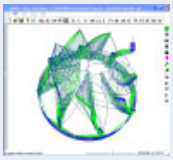
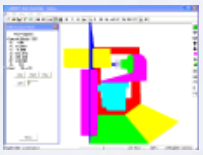
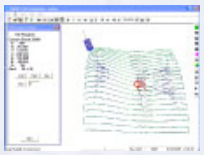
NEW SOFTWARE FOR GEOMETRICAL MODELING OF CUTTING OPERATIONS OF A FIVE-AXIS MILLING MACHINE, CNC PART SIMULATION, OPTIMIZATION AND VERIFICATION

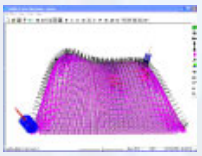
Results

1. Virtual Milling Machine which includes post processing software for MAHO600E and HERMLE UWF902H (Figure 1).
2. The Error Estimator (Figure 2), an interactive software prototype which includes evaluation of kinematics error (Table 1), over cut and undercut error (Table 2), dynamic tool inclination and machining strip evaluation (Figure 3), gouging detection, interface with Unigraphics (UG) solid modeler (Figure 4) and many other features.









3. The Tool Path Optimizer, an interactive software prototype which includes Space Filling Curve Generator (Figure 5), Grid Generator, Angle Optimization, Angle Insertion (Table 3) and many other optimization features.

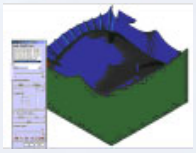
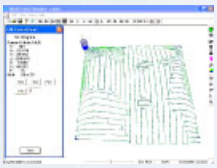


Table 3: Error versus number of inserted points, the basic grid size 15x20. S_1 on MAHO600E.

Number of inserted points at the max error	Max Error (mm) Conventional/ Angle Insertion	Path length (mm) Conventional/ Angle Insertion	Angular length(deg) Conventional/ Angle Insertion
0	19.300 / 19.300	5.714 / 5.714	162.202 / 162.202
8	4.241 / 0.416	0.714 / 0.168	68.660 / 20.631
16	1.707 / 0.138	0.357 / 0.084	43.016 / 10.629
32	0.490 / 0.092	0.178 / 0.042	20.647 / 5.352
64	0.158 / 0.089	0.089 / 0.021	10.955 / 2.680
128	0.099 / 0.089	0.044 / 0.010	5.378 / 1.340

4. Iges2Nurbs translator and viewer (Figure 6).
5. Practical machining (36 workpieces).
6. Eight international papers, three national papers and ten international conferences (six papers acknowledge the sponsorship of NECTEC and NSTDA).
7. One Ph.D. project, 15 senior projects at SIIT have been initiated and defended.
8. A Thai 5-axis machining website (www.5axis-thai.com).
9. A Seminar on 5-Axis Machining for Industry and Research (May 2003).



Selected Publications

1. E. Bohez, S.S. Makhanov and K. Sonthipermpoon, "Adaptive Non-Linear Tool Path Optimization for 5-Axis machining", Intern. Journal of Production Research, 2000, 4329-4345, Carfax Pub.
2. S. S. Makhanov, D. Batanov, E. Bohez, K. Sonthipaumpoon, W. Anotaipaibo (Table 3) (Table 3) (Table 3) on and M. Tabucanon, "On the Tool-Path Optimization of a Milling Robot", Computers and Industrial Engineering, 43 (2002), 455-472.
3. E. L.J. Bohez, "Compensating for Systematic Errors in 5-axis NC Machining", Computer-Aided Design, 34 (2002), 391-403.
4. S.S. Makhanov and S.A. Ivanenko, "Grid generation as Applied to Optimize Cutting Operations of a Five-axis Milling Machine", Applied Numerical Mathematics, 2003, v 46, 353-377.
5. S. S. Makhanov, M. Munlin and S.A. Ivanenko, "New Numerical Algorithms to Optimize Cutting Operations of a 5 Axis Milling Machine", Applied Numerical Mathematics, V49, N3-4, 2004, 395-413.
6. Erik L.J. Bohez, Nguyen Thi Hong Minh, Ben Kiatsrithana, Peeraphan Natasukon, Huang Ruei-Yun, Le Thanh Son, "The Stencil Buffer Sweep Plane Algorithm for 5-axis Tool Path Verification", Computer-Aided Design, v 35, issue 12, October 2003, 1129-1142
7. M. Munlin, S. S. Makhanov and E.L. J. Bohez, "Optimization of Rotations of a Five-Axis Milling Machine Near Stationary Points", Computer-Aided Design, v 36, issue 12, 2004, 1117-1128.

