ANALYSIS OF HARMONIC DISTORTION IN CNC TURNING CENTRES

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Abstract:

The objective of this paper is to explain the cause and effects of harmonic distortions due to the wide spread of CNC machines in Industries. Harmonics are of more concern today due to the extensive use of non-linear loads in the Industries that generates the harmonic problems in the power system. Harmonic Distortion can cause malfunction of sensitive electronic equipment. The primary need for the harmonic analysis and mitigation in CNC machines is to reduce the line current harmonics at partial load. The presence of harmonics in CNC machine was investigated by conducting a simulation using Fourier Transform technique in MATLAB/Simulink software. The simulation and the experimental results show a high level of harmonic distortion, at the Point of Common Coupling (PCC) in the distribution system. The reliability of harmonic analysis and mitigation in CNC machine has also been inferred. The purpose of conducting the harmonic study in CNC machines is to reduce the harmonics at partial loads and thereby reduce the harmonics in the whole supply system.

Keywords: *CNC turning centre, harmonic distortion, harmonics, non-linear loads, THD.*

1. Introduction

Manufacture sector of industries consumes almost one-third of the total electricity produced in the country. Computerized Numerical Control (CNC) machines are widely used in the manufacturing sector and have become an integral part of any shop floor due to its several advantages. With the increase in the use of non-linear loads in industries, a significant percentage of the distribution system is considered as a cause of concern. The non-linear loads generate harmonics which flows from the load towards power source and in turn produce additional losses which degrade the active power handling capacity of the equipment. Harmonic is a non-sinusoidal waveform with a frequency of an integral multiple of the fundamental frequency[2]. The harmonics can affect the voltage waveforms and thus cause malfunctions in other sensitive devices connected to the same network. The term harmonic is used for representing both current and voltage distortions. The non-linear loads include variable speed drives, switched modes power supplies, battery chargers, UPS systems, computers, electric lighting, etc. The Total Harmonic Distortion(THD) and Total Demand Distortion(TDD) are used to describe the harmonic contents in the waveforms and was calculated by using the equations given below. The term total demand distortion is very much like the total harmonic distortion.

$$THD_I = \sqrt{\sum_{h=2}^{\infty}\left(\frac{I_{h,rms}}{I_{1,rms}}\right)^2} \times 100\ \% = \frac{\sqrt{(I_{rms}^2 - I_{1,rms}^2)}}{I_{1,rms}} \times 100\ \% \quad (1)$$

$$TDD_I = \sqrt{\sum_{h=2}^{\infty}\left(\frac{I_{h,rms}}{I_{L,rms}}\right)^2} \times 100\ \% = \frac{\sqrt{(I_{rms}^2 - I_{1,rms}^2)}}{I_{L,rms}} \times 100\ \% \quad (2)$$

where, h is the harmonic order. $I_{L,rms}$ denote the RMS value of maximum demand load current (fundamental frequency component) at PCC. $I_{1,rms}$ is the RMS value of fundamental component. $I_{h,rms}$ is the RMS value of harmonic component of order h.

I_{rms} is the total RMS current.

The relation between total RMS current and the THD is represented by the equation(3). Thus reducing THD will reduce the total RMS current, enabling a reduction in additional losses in the network caused by the unwanted harmonics generated by the device.

$$I_{rms} = I_{1,rms}\left(\sqrt{1+\left(\frac{THD}{100}\right)^2}\right) \quad (3)$$

The filter is a generic term used to describe the types of equipment whose purpose is to reduce the harmonic current or voltage flowing in or being impressed upon specific parts of an electrical system, or both[2]. Passive filters are cost effective and can provide an adequate current harmonic cancellation, however, they are bulky, heavy, can introduce resonance in the power system and can only be tuned to cancel a single harmonic effectively. Therefore multiple filters have to be installed to eliminate more than one harmonic [1]. Active power filters are usually classified depending on the way they are connected to the electric system and are divided into shunt APFs and series APFs [7]. Active power filters are used for high horsepower ratings. A shunt APF is used to operate when abnormal voltage conditions are present, and it cancels out the current harmonics.

