PB	PB
PB	ZO	PS	PM	PB	PB	PB	PB

Where;

NB=Negative Big, NM=Negative Medium, NS=Negative Small, ZO=Zero, PS=Positive Small, PM=Positive Medium, and PB=Positive Big.

To find the physical quantity, center of area defuzzification method is adopted as follows

$$U = \frac{\sum u_i \mu_u(u_i)}{\sum \mu_u(u_i)}$$

Where;

.u_i is a variable in the universe of discourse U

μ_u is the member ship of variable u_i in the universe of discourse U

Figure10 shows the workpiece shape error after introducing fuzzy controller.

5 -DISCUSSION OF THE RESULTS

The tests results are given in figs. 7 and 8. Figure 7 shows the roundness profile, the roundness error and average undulation number for the workpieces before and after grinding. Figure 8 shows the roundness spectrum for the same workpieces. The vibration signals that had been picked up during grinding showed a periodical fluctuation of vibration amplitude for different frequencies in the zone (2.33-60Hz) which relative to the workpiece and wheel rotational frequencies and their harmonics. It is found that: when the average undulation number of the previous surface was small, the amplitudes of vibration at low frequencies (2.33-60Hz) were high. But the amplitudes at the higher frequencies (2.33-100Hz) were high when the average undulation number was high. However it was difficult to find a quantitative correspondence between the vibration amplitude and the height of undulation.

With referring to figure 7 and table (1) it can be seen that, the roundness error (0) of the workpiece resulted from grinding and RMS of vibration level that recorded during the operation are dependent on the initial workpiece roundness error. This can be described by the fact that, the initial roundness error affects the dynamics of the system and works exciter for it. This resulted in increasing of RMS of vibration.

The increase of vibration level (i.e. wheel-workpiece relative motion) caused the roundness error on the new profile. Figure 7 shows that also, the dependence of roundness error on the initial profile is high when this profile has a low undulation number. This is clear in case of workpieces No.3 and 4. It can also be seen from the same figure that, the undulation number resulted from grinding process depends on the initial undulation number on the workpiece circumferential and not only on the wheel workpiece speed ratio as reported before by liao and shiang [6].

The effect of initial workpiece profile on the ground profile is obvious when the amplitude spectra are considered as a parameter for roundness measurement as shown in figure8. It can be noted from the same figure that, the dominant harmonics before grinding are almost the same after grinding. The amplitudes at different harmonics also depend on their values before grinding process.

Referring to Figure10 that shows the workpiece shape error after introducing fuzzy controller. It can be noticed from the figure that, shape error can be compensated and reduced by about 20 % using fuzzy controller with a suitable capacitive transducer and actuator coupled with grinding wheel motion. The effect of initial profiles can be reduced or eliminated using such controller.

6-CONCLUSIONS

According to the given results and discussions, the following conclusions can be drawn for the cylindrical plunge grinding process:-

1. The initial workpiece profile has a considerable effect on the process as it disturbs the process and changes the wheel-workpiece dynamic interference.
2. The RMS of vibration signal exists during the process depends on the initial specimen roundness error. The amplitudes of vibration at different frequencies in the range up to 100 Hz. were found to be dependent on both roundness error and undulation number of initial specimen surface.
3. The roundness error of the ground workpiece depends on the roundness error and undulation number of the workpiece before grinding.
4. The undulation number on the ground workpiece circumference depends not only on the wheel-workpiece speed ratio, but also on undulation before grinding.

5. The effect of the initial workpiece profile on the ground one is obvious with the amplitude spectra of the profiles. The amplitude at different harmonics is corresponding to that before grinding.
6. Introducing the proposed fuzzy controller predicts the work piece shape error more accurately, and reduces it by about 20%

REFERENCES

[1]- R. Deiva Nathan, L. Vijayaraghavan, R. Krishnamurthy "In-process monitoring of grinding burn in the cylindrical grinding of steel" J. of materials processing Technology, Vol. 91, PP 37-42, 1999.

[2]- H. Kaliszer and g. trmal, *"forced vibration during plunge grinding and its effect on surface topography"*, Proc. Int. Con. on the new development in grinding, Pittasbrugh, Pa., P.709, (1972), USA.

[3]- Fraciszek Orynski, Witold Pawlowski " The influence of grinding process on forced vibration damping in headstock of grinding wheel of cylindrical grinder" Int. J. of machine Tools&Manufacture, Vol. 39, PP. 229-235, 1999.

[4]- K. H. Kim, K.F.Eman and S.M.Wv "Feasibility of form accuracy identification and control in cylindrical grinding" Int. J.Mach. Tool Des. Res., vol.26 , No.3, P.259, (1986).

