Journal of Advance Manufacturing Systems and Technology
Volume 3, Issue 1, January-June, 2018

The Elastic Spring Back Effect in Ti6Al4V Titanium Alloy with High Cutting Speeds on CNC End Milling Operation

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Abstract

This paper shows the influence of the elastic spring back on, displacement, tool wear and surface roughness of titanium alloy with high cutting speeds in CNC milling operation. At these high cutting speeds, the chemical and mechanical properties of Ti6Al4V cause complex wear mechanisms. In this work, a carbide two flute end mill tool is tested, and its wear behavior is studied. The performance of the carbide tool has been investigated in terms of tool life, displacements, spring back and surface roughness. A slower wear progression was found with an increase in cutting speeds, whereas the norm is an exponential increase in tool wear at elevated speeds. Observations based on scanning electron microscope (SEM) analysis shows that the spring back effect plays a major role in vibrations, surface roughness and tool wear.

Keywords: *CNC end Milling, tool wear, high speed, carbide tool, spring back effect, Vibration displacement and tool wear*

INTRODUCTION

Ti-6Al-4V titanium alloy is one of the most important materials in industry which is used in aerospace industry. Titanium alloys are also notoriously difficult to machine materials owing to their unique material properties imposing a major bottleneck in manufacturing systems. A series of machining experiments were conducted and surface roughness, tool life, tool wear, and displacement are investigated for CNC end milling. The CNC end milling uses solid carbide cutting tools and result in a paradigm shift in machining of titanium products.

Among several CNC industrial machining processes, milling is a fundamental machining operation. It is broadly used in a variety of manufacturing industries including the aerospace, automotive sectors, where quality is a vital factor in the production of slots, pockets, precision moulds and dies. The material of choice in literature Dearnley PA et al [2] is limited especially because Ti6Al4V known for causing spring back issues was not investigated. This leads to elastic deformation and to spring back after cutting with two flute carbide mill on CNC milling machine.

The elastic deformed material behind the cutting edge rubs against the tool's flank face and reduces the effective clearance angle so the surface quality of the work piece becomes poor. At higher cutting speeds and thus higher cutting temperatures the young's modulus is further decreased which increases the elastic behavior and the spring back. Ezugwu EO et al [6] confirms that the tool wear is the dominant wear in Ti6Al4V cutting just before chipping arises. The elastic spring back in Ti6Al4V cutting causes high compressive stresses on the flank face. The literature Abele E et al [18] shows the dependency of the cutting velocity in the spring back and the reliable results have been tabled. The optimization of the parameters of the machining will be carried out by using the Taguchi's method for design of experiments (DOE). Experimental validation has been performed, and the model is shown to predict the surface roughness, tool wear and tool vibration within an average of 10%.

The elastic recovery significantly increases the peak-to-valley cutting forces and enlarges the unstable feed rate range. This article presents the correlation of vibration signal feature, that is, displacement due to vibration (microns) during the machining and tool wear monitoring of a metal milling operation. Machining of Ti6Al4V has been carried out on using two flute carbide end mill and online vibration signals acquired using a Laser Doppler Vibrometer (LDV).

The measured tool wear forms correlate to features in the vibration signals in frequency domains. Analyses of the results suggested that the vibration signals' features are effective for use in cutting tool wear monitoring and wear qualification. Present work demonstrates the three-dimensional analysis to predict the work piece displacements in feed direction and corresponding tool wear with the help of induced vibrations in milling under dry machining conditions.

EXPERIMENTAL SETUP

The experiments are done on a CNC milling machine with 10 mm diameter carbide two flute end mill with work piece of Ti6Al4V with dimensions of 100X100X10 mm and a variation of cutting speed from 3000 to 4000 rpm. The displacement, tool wear and surface roughness and spring back are recorded.

Fig.1CNC milling machine where experimentation is done

TOOL GEOMETRY

In order to validate the proposed model, end milling tests were performed with two flute end of mill 10 mm diameter, 300helix angle and 100clearance angles at a range of feed rates from 0.1 to 0.3mm/rev. The Ti6Al4V is selected as a work piece material.

METHODOLOGY

In this work, Artificial Neural Network (ANN) is used to develop mathematical models of tool vibration, surface finish, tool wear and spring back. The main purpose of developing mathematical models with respect to machining responses and their factors is to optimize the machining process.

