An Approach to Pairing Bevel Gears from Conventional Cutting Machine with Gears Produced on 5-Axis Milling Machine

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Developed here is a new method to automatically find the optimal topological modification from the predetermined measurement grid points for bevel gears. Employing this method enables the duplication of any flank form of a bevel gear given by the measurement points and the creation of a 3-D model for CAM machining in a very short time. This method not only allows the user to model existing flank forms into 3-D models, but also can be applied for various other purposes, such as compensating for hardening distortions and manufacturing deviations which are very important issues but not yet solved in the practical milling process.

Introduction

Recently, cutting bevel gears on universal 5-axis milling machines has been widely accepted as a promising solution to replace the conventional cutting process. The process is highly flexible and does not require special tools. Thus, it is particularly suitable for small batches, prototypes, and repairs in use having unacceptably high lead times. In order to apply the milling process for bevel gear cutting, we should provide feasible solid models. However, the kinematic geometry of bevel gears is relatively complicated in accordance with the variety of the cutting method, such as Gleason (fixed settings, Duplex and Zerol), Klingelnberg (Cyclo-Palloid and Palloid) and Oerlikon, and it's not easy to generate the 3-D geometry model proper for milling.

In the calculation software *KISSsoft* (Ref. 1), the geometry calculation of straight and skew bevel gears for standard cone types has been available for many years, in accordance with ISO 23509 (Ref. 2). Then, the expansion to 3-D models of spiral bevel gears was made covering all cone types four years ago. Since the 3-D models of the spiral bevel gears have been available, there has been much interest from many companies worldwide. The first prototype based on the 3-D model was machined by Breton (Ref. 7), one of the major 5-axis milling machine manufacturers, and enjoyed very satisfactory results. Then one of their customers, who is using a 5-axis milling machine, wanted to produce a very large bevel gear pair to replace an existing pair. However, they had a special, hard to resolve problem in that the pinion shaft having a 1,500 mm length was too long to be cut on the Breton machine. So the pinion was produced on a conventional Gleason machine, but the customer wanted to produce the gear (d_{e2} = 500 mm) on the Breton machine. We always recommend to our users that the model for the pinion and gear must be generated by the same software and thus the combination of a pinion, manufactured on a Gleason machine, should not be combined with a gear based on the model. But the customer insisted, so we had to invent something!

We got the basic gear data and the measurement grid points of the flank form of the gear produced by their Gleason software from the customer. However, the design data didn't include the formal definition of the flank modifications. Thus, the comparison of these measurement points with the 3-D model naturally showed small deviations. The deviation could not be eliminated easily by varying the geometric parameters and applying typical modifications such as barreling (profile crowning) and lead crowning. Thus, we developed a creative solution to generate a 3-D model of the gear and to adapt it to the given grid point from Gleason. In the following chapters we will show the procedure of the method and the application results.

Topological Modification of the Bevel Gear

The basic cone geometry of the bevel gear can be defined in accordance with ISO 23509, and the flank form is defined from the transverse tooth forms calculated along the face width. The trace form

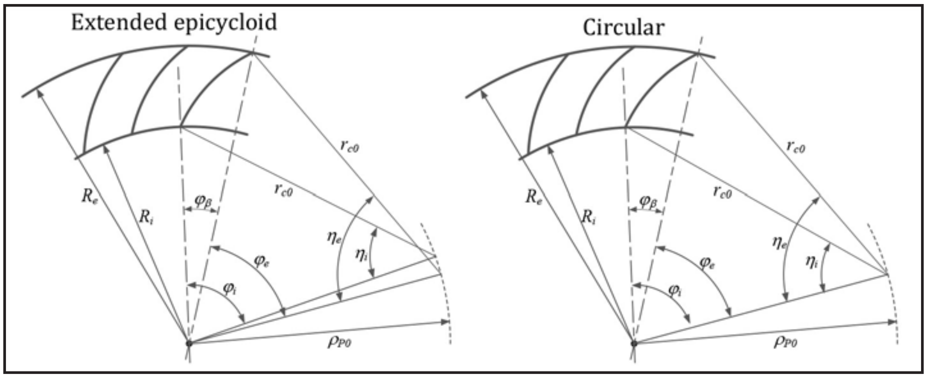

Figure 1 Face hobbing (left) and face milling (right) processes.