Every device connected to the supply system is not operating at nominal load all the time, especially if it is a variable- speed drive controlling a motor's speed, based on the varying needs of the load. The harmonic content increases rapidly with the decreasing value of the load. The performance of the CNC machines in the industries is greatly affected by the presence and magnitude of harmonics produced. The presence of harmonics in CNC machines leads to the generation of tool chatter, poor surface finish, and critical productivity. Harmonic mitigation on CNC machine makes it easier to achieve the consistent surface finish on parts and provide better-performing devices. Harmonic measurement test and analysis were conducted on the CNC machines with different parameter settings, and it confirmed the presence of lobes. The primary intent of this paper is to report our findings of the harmonics and the effectiveness of the harmonic analysis and mitigation in the CNC machines.

2. Harmonic Standards

Harmonic standards are available to limit the harmonic distortions at the point of common coupling(PCC). In 1992, the Institute of Electrical and Electronics Engineers updated the IEEE 519-1981,"Guide for harmonic control and reactive compensation of static power converters" guidelines as IEEE 519-1992 "IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems." This guidance is intended to help the problems involved in the harmonic control and reactive compensation of Static power converters, and provide an application guide.

IEEE Std 519-2014 is a newly published revision to the IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems[6]. The limits in this recommended practice are intended for application at a point of common coupling (PCC) between the system owner or operator and a user. PCC was usually taken as the point in the power system closest to the user where the system owner or operator could offer service to another user[3]. For industrial users (i.e., manufacturing plants) via a dedicated service transformer, the PCC is on the HV side of the transformer. For commercial users (office parks, shopping malls, etc.) supplied through a common service transformer, the PCC is commonly on the LV side of the service transformer[3].

The current and voltage distortion limits recommended here establish the maximum allowable distortion limit for a customer, and it is listed in Table 1 and 2 respectively. The standard sets the limits for individual current harmonics and for total demand distortion (TDD) for a given short circuit current to load current ratio (I_{sc}/I_L). The recommended standard has a feature as, larger I_{sc}/I_L ratios, have the ability to withstand larger current harmonics distortion.

The International Electro-technical Commission (IEC) presents standards on electromagnetic compatibility in several publications that cover many disturbing electrical phenomena[5]. The standard IEC 61000-3-2 and the prospective standard IEC 61000-3-12 only restrict the level of harmonics at nominal load, but there are no restrictions on harmonics at partial load. IEC 61000-3-2 limits for the harmonic emissions in LV network of equipment whose input current is up to and including 16A. The IEC 61000-3-4 deals with equipment with rated input current higher than 16A[5].

3. Experimental Setup

An experimental setup, as shown in Fig. 1, was implemented in the PSG Fanuc centre for advanced CNC and robotics laboratory at PSG College of Technology, Coimbatore, India, to analyze the harmonic distortion of the current waveform drawn by the CNC turning centre, Midas 6 at various parameter settings. The Fluke 435 Series II Power Quality and Energy Analyzer was used for capturing the harmonic data in the CNC turning centre. The specification of the CNC turning centre was listed in Table 3.

4. Harmonic Measurements

Total Harmonic Distortion (THD) and Total Demand Distortion (TDD) are the two most common indices that are used to quantify harmonic distortion in power systems [4]. The Fluke 435 power quality analyzer was used for the harmonic measurements. The measurement process and display of data are optimized to get the most relevant information as quickly as possible. Multiple parameters are measured simultaneously and presented in formats that quickly describe the state of the power quality of the system. Data can be quickly accessed as single digital values, trend graphs, waveforms, phasor diagrams or analyzed and organized into a tabular format such as the event data where the magnitude, duration and time stamping enable rapid correlation to problems experienced[8]. The voltage and current harmonic data captured from the measuring equipment at different parameter conditions are listed in Table 4 and Table 5. The machined product obtained after the harmonic distortion measurement test is shown in Fig.2.