WORK PIECE MATERIAL TI6AL4V

Generally, Ti-6Al-4V is used in applications up to 400oC. It has a density of roughly 4420 kg/m3, Young's modulus of 120 GPa, and tensile strength of 1000 MPa. By comparison, annealed type 316 stainless steel has a density of 8000 kg/m3, modulus of 193 GPa, and tensile strength of 570 MPa. Tempered 6061 aluminum alloy has a density of 2700 kg/m3, modulus of 69 GPa, and tensile strength of 310 MPa, respectively.

ARTIFICIAL NEURAL NETWORK (ANN): is the best method to predict spring back effect of material Ti6Al4V. ANN is one of the most powerful technique, currently being used in various fields of engineering for complex relationships which is difficult to describe with physical models. The input and output data set of the ANN model is generated to predict surface roughness, tool wear, displacement and spring back effect.

The parameters of the artificial neural network are spindle speed, feed rate and depth of cut with passes.

USED CUTTING PARAMETERS

The used cutting parameters are shown in the table. The depth of cut for all tests fixed as 0.3, 0.6 and 1 mm respectively. All tests are conducted in a dry condition are shown in Table 1.

Table 1: L27 Orthogonal Array with experimental value

Trail No	Spindle speed RPM	Depth of cut mm	Feed mm/rev	passes	Surface Roughness R_a µm	Displacement V_x µm	Displacement V_y µm	Tool Wear V_B µm	Elastic spring back µm
1	3000	1.0	0.1	1	1.5931	7.2168	5.78	0.17	0.1421
	3000	1.0	0.1	2	1.4317	7.2265	5.78	0.17	0.1465
	3000	1.0	0.1	3	0.5656	7.2299	5.7115	0.17	0.1557
	3000	1.0	0.1	4	0.5655	7.1803	5.3514	0.1704	0.1625
2	3000	1.0	0.2	1	1.7304	7.2074	5.78	0.17	0.1445
	3000	1.0	0.2	2	0.5937	7.2299	5.7174	0.17	0.1471
	3000	1.0	0.2	3	0.6171	7.2292	5.3283	0.17	0.1537
	3000	1.0	0.2	4	0.5682	6.496	4.9918	0.17	0.1636
3	3000	1.0	0.3	1	1.0796	7.2257	5.7007	0.17	0.15
	3000	1.0	0.3	2	0.9046	7.2291	5.3	0.17	0.1551
	3000	1.0	0.3	3	1.3005	7.2283	5.4269	0.17	0.1548

	3000	1.0	0.3	4	0.9296	6.7639	5.3686	0.17	0.1654
4	3000	0.6	0.1	1	0.8558	6.985	5.7753	0.17	0.1358
	3000	0.6	0.1	2	0.5663	7.2251	5.745	0.1701	0.1368
	3000	0.6	0.1	3	0.5667	5.9651	5.7632	0.2725	0.137
	3000	0.6	0.1	4	0.572	5.9030	5.6991	0.2761	0.1401
5	3000	0.6	0.2	1	1.0397	7.135	4.8344	0.17	0.1358
	3000	0.6	0.2	2	1.7744	7.047	5.7465	0.17	0.1378
	3000	0.6	0.2	3	1.0936	5.9212	5.7724	0.2226	0.1377
	3000	0.6	0.2	4	0.5873	5.9087	5.7405	0.2671	0.1668
6	3000	0.6	0.3	1	1.851	7.2172	5.7275	0.17	0.1716
	3000	0.6	0.3	2	1.8503	7.2284	5.7785	0.17	0.1774
	3000	0.6	0.3	3	1.4813	6.926	5.7797	0.1761	0.1774
	3000	0.6	0.3	4	0.581	6.1257	5.7746	0.2472	0.1787
7	3000	0.3	0.1	1	0.5921	5.9482	5.5431	0.269	0.135
	3000	0.3	0.1	2	0.6231	5.9055	5.1687	0.28	0.135