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will be the extended epicycloid form by face hobbing process or circular form by face milling (Fig. 1). In *KISSsoft*, the tooth form is supposed to the planar involutes of the virtual spur gear in transverse section. Then, the tooth flank surface is generated by splining the tooth forms of each section.

Bevel gear machine tool manufacturers (such as Klingelnberg and Gleason) have their own methods to generate the tooth form based on the generating motion of the cutter. The tooth form is known as an octoid and is slightly different from spherical or planar involute tooth form. However, the difference of the tooth forms is normally less than the tolerance range and will pose no problem in practical use. This can be verified from the fact that the bevel gears are always produced in pairs by the same process in order to achieve a good contact pattern in practice. In order to validate the practical usage of the 3-D model we compared our model with reference models of manufacturer programs and also carried out the contact pattern check with the actual model. The results showed the tooth flanks along the face width of the two models are very well matched with only slight differences (Ref.3).

One of the most important tasks is to find the optimal modification to give good contact pattern in a bevel gear pair. The contact pattern of the bevel gear pair can be easily optimized by using proper modifications (Fig. 2). There are eight types of modifications available for bevel gears in *KISSsoft* (profile; crowning; eccentric profile crowning; pressure angle modification; helix angle modification; lead crowning; eccentric lead crowning; twist; and topological modification). The user can define different combinations of modification for drive and coast flanks to optimize the contact pattern separately.

However, if the target modification has highly non-linear or irregular pattern, the simple combination of the conventional modifications cannot be applied. In that case, the topological modification should be used to allow the user to freely define any type of modification that can't be covered by the conventional modifications. The user can define the modifications in a data map of factors at any position along the face width and along the tooth height by using the topological

