Experimental Passive Suppression of the Regenerative Chatter Phenomenon by Variation of the Frequency and Amplitude of the Spindle Motor Excitation in Turning

Kamyar Foroojani Zadeh [1, 2], Reza Nosouhi[1, 2*]
[1]Modern Manufacturing Technologies Research Center, Najafabad Branch, Islamic Azad University, Najafabad, Iran
[2]Department of Mechanical Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran
*Email of Corresponding Author: rezanosuhi@pmc.iaun.ac.ir
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Abstract
The suppression of the regenerative chatter phenomenon in turning process via the variation of the frequency and amplitude of the spindle motor excitation is carried out in this research. A programmable inverter is employed for variable periodic excitation of the spindle motor. A set of turning experiments is designed and performed on a number of conical work pieces both in constant spindle speeds and variable spindle speeds. The work-piece material was 1.7224 steel. These experiments are carried out in different spindle speeds so that the stability lobes diagram could be achieved. The results showed that the passive variations of the spindle speed increase the critical depth of cut in higher spindle speeds, while in lower spindle speeds it is case sensitive. It also showed that the increasing of the excitation frequency reduces the critical depth of cut, while increasing the amplitude increases the critical chip thickness in lower spindle speeds and reduces that in higher spindle speeds.

Keywords
Regenerative Chatter Suppression, Spindle Speed, Excitation Variation, Stability Lobes Diagram

1. Introduction
Regenerative chatter is a term which is subjected to the self-excited vibration which is occurred during the machining. The phenomenon mainly occurs because of the chip thickness variations caused by the successive machining paths. Regenerative chatter causes some limitations in machining specifically in roughing processes. Therefore, the suppression of this phenomenon has been attractive for machine manufacturers and researchers.

There are different methods for control and suppression of the chatter phenomenon, including the active and passive methods. In active methods, usually the chatter control is achieved by excitation of the machine, or altering the machine structure in accordance with the displacement of the tool, which uses the feedback control strategies to control the chatter. This is a very effective method of controlling the chatter and raising the stability lobes, while it is expensive and case sensitive method. There are on the other hand, some passive methods in which the excitation or change of the machine structure is independent from the amount of the tool displacement or chatter occurrence. These methods are less effective in chatter suppression, while they are less expensive and could be applied on every machine with different structures.

There are a number of research works about the passive methods of the chatter suppression available in the literature. Wang and Lee proposed the change in the machine tool structure so that they can delay the chatter occurrence [1]. Yousof et al. used the non-standard milling tools (variable helix and pitch angles tools) to alter the cutting behavior of each of the tool teeth and increase the critical depth of cut [2]. The method was also practiced by some other researchers [3-7]. The dissipation of the chatter energy in milling was performed by Kim et al. [8]. They implanted a damper in the milling cutter and dissipated the energy by friction. Semercigil and Chen used an impact damper for suppression of the chatter vibration [9].

In this research, the regenerative chatter suppression via the spindle speed variation was experimentally studied. This research work can be considered under the passive strategies category, in which the excitation is independent from the amount of the tool displacement. A number of conic work pieces were produced so that the depth of cut could be increased linearly during the turning process. The turning experiments were carried out in different spindle speeds, both in constant spindle speed and variable spindle speed conditions. Whenever the regenerative chatter was beginning, the turning process was being stopped and the depth of cut was being measured. The experiments were carried out in different spindle speeds so that the stability lobes diagram could be resulted.

2. The test setup

The conic work pieces which were employed for turning experiments are shown in Figure 1. The conical design of the work pieces was because of the linear increase in the depth of cut during the turning process. In another word, the depth of cut was increased until the chatter phenomenon was occurred.

Figure1. The work-piece

The variations in the spindle speed were caused by a PLC (MOELLER EASY 820) and an inverter (DELTA). The PLC was connected to the inverter which was connected to the spindle motor and produced a harmonic sinusoidal variation in the spindle speed.

To investigate the effect of the amplitude of the spindle speed variations on the results, the experiments were carried out in different frequencies and amplitudes of spindle speed variation. The variations of the spindle speed were about the determined spindle speed with %10 and %15 variations in the amplitude. Furthermore, the time period of the variations was selected 4 and 8 seconds so that the effect of the variation frequency could also be studied.

The experiments were performed on the 1.7224 steel. The variations of the spindle speeds in both 4s and 8s time periods are listed in Tables 1 and 2 for %10 and %15 amplitude variations respectively. Also, the minimum and maximum of the frequency of the pulses which was sent to the motor by the inverter are denoted by F_{min} and F_{max} respectively.