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Table 1: Kinematics error for the optimized and non-optimized tool path. Surface S_1 MAHO600E

Grid size	No optimization max error/max angle var (mm/degree)	Optimization max error/max angle var (mm/degree)	Max error/angle var decrease (%)	Path length Non-opt/opt(mm)
10 x 20	23.862 / 168.779	12.426 / 78.072	47.925 / 53.743	2825.67 / 2255.54
15 x 20	19.300 / 162.186	8.517 / 101.524	55.870 / 34.403	2500.3 / 2123.02
20 x 20	20.228 / 160.08	7.558 / 84.927	62.636 / 46.947	2367.57 / 2101.15
30 x 20	16.253 / 141.89	7.162 / 88.23	55.934 / 37.818	2183.63 / 2038.27
40 x 20	8.711 / 103.885	6.878 / 88.399	21.042 / 14.907	2069.32 / 2020.11
100 x 20	7.395 / 90.898	7.103 / 89.102	3.949 / 1.976	1916.11 / 1911.17
130 x 20	3.999 / 68.416	3.999 / 68.416	0.000 / 0.000	1876.49 / 1876.49

Table 2: Undercut error optimization. S_1 on MAHO600E.

Grid size	No optimization max error (mm)/max angle (deg) undercut	overcut	Optimization max error (mm)/max angle (deg) undercut	overcut	Path length Non-opt/Opt (mm)	Angular length Non-opt/Opt (mm)
10 x 20	8.41 / 169.66	23.86 / 170.03	1.84 / 28.26	38.46 / 157.94	2825.67 / 3575.11	7768.03 / 7867.60
15 x 20	7.23 / 164.57	19.30 / 162.20	1.98 / 40.47	32.92 / 159.15	2500.3 / 2417.3	7926.18 / 7339.96
20 x 20	6.78 / 159.42	20.23 / 160.83	0.96 / 26.98	7.56 / 87.37	2367.57 / 2101.14	7976.88 / 7148.41
30 x 20	6.25 / 149.31	16.25 / 141.94	0.00 / 12.57	7.16 / 89.19	2183.63 / 2032.2	8022.24 / 7848.15
40 x 20	5.39 / 139.65	8.71 / 104.12	0.00 / 9.64	6.88 / 88.56	2069.32 / 2020.11	8040.19 / 7788.45
100 x 20	0.00 / 4.00	7.40 / 90.90	0.00 / 4.00	7.10 / 89.20	1916.11 / 1911.17	8059.30 / 8036.42
130 x 20	0.00 / 3.09	4.00 / 68.42	0.00 / 3.09	4.00 / 68.41	1876.49 / 1876.49	8060.76 / 8080.76

8. W. Anotaipaiboon and S.S. Makhanov, Tool path generation for five-axis NC machining using adaptive space-filling curves, International Journal of Production Research, accepted
9. M. Munlin and S.S. Makhanov, Angle Correction for Five Axis Machining Near Singularities, ICCAS 2004, Bangkok, August 2004
10. M. Munlin and S.S. Makhanov, Tool Path Generation, Simulation And Optimization of a Five-Axis Milling Machine, TENCON 2004, Chiang Mai Thailand.

Conclusions

We have developed a new version of the 5-Axis Virtual Milling Machine to generate, optimize, visualize and edit tool paths of multi axis milling machines. The new features include a new postprocessor for HERMLE UWF920H. We are now also capable of visualizing undercuts and overcut loops, displaying scallops and machining strips. The new results include the Nurbs Viewer, the optimal tool inclination, the optimal machining strip and a new angle inserting algorithm based on the equi distribution principle.

A first version of the software open source library includes two postprocessors for MAHO 600 and HERMLE UWF920H, Space Filling Curves Generator along with the Nurbs Viewer. A new version of the website www.5axis-thai.com has been designed.

Since the beginning of the project in 2001 the 5-axis Thai group has published 8 international, 3 national papers and more than 10 proceedings of international conferences. The papers acknowledge the sponsorship of NECTEC and NSTDA.

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