Table 1. Current distortion limits for systems rated 120 V through 69 kV [3]

Maximum Harmonic Current Distortion in Percent of I_L						
Individual harmonic Order (Odd Harmonics)[a,b]						
I_{sc} / I_L	$3 \le h < 11$	$11 \le h < 17$	$17 \le h < 23$	$23 \le h < 35$	$35 \le h \le 50$	TDD
<20[c]	4.0	2.0	1.5	0.6	0.3	5.0
20<50	7.0	3.5	2.5	1.0	0.5	8.0
50<100	10.0	4.5	4.0	1.5	0.7	12.0
100<1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

[a]Even harmonics are limited to 25% of the odd harmonics limits above.
[b]Current distortions that result in a dc offset, e.g., half-wave converters, are not allowed.
[c]All power generation equipment is limited to these values of current distortion, regardless of actual I_{sc} / I_L .
where
I_{sc} : maximum short- circuit current at Point of Common Coupling(PCC).
I_L : maximum demand load current (fundamental frequency component) at the PCC under normal load operating conditions.

TDD: Total Demand Distortion is the harmonic current distortion in % of the maximum demand load current.

Table 2. Voltage distortion limits[3]

Bus Voltage V at PCC	Individual harmonic(%)	Total Harmonic Distortion THD(%)
$V \le 1.0$ kV	5.0	8.0
1 kV<$V \le 69$ kV	3.0	5.0
69 kV<$V \le 161$ kV	1.5	2.5
161 kV<V	1.0	1.5[a]

[a]High-voltage systems can have up to 2.0% THD where the cause is an HVDC terminal that will have attenuated at points in the network where future users may be connected.

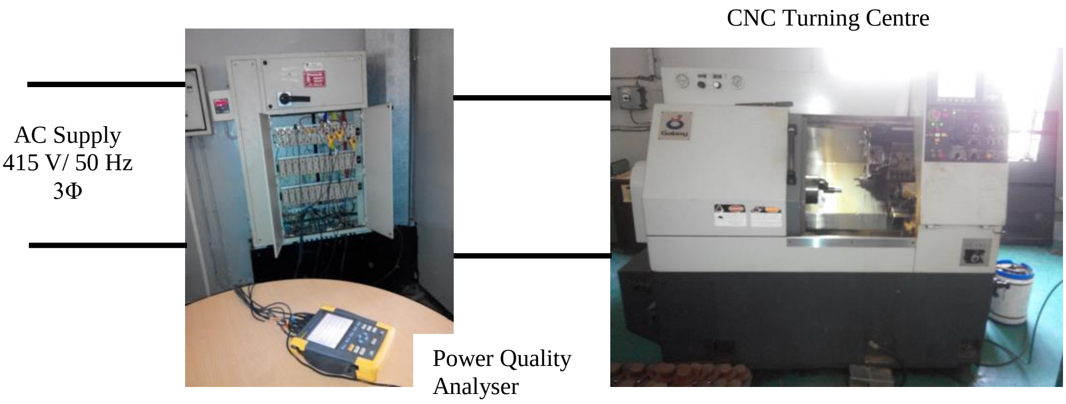

Fig. 1. Experimental set up

Table 3. Specifications of CNC universal turning centre

Turing Dia (Max)	240 mm
Chuck Size	169 mm
Bar Capacity (Max)	40 mm
Spindle Size	A2-5
Spindle Speed	40-4000 rpm (standard) 60-6000 rpm (optional)
Spindle Power (30 mins/Cont. Rating)	7.5 / 5.5 kW
X- Travel	140 mm
Z- Travel	365 mm
Rapid Traverse	32 m/min
Machine Power Consumptions	15 kVA