	3000	0.3	0.1	3	0.5788	5.9036	5.7048	0.2769	0.1408
	3000	0.3	0.1	4	0.5822	5.9036	5.7221	0.2728	0.1541
8	3000	0.3	0.2	1	1.7252	6.0016	5.5422	0.1761	0.1422
	3000	0.3	0.2	2	1.1255	5.9643	5.7554	0.2772	0.1544
	3000	0.3	0.2	3	0.6236	6.1413	5.7789	0.2523	0.1778
	3000	0.3	0.2	4	0.575	6.0635	5.7746	0.2593	0.1778
9	3000	0.3	0.3	1	1.8332	6.4551	5.6321	0.1704	0.1594
	3000	0.3	0.3	2	1.3441	6.0699	5.7797	0.2168	0.1666
	3000	0.3	0.3	3	0.814	6.3401	5.7798	0.2378	0.1762
	3000	0.3	0.3	4	0.5753	6.0763	5.775	0.2585	0.1788
10	3500	1.0	0.1	1	1.7247	7.2183	5.764	0.17	0.1411
	3500	1.0	0.1	2	1.227	7.1591	5.78	0.17	0.151
	3500	1.0	0.1	3	0.5844	7.1755	5.7787	0.1701	0.1525
	3500	1.0	0.1	4	0.5656	7.148	4.9108	0.1843	0.1527
11	3500	1.0	0.2	1	1.8037	7.2227	5.7797	0.17	0.143

Journal of Advance Manufacturing Systems and Technology
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									4
	3500	1.0	0.2	2	0.9568	7.2256	5.7789	0.17	0.145 6
	3500	1.0	0.2	3	0.5848	7.2251	5.3442	0.17	0.140 2
	3500	1.0	0.2	4	0.6024	6.3099	4.8344	0.175 5	0.152 8
12	3500	1.0	0.3	1	1.8349	7.2238	5.7745	0.17	0.146 4
	3500	1.0	0.3	2	1.7815	7.2261	4.9434	0.17	0.142 1
	3500	1.0	0.3	3	1.8519	7.0019	5.0041	0.17	0.140 2
	3500	1.0	0.3	4	1.4926	5.9875	4.8234	0.171 1	0.151 9
13	3500	0.6	0.1	1	1.7871	5.9557	5.7787	0.274 7	0.135 6
	3500	0.6	0.1	2	0.6133	7.1634	5.0684	0.271 8	0.135 6
	3500	0.6	0.1	3	0.5674	6.444	5.7447	0.277 7	0.135 5
	3500	0.6	0.1	4	0.5665	5.9821	5.4079	0.279	0.137 5
14	3500	0.6	0.2	1	0.7904	6.9652	4.9014	0.240 1	0.135 3
	3500	0.6	0.2	2	0.7485	7.0989	5.1987	0.179 1	0.136 4
	3500	0.6	0.2	3	1.2642	5.9287	5.7136	0.251	0.135

								8	6
	3500	0.6	0.2	4	0.7515	5.9019	4.9865	0.27	0.142
15	3500	0.6	0.3	1	1.8117	6.8022	4.7941	0.1712	0.1387
	3500	0.6	0.3	2	1.7171	7.1010	5.6855	0.1701	0.1687
	3500	0.6	0.3	3	1.6102	6.3357	5.7728	0.2011	0.1678
	3500	0.6	0.3	4	0.7107	6.0546	5.6135	0.2468	0.1785
16	3500	0.3	0.1	1	0.5866	5.9871	5.6549	0.2778	0.1351
	3500	0.3	0.1	2	0.5685	6.2147	4.8448	0.28	0.135
	3500	0.3	0.1	3	0.5668	5.9775	5.0386	0.28	0.1356
	3500	0.3	0.1	4	0.5749	5.9085	5.4084	0.2771	0.1395
17	3500	0.3	0.2	1	0.6778	5.9499	5.0362	0.26	0.1353
	3500	0.3	0.2	2	0.9599	5.9388	4.8183	0.28	0.1358
	3500	0.3	0.2	3	0.9691	5.9823	5.7571	0.2688	0.1574
	3500	0.3	0.2	4	0.6191	5.9874	5.6838	0.2566	0.1782
18	3500	0.3	0.3	1	1.3556	6.1973	5.3416	0.19	0.171
	3500	0.3	0.3	2	1.1529	6.2978	5.2309	0.2795	0.168