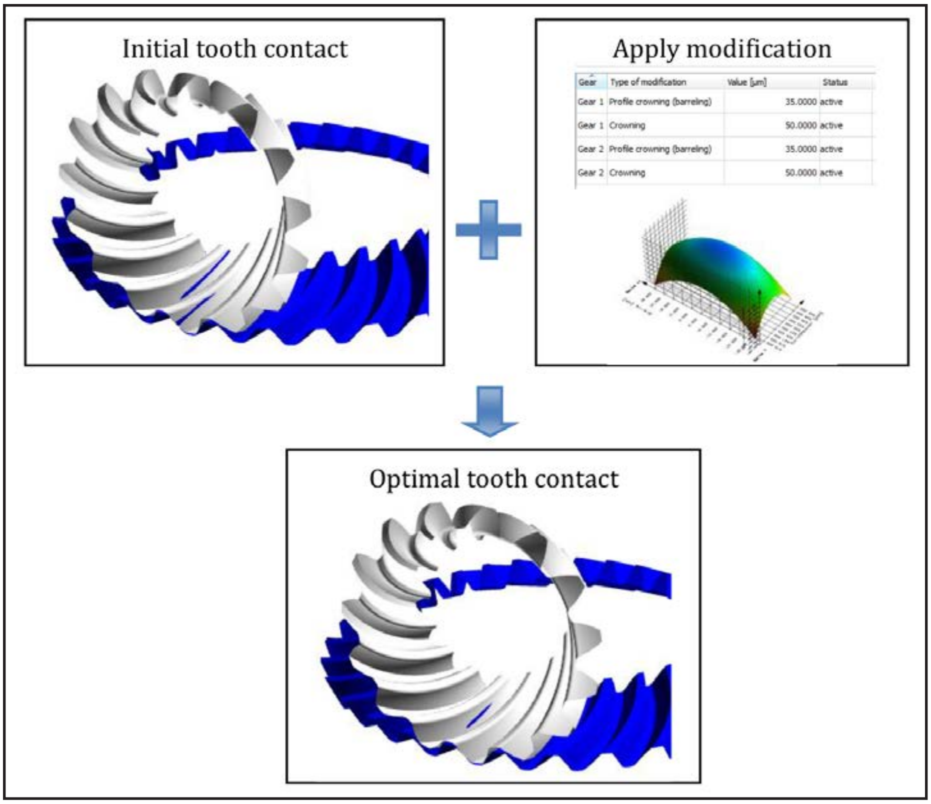


Figure 2 **Optimal contact pattern with flank modifications.**

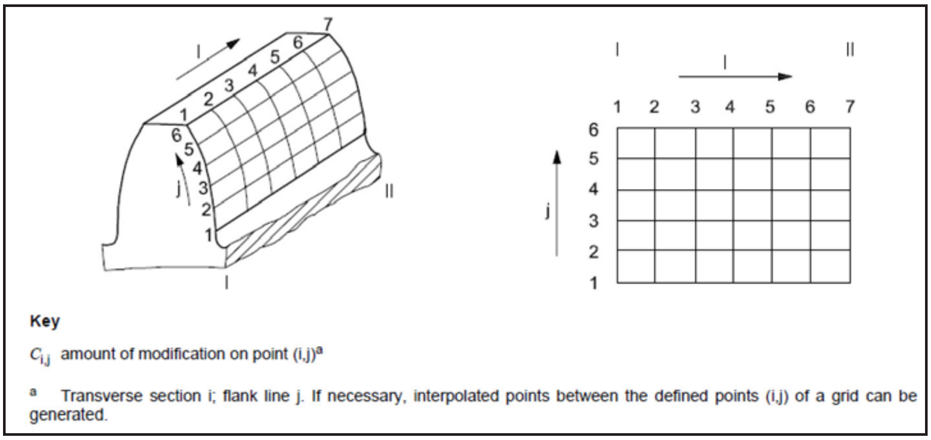


Figure 3 **Definition of topological modification in ISO 21771 (Ref. 5).**

modification following the convention in ISO 21771 (Ref.4) as shown in Figure 3.

Figure 4 shows an example of the file structure of the modification used in *KISSsoft*. The example data map defines the progressive tip relief on Side I and no modification on Side II. Note that the modification values in the data map are normalized and the actual local modifications are calculated with *Ca_local = fij * Ca*, where *fij* is the modification factor at (i, j) node and *Ca* is the amount of modification. The intermediate values in between the data can be interpolated by linear, quadratic, or spline approximation along the tooth width and height, respectively.

The adjustment of the bevel gear models to any predetermined measurement grid points should now be possible by applying the topological modification. That is, the modification can be calculated as the deviation between the surface of the 3-D model and the measurement grid points of the target model. The measurement grid points report contains the Cartesian coordinates and the normal vectors of the grid points with the format of (*XP YP ZP XN YN ZN)*. The reference coordinate system of the data is different according to the measurement machines. For example, the reference coordinate system of Klingelnberg format is using the convention shown in Figure 5. The order of the indexes for the points and the sections are defined according to ISO/TR 10064-6 (Ref. 5) as well as the convention from the manufacturers such as Klingelnberg (Ref. 6). Here the index of the lines starts from the root to the tip, and the index of the columns from Side II (heel) to Side I (toe).

In applying the modification, however, various problems have arisen. The definition of topological modification surface in helical gears is located between the tip and the root form diameters, but the diameters over the tooth width for bevel gears are changing.

On the other hand, the effort to transform the measured grid points to the format of the topological modifications is greatly increased. While the measurement direction of the distance between the two corresponding grid points for adjustment calculation is different from the normal of the tooth form (that is, the path of contact) along which the modification is applied. Moreover, even the deviation values are given correctly, we cannot easily reach to the exact surface points because the target modification can have highly nonlinear pattern.