Table1. the spindle speed variations with %10 variations

constant spindle speed (rpm)	125	180	250	355	500	710	1000
n_{min} (rpm)	112.5	162	225	319.5	450	639	900
n_{max} (rpm)	137.5	198	275	390.5	550	781	1100
Spindle speed that disposed by gearbox (rpm)	180	250	355	500	710	1000	1400
F_{min} (%)	62	65	63	64	60	64	64
F_{max} (%)	76	79	77	78	73	78	79

Table2. The spindle speed variations with %15 variations

constant spindle speed (rpm)	125	180	250	355	500	710	1000
n_{min} (rpm)	106.25	153	212.5	301.25	425	603.5	850
n_{max} (rpm)	143.75	207	287.5	408.25	575	816.5	1150
Spindle speed that disposed by gearbox (rpm)	180	250	355	500	710	1000	1400
F_{min} (%)	59	61	60	60	57	60	61
F_{max} (%)	80	83	81	82	77	82	82

It is emphasized that the variations were about each of the spindle speeds. The critical depth of cut was measured in all of the turning experiments.

In order to measure the critical depth of cut, the cylindrical turning tests were performed on the conical test work pieces on the manual lathe. Since the depth of cut was increasing gradually while cylindrical turning, the lobe of the stability could be recognized once the chatter phenomenon occurred. The machine was stopped when the chatter phenomenon happened, and the critical depth of cut was assigned for that machining condition.

3. Results and discussion:

It should be noted that the main purpose of this study was to increase the critical depth of cut by variation of the spindle speed. However, the results showed that the variations in the spindle speed do not increase the critical depth of cut in all of the experiments. The experiments also showed that the frequency and amplitude of the spindle speed variations affect the critical depth of cut.

3.1 The effect of the variations frequency

The effect of the variations' time period on the critical depth of cut with %10 variations in the spindle speed is presented in Figure 2.

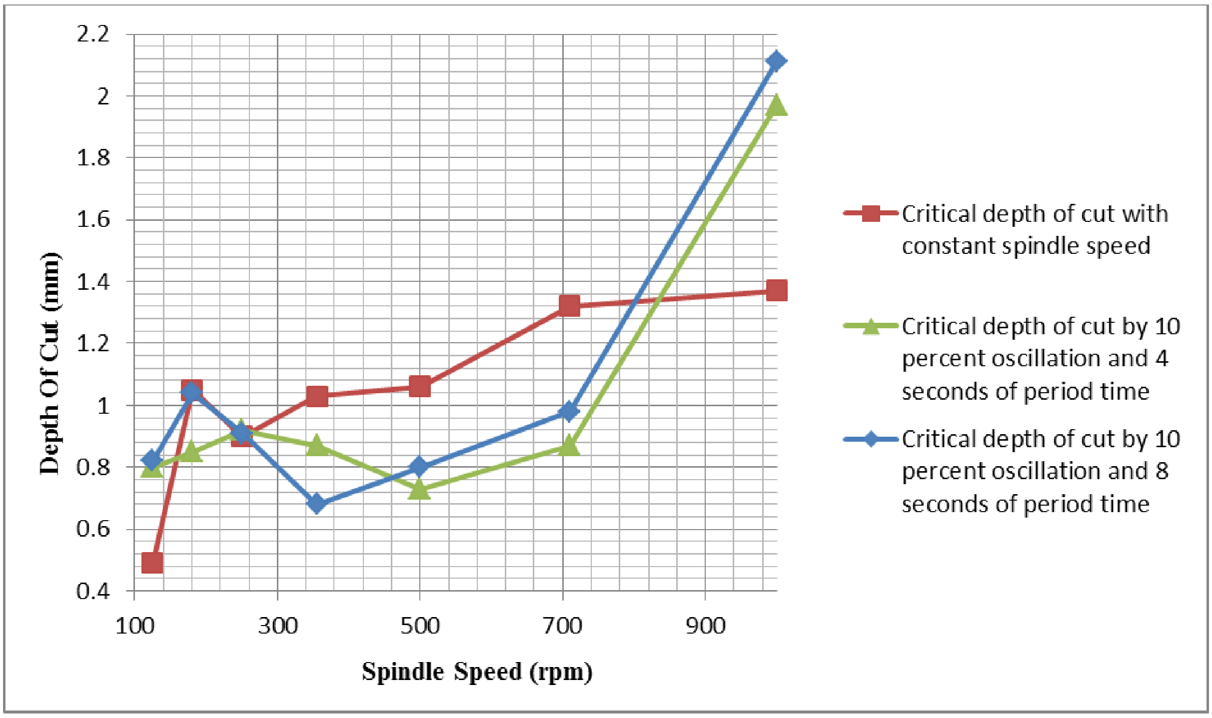

Figure2. the effect of the variations' time period on the critical depth of cut with %10 variations of the spindle speed

It is showed that neglecting some fluctuations, the critical depth of cut with the oscillation of the spindle speed with the 8 seconds time period was higher than that with the oscillation of the spindle speed with the 4 seconds time period. Therefore the increasing of the frequency reduces the critical depth of cut. The same results could be achieved while machining with the %15 variations in the spindle speed, as showed in Figure 3.