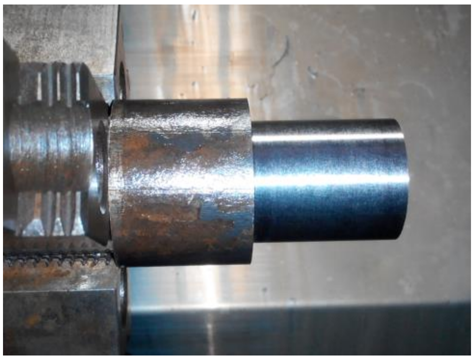

Fig.2. Machined product

Table 4. Measured current harmonics of CNC universal turning centre

Frequency (Hz)	Current Harmonics	Spindle speed = 1000 rpm, Depth of cut = 0.5 mm, Feed rate = 0.1 mm/rev	Spindle speed = 1000 rpm, Depth of cut = 0.5 mm, Feed rate = 0.25 mm/rev	Spindle speed = 1200 rpm, Depth of cut = 0.5 mm, Feed rate = 0.1 mm/rev	Spindle speed = 1200 rpm, Depth of cut = 0.5 mm, Feed rate = 0.25 mm/rev	Spindle speed = 1200 rpm, Depth of cut = 1 mm, Feed rate = 0.1 mm/rev	Spindle speed = 1000 rpm, Depth of cut = 1 mm, Feed rate = 0.25 mm/rev
250	I_{h5}	23.82	24.44	23.89	24.1	26.08	26.37
350	I_{h7}	23.1	24.68	23.91	24.44	24.88	23.19
550	I_{h11}	3.74	3.08	3.53	3.07	2.6	3.04
650	I_{h13}	5.34	4.77	4.74	5.68	5.68	6.63
850	I_{h17}	1.01	1.18	1.38	1.11	1.51	1.09
950	I_{h19}	1.88	2.24	2.33	2.12	1.88	1.23
1150	I_{h23}	1.13	0.83	0.5	0.95	0.91	0.85
1250	I_{h25}	1.29	0.64	0.84	0.85	0.94	0.58
1450	I_{h29}	1.15	0.73	0.73	0.76	0.82	0.61
1550	I_{h31}	0.89	0.56	0.58	0.6	0.6	0.49
1750	I_{h35}	0.83	0.63	0.75	0.53	0.54	0.55
I_{Max}(Amps)		**4.9**	**4.8**	**4.7**	**5**	**5.1**	**5.4**

Table 5. Measured voltage harmonics of CNC universal turning centre

Frequency (Hz)	Voltage Harmonics	Spindle speed = 1000 rpm, Depth of cut = 0.5 mm, Feed rate = 0.1 mm/rev	Spindle speed = 1000 rpm, Depth of cut = 0.5 mm, Feed rate = 0.25 mm/rev	Spindle speed = 1200 rpm, Depth of cut = 0.5 mm, Feed rate = 0.1 mm/rev	Spindle speed = 1200 rpm, Depth of cut = 0.5 mm, Feed rate = 0.25 mm/rev	Spindle speed = 1200 rpm, Depth of cut = 1 mm, Feed rate = 0.1 mm/rev	Spindle speed = 1000 rpm, Depth of cut = 1 mm, Feed rate = 0.25 mm/rev
250	V_{h5}	3.38	3.14	3.42	3.54	3.22	3.85
350	V_{h7}	1.1	0.95	1.08	1.19	1.12	1.29
550	V_{h11}	0.26	0.13	0.29	0.32	0.26	0.29
650	V_{h13}	0.09	0.08	0.08	0.09	0.06	0.25
850	V_{h17}	0.32	0.28	0.28	0.28	0.3	0.34
950	V_{h19}	0.12	0.12	0.16	0.17	0.14	0.05
1150	V_{h23}	0.17	0.08	0.1	0.16	0.14	0.19
1250	V_{h25}	0.14	0.11	0.12	0.16	0.09	0.16
Phase Voltage V_{rms} (Volts)		**230.1**	**231.42**	**231.44**	**230.34**	**229.72**	**227.4**

5. Harmonic analysis

An analysis of the recorded data helps to reveal the harmful effects of harmonics and power factor issues. The measured harmonic data in CNC machine at different parameter are evaluated by using Fourier transform technique. According to Fourier theorem, any non-sinusoidal waveform can be represented by the fundamental wave, plus one or more harmonics. The FFT Analysis tool of the Powergui block available in MATLAB/ Simulink software is used to perform Fourier analysis of simulation data signals. The voltage harmonic distortion at different parameter setting is shown in Fig. 3. At all conditions the THDv being less than 4.25 % is within the acceptable standard limit and none of the individual harmonics crosses the normal threshold value.