Thus, the procedure to get the topological modification, so that the final model becomes equivalent with the target model, cannot be finished in just a single step but requires rather several iterations (Fig. 6). In each step, the distance between the corresponding measurement points are calculated and converted into the dimension in the virtual cylindrical gear. Then the topological modification is calculated based on these values and applied to generate a new measurement grid. The procedure iterates until the given acceptance criteria are met. The acceptance criteria are given as the maximum distance between the surface of the 3-D model and the corresponding measurement points is smaller than the user-defined tolerance.

```
*************************************************************************************
COLUMNS= total number of columns including index column
DATA
index dummy bf1 bf2 ..... bfn
index lf1   f11 f12 ..... f1n
...
index lfm   fm1 fm2 ..... fmn
END

lfj : length factor (factor of length of path of contact)
    : lfj = 0.0 is at the root, lfj = 1.0 is at the tip
bfi : width factor (factor of face width)
    : bfi = 0.0 is on side I, bfi = 1.0 is on side II
fij : modification factor (local modification Ca_local = fij * Ca)
*************************************************************************************

COLUMNS=13
DATA
1   -1.000  0.000  0.100  0.200  0.300  0.400  0.500  0.600  0.700  0.800  0.900  1.000
2    1.000  1.000  0.988  0.951  0.891  0.809  0.707  0.588  0.454  0.309  0.156  0.000
3    0.900  0.810  0.800  0.770  0.722  0.655  0.573  0.476  0.368  0.250  0.126  0.000
4    0.800  0.640  0.632  0.609  0.570  0.518  0.452  0.376  0.291  0.198  0.100  0.000
5    0.700  0.490  0.484  0.466  0.437  0.396  0.346  0.288  0.222  0.151  0.076  0.000
6    0.600  0.360  0.356  0.342  0.321  0.291  0.255  0.212  0.163  0.111  0.056  0.000
7    0.500  0.250  0.247  0.238  0.223  0.202  0.177  0.147  0.114  0.077  0.039  0.000
8    0.400  0.160  0.158  0.152  0.143  0.129  0.113  0.094  0.073  0.049  0.025  0.000
9    0.300  0.090  0.089  0.086  0.080  0.073  0.064  0.053  0.041  0.028  0.014  0.000
10   0.200  0.040  0.040  0.038  0.036  0.032  0.028  0.024  0.018  0.012  0.006  0.000
11   0.100  0.010  0.010  0.010  0.009  0.008  0.007  0.006  0.005  0.003  0.002  0.000
12   0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000
END
```

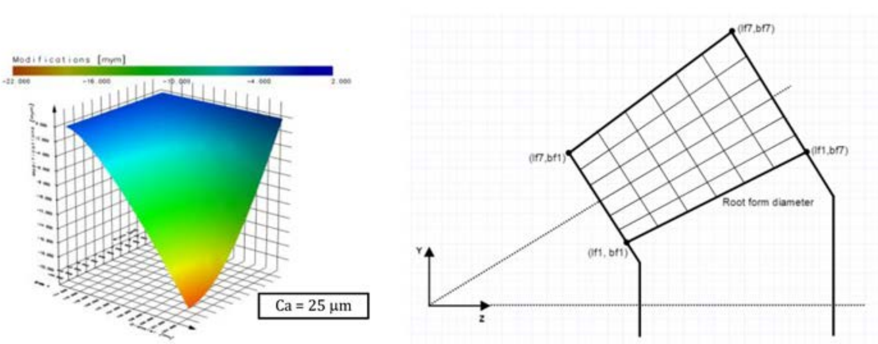
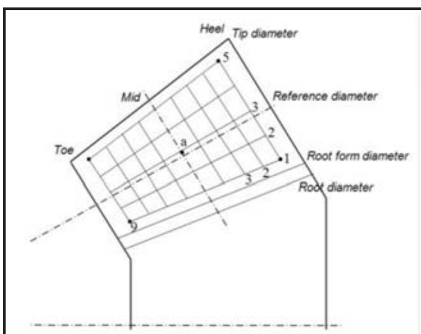


Figure 4 Definition of topological modification and example.




```
-----------------------------------------------------------------
 J  I       XP          YP          ZP       XN     YN     ZN
-----------------------------------------------------------------
IN SPALTE  5 / ZEILE  3 :   ZAHNDICKENWINKEL =  0.266995 rad
 1  1    -18.2562    29.5731    180.8263  -.7138 -.3043 -.6306
 1  2    -18.6412    31.9205    180.3613  -.7532 -.1235 -.6460
 1  3    -18.6472    34.4531    179.8957  -.7657  .0144 -.6429
 1  4    -18.3081    37.1179    179.4362  -.7647  .1325 -.6305
 1  5    -17.6326    39.8802    178.9885  -.7545  .2376 -.6116
 2  1    -13.7726    30.6162    174.6872  -.7663 -.2239 -.6021
 2  2    -13.8719    32.9663    174.2261  -.7836 -.0300 -.6205
 2  3    -13.5611    35.4555    173.7642  -.7773  .1126 -.6189
 2  4    -12.8847    38.0330    173.3085  -.7594  .2324 -.6076
 2  5    -11.8565    40.6637    172.8649  -.7336  .3375 -.5897
```

Figure 5 Measurement grid convention of Klingelnberg machine format.

Application and Result

We used 11×7 points for the measurement and topology template definition; that is, 11 points starting from Side I (toe) to Side II (heel), and 7 points from the root form diameter to the tip diameter without margins. The position of each measurement point is defined as the length factor of the path of contact from the root form diameter to the tip diameter (column values in yellow in Table 1) and the face width factor from Side I to Side II (row values in yellow in Table 1).