	3500	0.3	0.3	3	1.2199	6.3982	5.7789	0.24	0.175
	3500	0.3	0.3	4	0.618	6.1	5.7274	0.2506	0.1788
19	4000	1.0	0.1	1	1.035	6.9091	5.345	0.23	0.142
	4000	1.0	0.1	2	1.7604	6.5093	5.78	0.1736	0.1427
	4000	1.0	0.1	3	1.8603	6.2002	5.78	0.1774	0.1386
	4000	1.0	0.1	4	0.569	7.0896	5.1552	0.185	0.151
20	4000	1.0	0.2	1	1.7634	6.8029	5.696	0.2158	0.139
	4000	1.0	0.2	2	1.8608	6.2821	5.78	0.1774	0.1386
	4000	1.0	0.2	3	0.7461	7.2102	5.7192	0.1719	0.1369
	4000	1.0	0.2	4	0.5685	7.1564	4.9154	0.1775	0.1475
21	4000	1.0	0.3	1	1.8662	6.6739	5.7783	0.1771	0.137
	4000	1.0	0.3	2	1.1765	7.1909	5.6699	0.1706	0.1373
	4000	1.0	0.3	3	1.4785	7.1041	5.2036	0.1703	0.1382
	4000	1.0	0.3	4	1.5389	6.2998	4.8507	0.1705	0.1464
22	4000	0.6	0.1	1	1.8653	6.0032	5.7085	0.2794	0.1357
	4000	0.6	0.1	2	1.8478	6.3869	5.2778	0.279	0.135

								3	7
	4000	0.6	0.1	3	0.583	6.9102	5.4876	0.2746	0.1353
	4000	0.6	0.1	4	0.566	6.149	5.2236	0.2793	0.1369
23	4000	0.6	0.2	1	1.8504	6.2642	5.2813	0.279	0.1356
	4000	0.6	0.2	2	0.6373	7.2149	4.7896	0.2678	0.1356
	4000	0.6	0.2	3	0.67	6.7498	5.6431	0.2547	0.1353
	4000	0.6	0.2	4	0.592	5.919	4.9643	0.2765	0.1382
24	4000	0.6	0.3	1	1.1363	7.1104	4.7891	0.2598	0.1358
	4000	0.6	0.3	2	1.7287	6.9127	4.7922	0.1757	0.1382
	4000	0.6	0.3	3	1.8089	5.9982	5.4389	0.186	0.1376
	4000	0.6	0.3	4	1.1685	5.9145	5.0687	0.255	0.16
25	4000	0.3	0.1	1	1.8432	5.944	5.6535	0.2788	0.1352
	4000	0.3	0.1	2	0.5926	6.6801	4.7899	0.28	0.135
	4000	0.3	0.1	3	0.5701	6.29	4.7896	0.28	0.1351
	4000	0.3	0.1	4	0.5665	6.0544	5.0533	0.2794	0.137
26	4000	0.3	0.2	1	0.6479	6.9681	4.7905	0.271	0.135

								3	2
	4000	0.3	0.2	2	0.6853	6.3587	4.7894	0.28	0.1351
	4000	0.3	0.2	3	1.1587	5.9549	4.7995	0.2799	0.1352
	4000	0.3	0.2	4	0.7756	5.908	4.9072	0.2686	0.1517
27	4000	0.3	0.3	1	1.6756	6.9642	4.7905	0.1998	0.1631
	4000	0.3	0.3	2	1.716	6.6072	4.7901	0.2797	0.1632
	4000	0.3	0.3	3	1.7418	6.431	5.6104	0.26	0.172
	4000	0.3	0.3	4	0.8522	6.1316	5.4171	0.24	0.1787