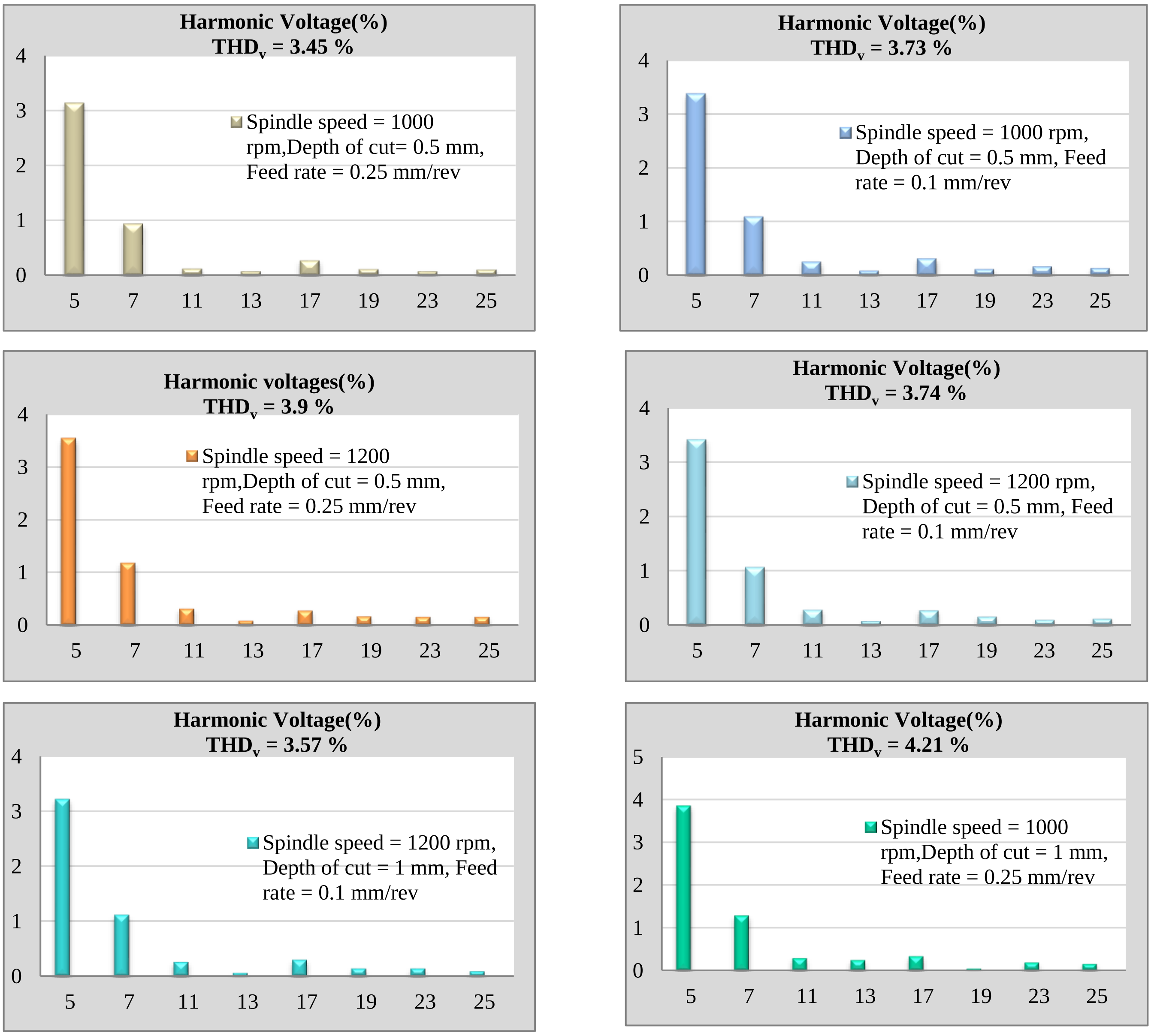

Fig.3: The voltage harmonic distortions of the CNC turning centre at different settings

The current harmonic distortions in the CNC turning centre at different parameter values were shown in Fig.4. The current waveform drawn by the CNC turning centre and its amplitude spectrum are illustrated in Fig.5. The current waveform is highly distorted compared to the ideal sine wave due to the high penetration of the non-linear load. The total harmonic distortions in the current waveforms are found to be greater than 40%, the 5th and 7th harmonic were found to be violating the standard limits. The increased current harmonic distortion will reduce the efficiency of the system due to increased system losses.

The current and voltage distortion should be limited to an acceptable level at any point in the system, and the entire system should be operated without substantial harmonic distortion anywhere in the system[2]. The effective way to meet the recommended harmonic distortion limits is to filter the harmonics at individual load and measure them at the selected PCC [5].