[5]- Hyun Seung C. et al "Machining error compensation of exaternal cylindrical grinding using thermally actuated rest", Journal of Mechatronics, Elseveir science Ltd, Vol 12, PP643-656, 2002.

[6]- Y. S. liao and L.C.shiang "Computer simulation of self excited and forced vibrations in the external plunge grinding process" Trans.ASME Journal of Eng. for Industry, Vol.113, P.297, (1991).

[7]- A. S. Kelzone and P.M. Gukyamukhow, "Internal grinding by spindles on elastic supports", Vestink-Ostroeniya, Vol.63, Issue 8, P.30, (1983).

[8]- K. Steffens and H. Follinger, "A new approach for investiging dynamic effects in grinding" Annals of CIRP, Vol.34, P.267, (1985).

[9]- J. S. Sexton "Chatter vibration and their suppression through the wheel design" Industrial diamond review vol.3 P.161, (1982).

NOMENCLATURE

a_n	the wave amplitude.
F_P	the periodic force.
F_S	the static force.
$F(t)$	the grinding force.
k_g , k_w	the grinding wheel and workpiece wear stiffness respectively.
N	undulation number on workpiece profile.
n	number of waves on workpiece profile.
$U_{\circ}(t)$	the total infeed of the grinding wheel at the time instant t.
$W_w(t)$	total amount of wear of the workpiece.

$W_g(t)$	total amount of wear of the grinding wheel.
$X_c(t)$	elastic deformation at contact area.
$X_m(t)$	elastic deformation of machine tool structure.
X_p	total infeed of the wheel due to the periodic force F_P.
$W_g(t)$	instantaneous amount of wear of the wheel.
$W_w(t)$	instantaneous amount of wear of the workpiece.
f	is the grinding force
L	is the workpiece length
E	is the modulus elasticity
I	is the second moment of area
K_{head}	stiffness of the head stock
K_{tail}	stiffness of the tail stock

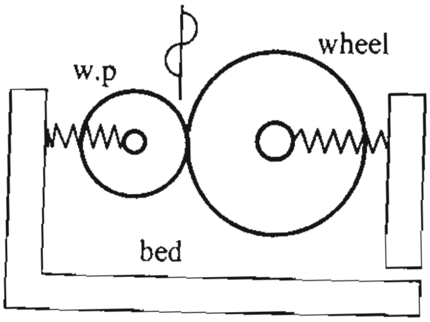


Fig. 1 The grinding wheel-workpiece interaction in cylindrical plunge grinding operation

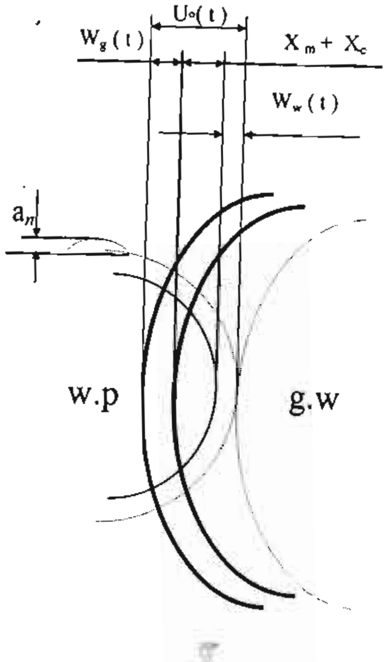


Fig. 2. The total infeed of the grinding wheel at the time instant t

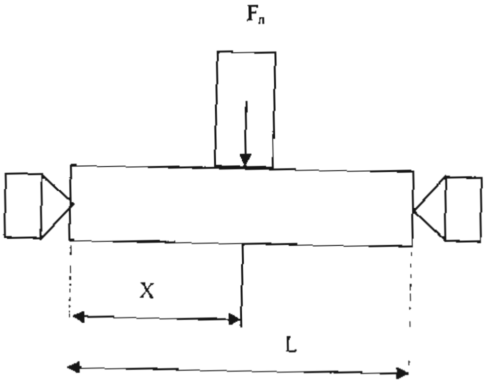


Fig.3 Workpiece during grinding

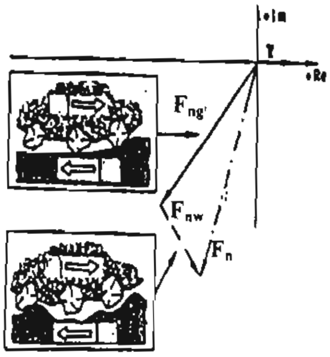


Fig. 4. The effect of initial waviness on dynamic normal force [7].