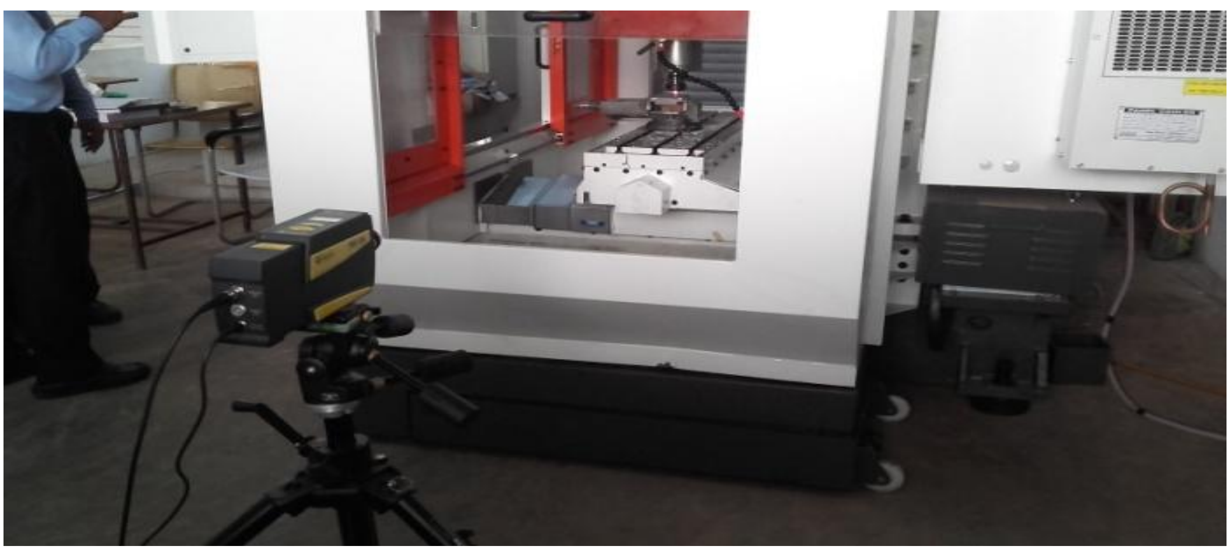

Figure 2: Milling cutter a) Tool holder with a work piece and Laser Doppler Vibrometer (LDV)

SCANNING ELECTRON MICROSCOPE (SEM) is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that contain information about the sample's surface topography and composition. Scanning Electron Microscope (SEM) was used to measure tool wear and spring back effect of a machined surface.

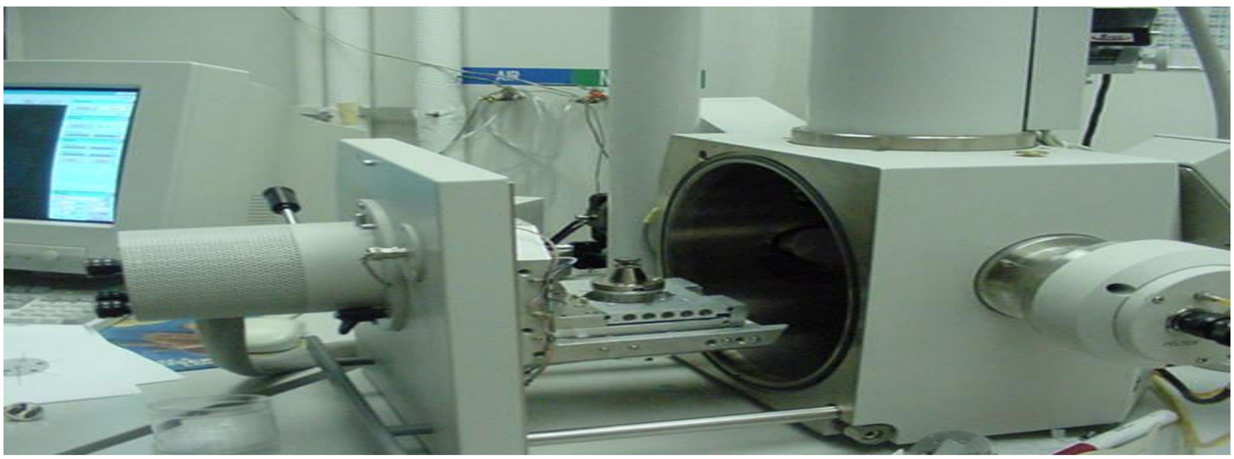

Figure 2: b) Scanning Electron Microscope (SEM) for measurement of tool wear of end mill and spring back of a work piece material