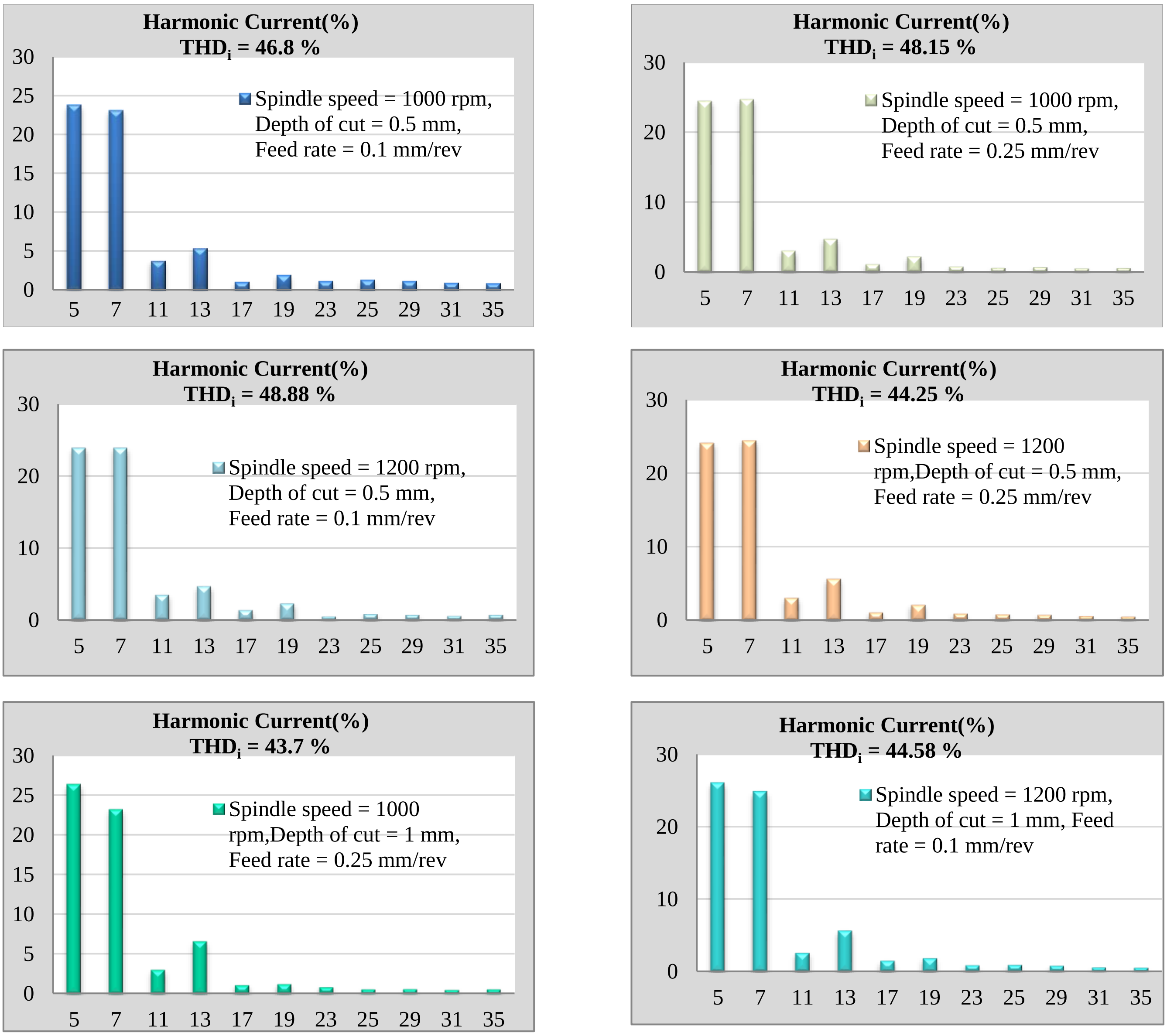

Fig.4. The current harmonic distortions of the CNC turning centre at different settings

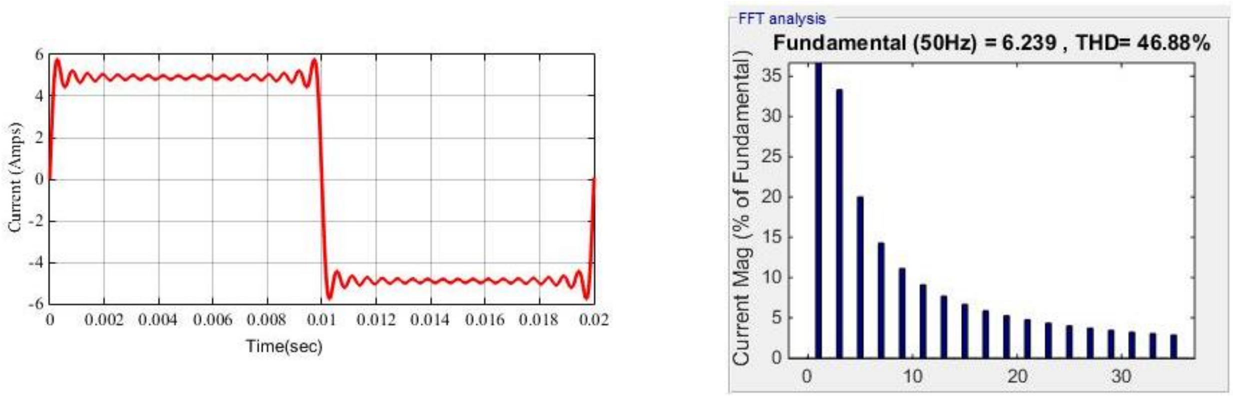

Fig.5. The current waveform at the PCC and the current spectrum at a spindle speed of 1000rpm, Depth of cut of 0.5 mm and Feed rate of 0.1 mm/rev.

6. Conclusion

This paper concentrates on the harmonic measurement and analysis in CNC turning centre. The report indicates that the harmonic reduction at the device level in CNC turning centre has intangible credits on the power system. Passive harmonic filters can solve the 5th and 7th harmonic pollution in the electrical distribution system produced due to the operation of CNC machines in the manufacturing industry. Once the proposed filter can mitigate the harmonics to the standard level, then we can suggest the same for other machines also and will be a great achievement to the industry. The harmonic mitigation gives intangible benefits in the form of increased life of equipment and free from unforeseen, unpredictable supply waveform and magnitude deformations.

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