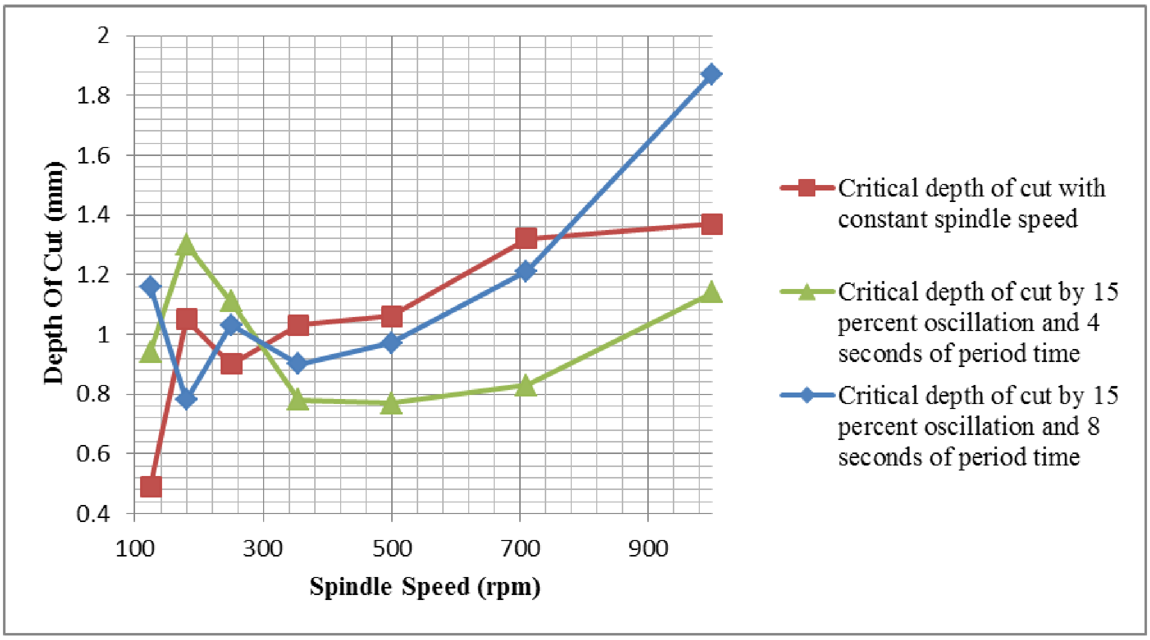

Figure3. the effect of the variations' time period on the critical depth of cut with %15 variations of the spindle speed

3.2 The effect of the variations amplitude

It was observed that increasing the variations amplitude would result in the reduction of the critical depth of cut in higher spindle speeds, while it causes the critical depth of cut to increase in lower spindle speeds. Figure 4 and Figure 5 show the results of the critical depth of cut in %10 and %15 variations amplitude with 4 seconds and 8 seconds of the variations time period respectively.