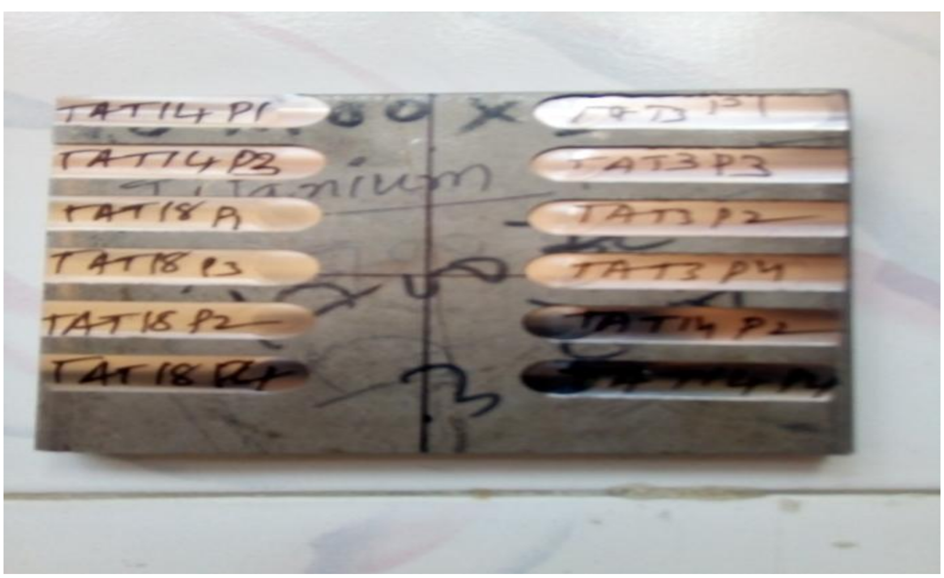

Fig 3: a) the machined work piece

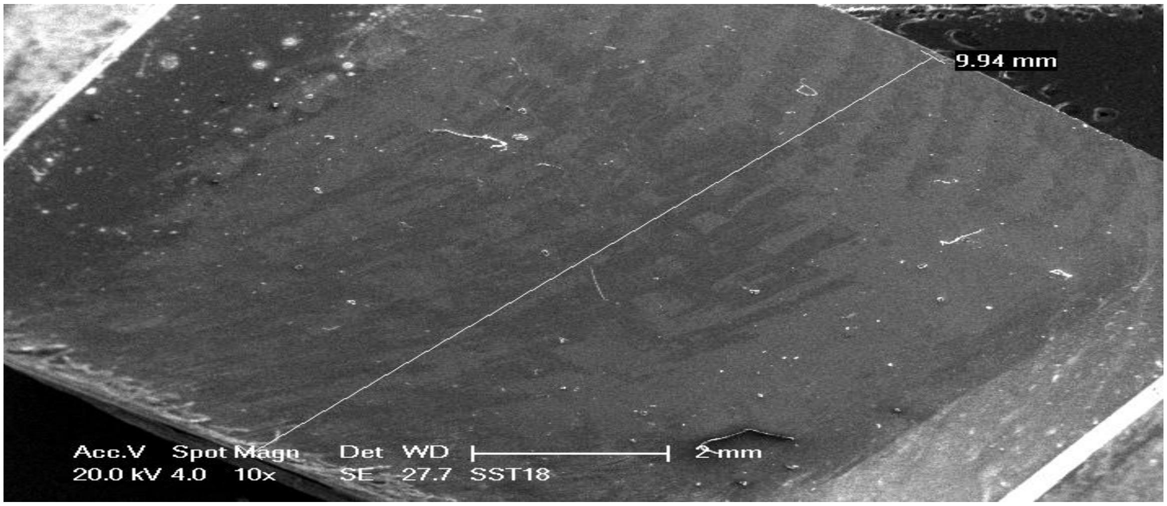

Fig 3: b) the spring back of a work piece material is measured using SEM

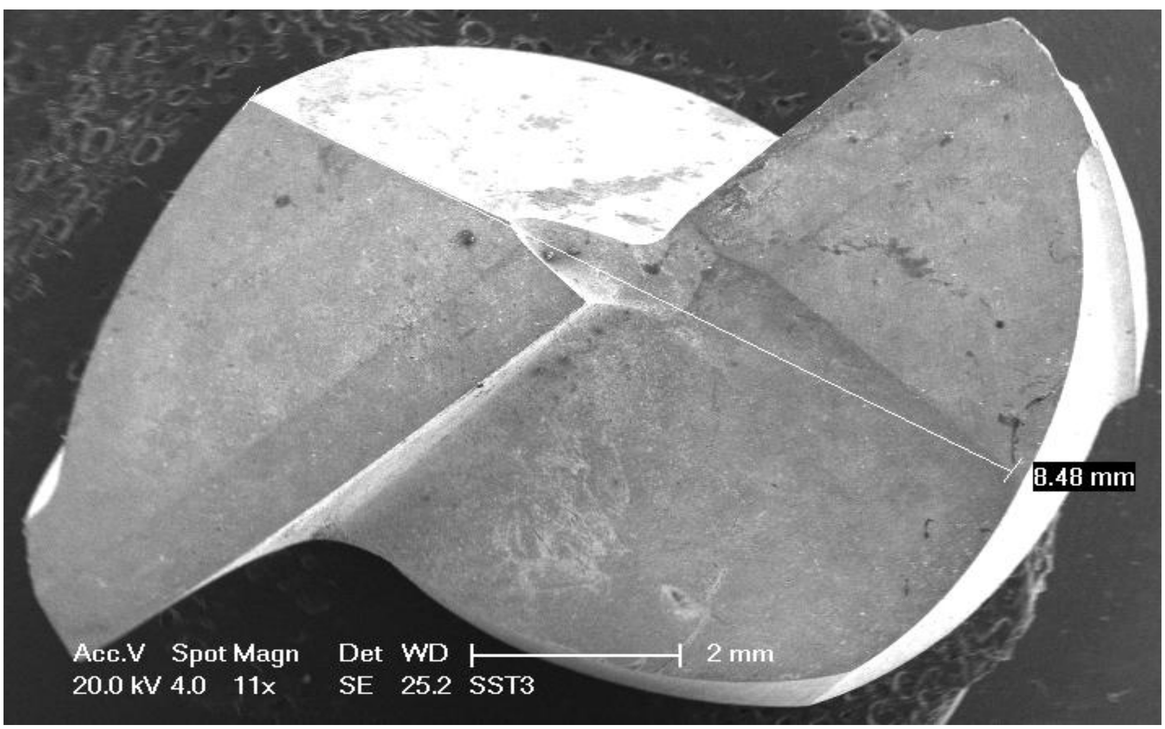

Fig 3: c) the end mills used in experimentation

Fig 3: d) the measurement of tool wear of an end mill using SEM

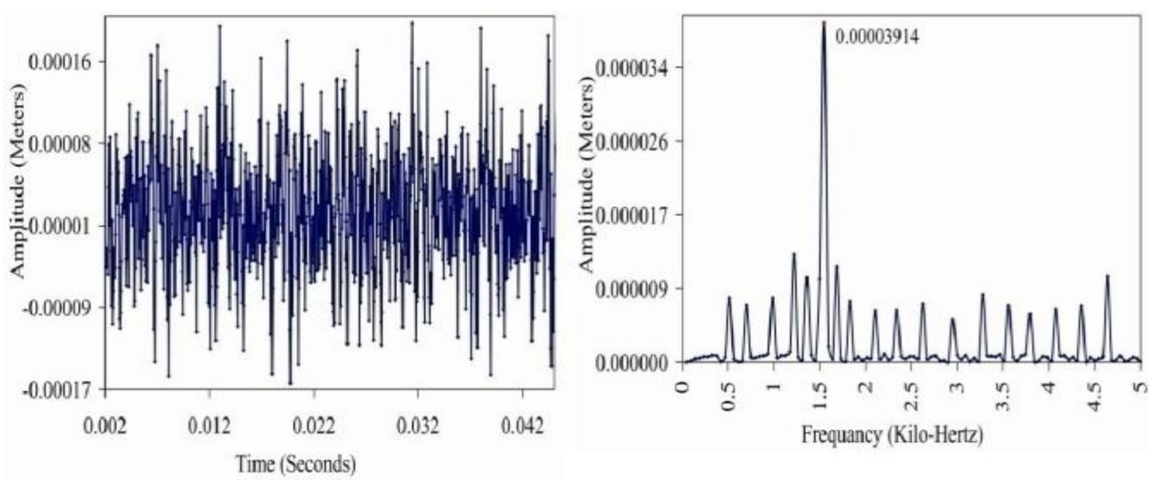

Fig 4: FFT curves from Laser Doppler Vibrometer

CONCLUSIONS

In the present study, the machining parameters in CNC milling of Ti6Al4V machining with tungsten carbide tool bit have been optimized using Artificial Neural networks. The Taguchi L27 orthogonal array has been used and twenty seven experiments are carried out. The primary object is to develop mathematical models based on experimental results, for obtaining low surface roughness and cutting tool vibration and spring back effect. The predicted surface roughness from the model is compared to the values measured experimentally.

The optimum cutting parameters for minimum surface roughness, tool vibration, tool wear and spring back effect based on the analysis of experiment results are cutting speed = 3500RPM, feed = 0.1 mm/rev, and depth of cut = 0.6 mm which resulted in surface roughness of 0.5674 µm, tool vibration of 6.444 µm. The optimum spring back effect of a tool is measured as 0.1355 µm and the tool wear as 0.2777 µm.

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