Topological modification for the right flank. Table 1 shows the topological deviation and modification template values for the right flank according to the calculation steps. In the calculation, we set the acceptable maximum deviation to 5 µm.

Step1. In the first step we measure the deviation by the normal distance between the measurement points of the Gleason model with the flank surface of 3-D model (see Deviation 1 in Table 1). Then, we use the Deviation 1 as the initial topological template, Modification 1. The green-colored fields in the table indicate the border of the tooth flank. In our modeling strategy we use a slightly bigger surface area to cover the real gear surface and it's not possible to measure correct distances at the borders. Thus we ignore the border values in the acceptance checking in the calculation procedure and use the extrapolated values for the values. The maximum distance of the initial step gives 575 µm at the position (0.965, 0.696). The deviation shows relatively big values because we intentionally increased the tooth thickness of the *KISSsoft* model to completely cover the surface of the target model and to give positive distances. Thus, the final model is compensating not only the topological deviation of the surface but also the tooth thickness deviation of the model.

Step 2. After applying the topological modification of the first step, the maximum distance at the position (0.965, 0.696) reduced to 65 µm and the new maximum distance is 135 µm at the position (0, 0.879) (see Deviation 2 in Table 1). From Deviation 2 you will see the three points at (0, 0.089), (0.522, 0.089) and (0.965, 0.193) have deviations less than the acceptance criteria of 5 µm (values in blue). In this case we use the same topological modification values of the last step at those positions. For the remaining positions we build a new topological modification by linear summation of the deviation of each point and the last topological modification, which is:

$$\text{Modification 2} = \text{Modification1} + \text{Deviation 2}$$

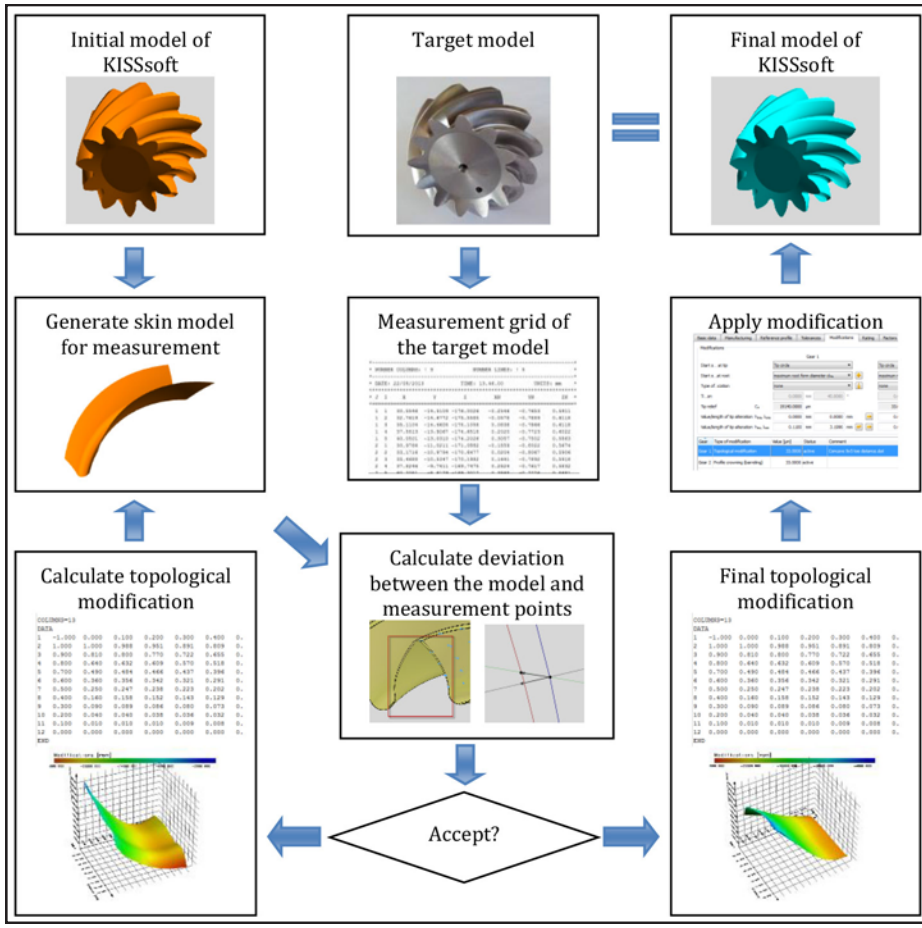


Figure 6 Procedure to get topological modification for target model.