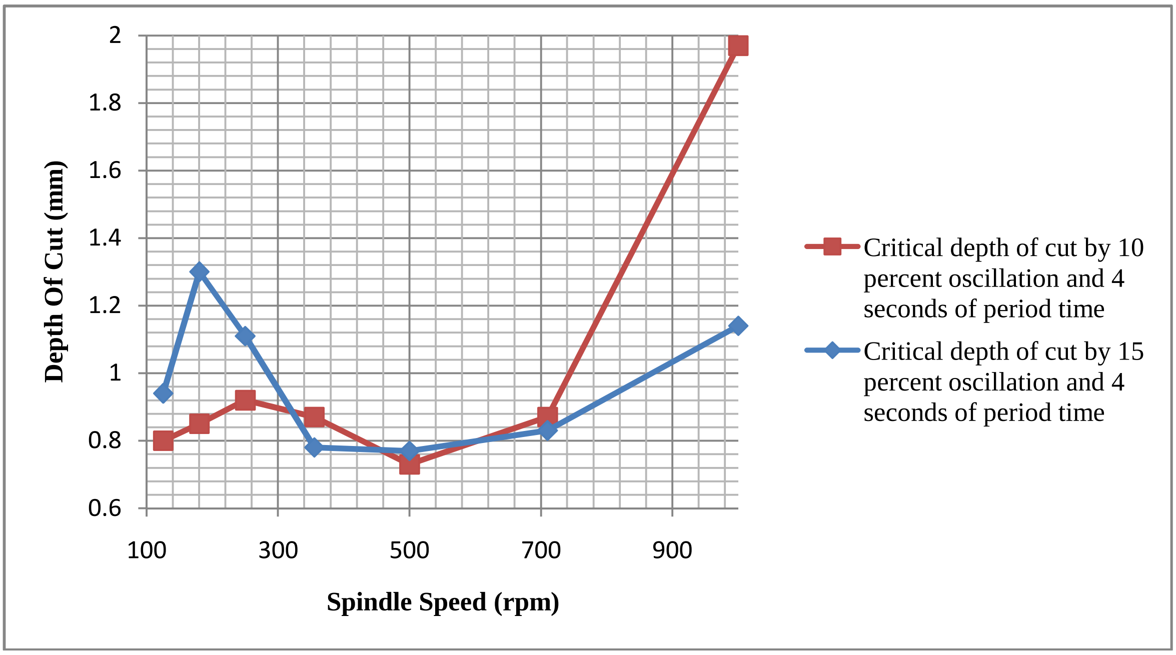

Figure4. the critical depth of cut in different variations amplitude with 4 seconds time period

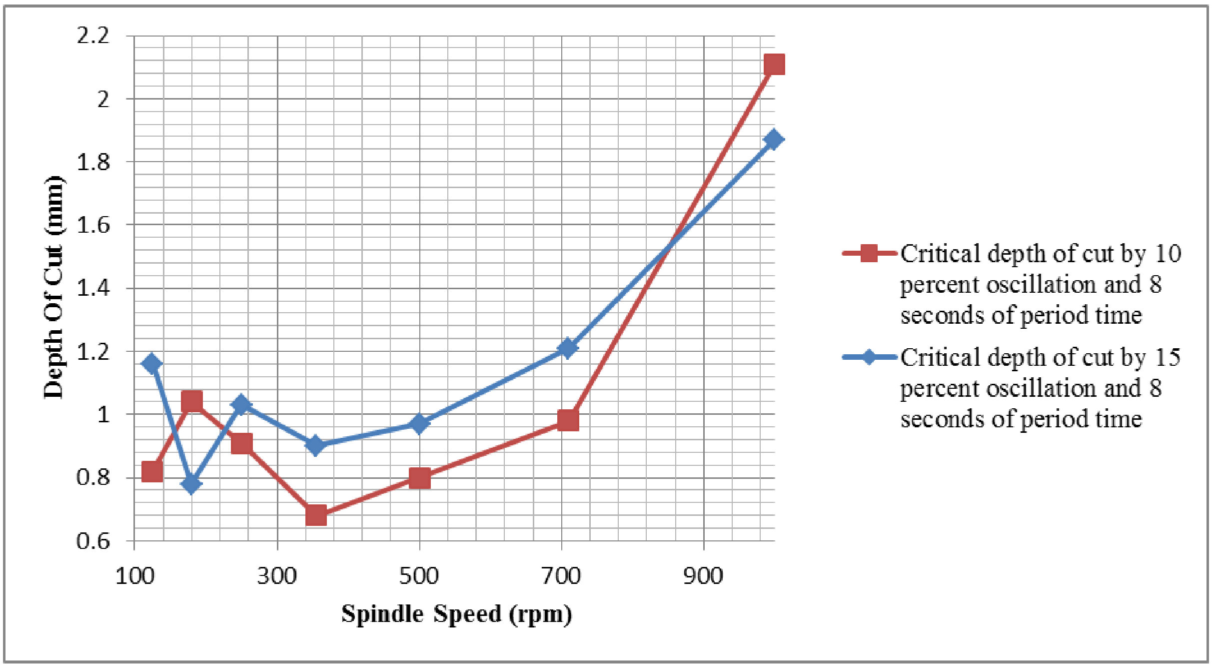

Figure5. The critical depth of cut in different variations amplitude with 8 seconds time period

The results also showed that the spindle speed variations excel the critical depth of cut mainly in high spindle speeds, as it can be seen in Figs. 2 and 3. In other spindle speeds, the results are case sensitive and should be investigated separately.

The achieved results could be summarized as follows:

1- The variations of the spindle speed alter the dynamic behavior of the machine tool in chatter. The critical depth of cut changes as a result of these variations.
2- The variations of the spindle speed increase the critical depth of cut in high spindle speeds. However, in lower spindle speeds, it is case sensitive and should be investigated for different machining conditions.
3- The amplitude of the spindle speed variations changes the critical depth of cut in different directions. In lower spindle speeds, increasing of the amplitude leads to an increase in the critical depth of cut, while in higher spindle speeds reduces the critical depth of cut.
4- The frequency of the spindle speed variations also affects the critical depth of cut. Neglecting some fluctuations, it was observed that the machining conditions with higher spindle speed frequency have lower critical depth of cut.

4. Conclusion

The passive chatter suppression by altering the spindle excitation in turning was performed in this research. The variations in the spindle excitation resulted in rising of the stability in high spindle speeds, while in lower spindle speeds it should be studied further. The appropriate excitation frequency and amplitude were also determined by the experimental tests.

5. References

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