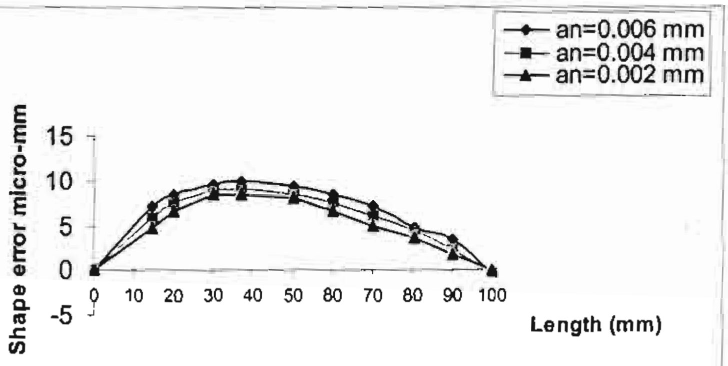
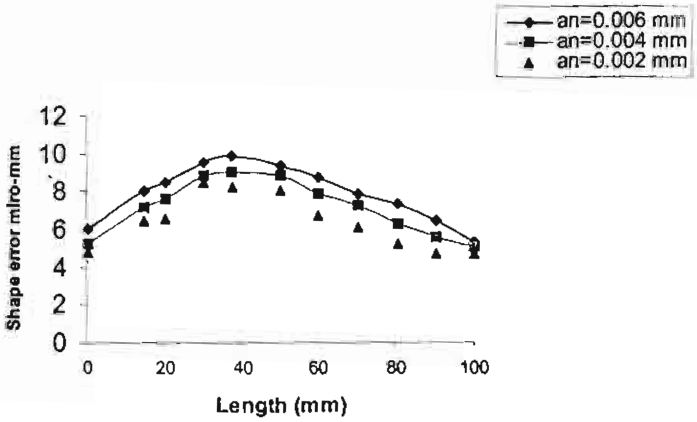
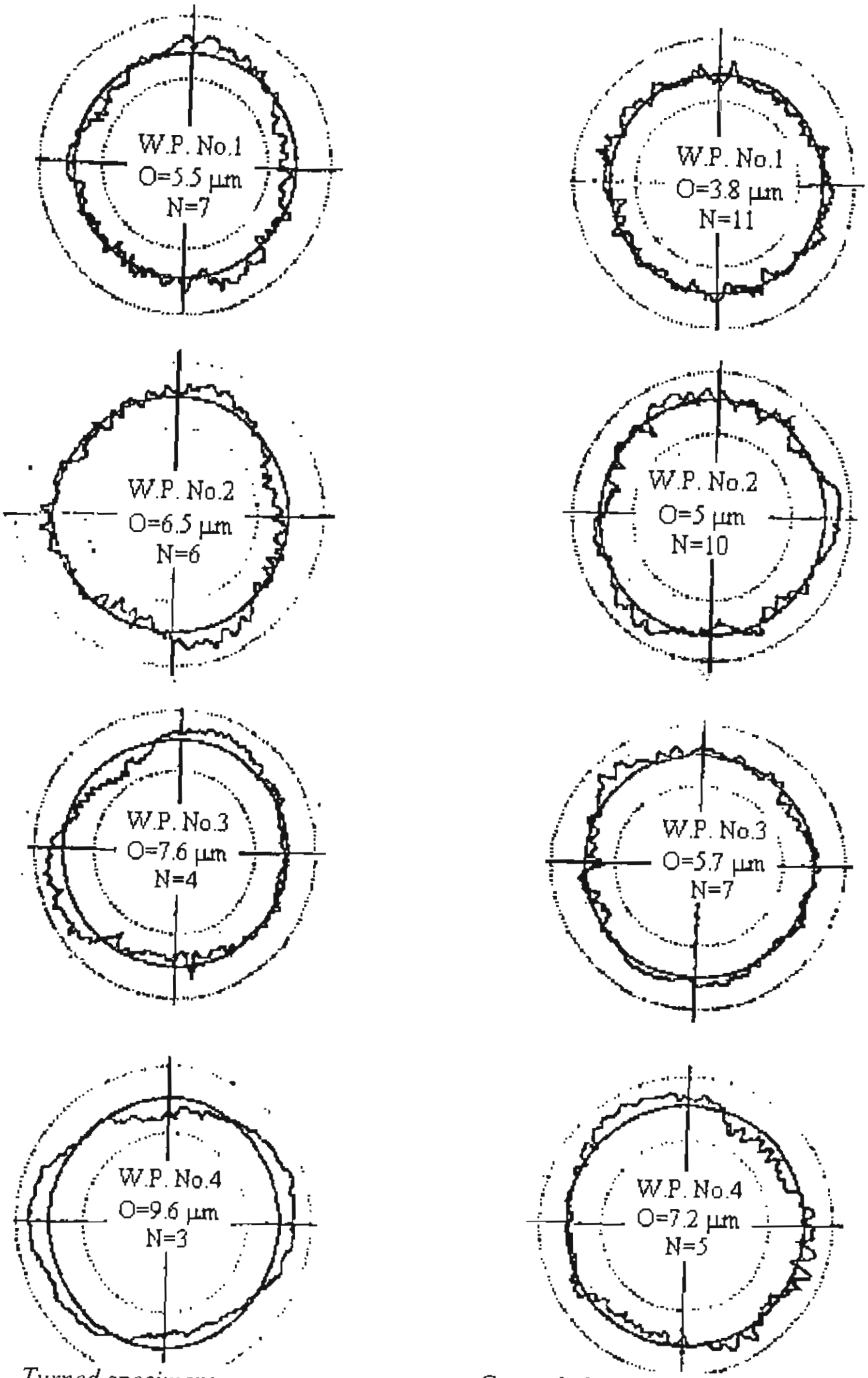