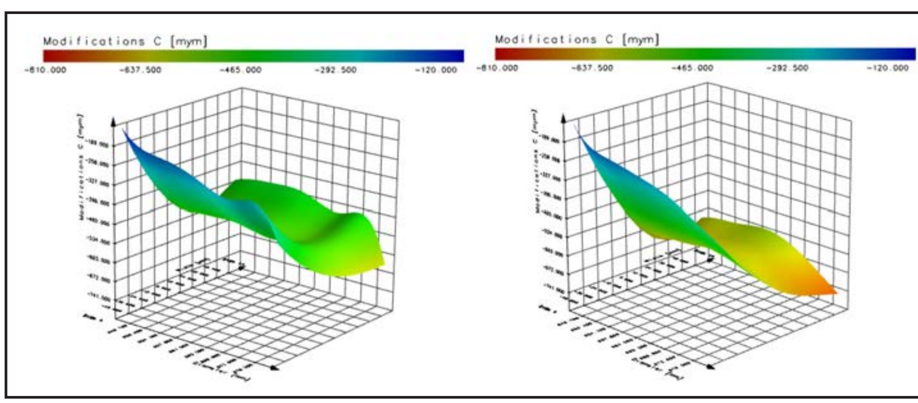


Figure 7 Modifications for right flank at Step 1 (left) and Step 11 (right).

Table 1 Topological deviations and modifications according to iteration steps (right flank, values in μm)

Deviation 1	1	-1	0	0.089	0.193	0.297	0.399	0.5	0.599	0.696	0.789	0.879	1
Modification 1	2	1	395	446	496	536	567	591	608	619	626	629	631
	3	0.965	342	397	451	495	528	552	568	575	574	566	558
	4	0.744	289	348	407	453	489	514	527	530	523	504	484
	5	0.522	245	311	376	428	468	495	510	511	500	473	446
	6	0.301	207	280	353	412	458	490	508	510	498	467	436
	7	0.08	168	251	333	401	455	493	515	521	510	479	447
	8	0	129	222	314	390	451	495	523	532	522	490	459
Deviation 2	1	-1	0	0.089	0.193	0.297	0.399	0.5	0.599	0.696	0.789	0.879	1
	2	1	22	-7	-36	-18	-2	10	20	26	27	21	15
	3	0.965	19	12	4	19	33	46	56	65	71	72	73
	4	0.744	16	30	44	57	69	82	93	104	115	123	131
	5	0.522	-15	4	22	39	55	70	81	92	102	106	111
	6	0.301	-4	14	32	49	66	82	93	105	115	121	127
	7	0.08	-14	8	30	49	67	84	98	111	122	128	134
	8	0	-24	3	29	49	69	87	103	116	129	135	141
Modification 2	1	-1	0	0.089	0.193	0.297	0.399	0.5	0.599	0.696	0.789	0.879	1
	2	1	382	414	451	515	561	598	625	641	646	640	631
	3	0.965	373	409	451	514	561	598	624	640	645	638	629
	4	0.744	316	378	451	510	558	596	620	634	638	627	612
	5	0.522	237	311	398	467	523	565	591	603	602	579	548
	6	0.301	216	294	385	461	524	572	601	615	613	588	554
	7	0.08	170	259	363	450	522	577	613	632	632	607	573
	8	0	118	222	343	439	520	582	626	648	651	625	590
Deviation 3	1	-1	0	0.089	0.193	0.297	0.399	0.5	0.599	0.696	0.789	0.879	1
	2	1	-45	14	72	74	75	77	81	88	104	122	141
	3	0.965	-11	14	39	38	39	41	45	51	60	70	81
	4	0.744	22	14	6	1	2	6	10	13	16	18	20
	5	0.522	0	0	0	5	8	12	17	20	23	27	30
	6	0.301	4	5	6	11	12	15	19	23	27	30	34
	7	0.08	6	4	2	6	9	14	18	21	26	30	33
	8	0	7	2	-3	2	6	12	17	20	26	29	32
Modification 3	1	-1	0	0.089	0.193	0.297	0.399	0.5	0.599	0.696	0.789	0.879	1
	2	1	383	395	410	471	516	645	675	698	713	718	725
	3	0.965	377	395	416	476	522	639	669	691	705	708	712
	4	0.744	336	392	457	510	558	602	630	647	654	645	633
	5	0.522	237	311	398	467	531	577	608	623	625	606	580
	6	0.301	211	294	391	472	536	587	620	638	640	618	588
	7	0.08	170	259	363	456	531	591	631	653	658	637	609
	8	0	118	222	343	439	526	594	643	668	677	654	623
Modification 11 (Final step)	1	-1	0	0.089	0.193	0.297	0.399	0.5	0.599	0.696	0.789	0.879	1
	2	1	376	432	498	555	602	645	675	698	713	726	744
	3	0.965	364	422	490	548	595	639	669	691	705	715	728
	4	0.744	288	357	438	505	552	602	630	647	654	645	633
	5	0.522	246	319	404	476	537	577	608	629	633	615	591
	6	0.301	218	298	391	472	536	587	620	638	640	625	605
	7	0.08	170	259	363	456	531	591	631	653	664	644	617
	8	0	123	225	343	439	526	594	643	667	683	660	629
Deviation 12 (Final step)	1	-1	0	0.089	0.193	0.297	0.399	0.5	0.599	0.696	0.789	0.879	1
	2	1	19	10	1	-2	3	-5	0	2	6	-2	-11
	3	0.965	8	5	2	0	2	0	2	3	4	0	-3
	4	0.744	-2	1	4	2	2	5	4	4	2	3	4
	5	0.522	4	3	2	2	3	4	4	2	2	4	5
	6	0.301	3	3	2	2	1	1	2	2	3	0	-3
	7	0.08	5	3	0	1	1	0	3	4	2	1	1
	8	0	8	3	-2	1	1	0	3	5	0	2	4