Fig.(5)Shape error at different initial surface profile using rigid



Figure(6) Shape error for different initial profile using flexible stock



Turned specimens *Grounded specimens*

Figure 7. Polar plot of roundness profile

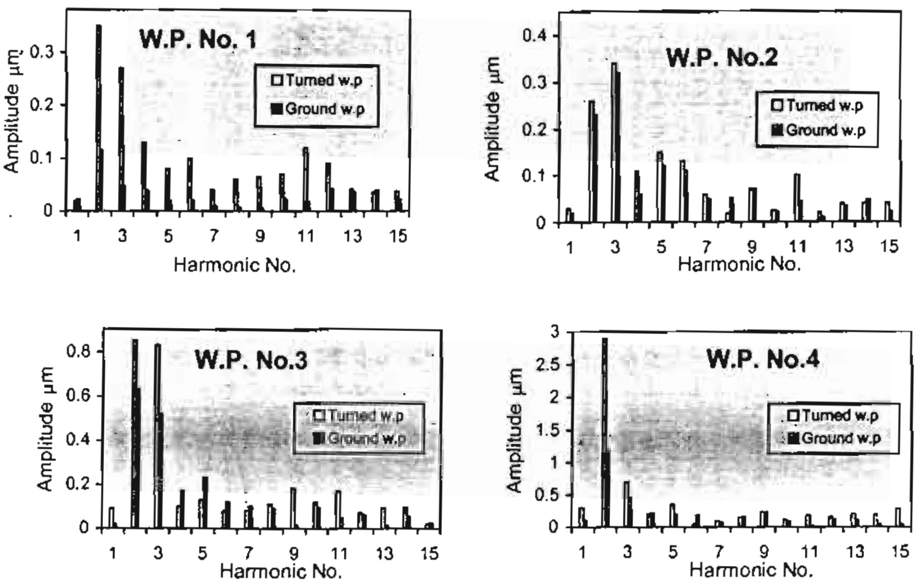


Figure 8 Roundness Spectrum of turned and grounded workpieces

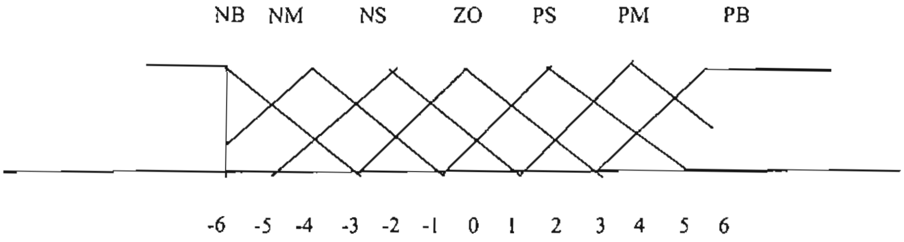


Fig. (9) Membership function of fuzzy controller

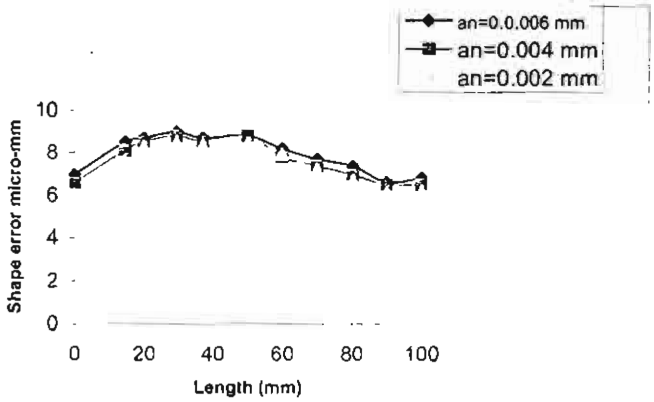


Fig.(10) Shape error using fuzzy controller