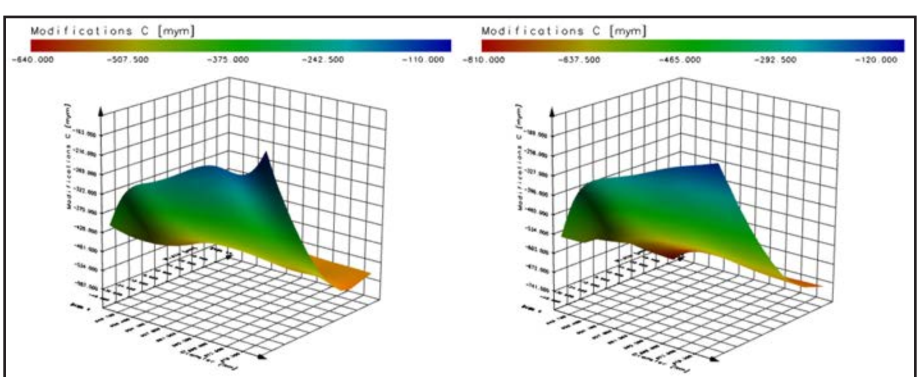


Figure 8 Modifications for left flank at Step 1 (left) and Step 14 (right).

Step 3. Now Deviation 3 after applying Modification 2 shows smaller distances than Deviation 2, and more positions fitting into the acceptance deviation. The new maximum distance is 70 μm at the position (0.965, 0.879) (see Deviation 2 in Table 1). However, the deviation in several positions — such as the positions at (0.956, 0.089) and (0.956, 0.193) — increased because the surface is generated by spline approximation from the topological modification template (values in red). In this case we build a new topological modification from the last topological modification, that is:

Modification3 = Modification2 – SIGN (Modification2 – Modification1) * (Deviation2) + (SIGN(Deviation2) + SIGN (Deviation3))/2*(Deviation2–Deviation3).

Step 11 (final step). We then needed to iterate 11 steps until all deviations fit into the acceptance criteria. You can find the final topological modification as Modification 11, and the final deviation as Deviation 12, in Table 1. Now all the deviation values are less than the maximum deviation of 5 μm — except the values at the border.

The graphical comparison of the modification surfaces of Step 1 and the Step 11 (final step) are shown in Figure 1. As you can expect, the final modification surface doesn't not show a regular pattern, and it's impossible to achieve the modification by simple combination of the conventional modification types such as crowning and barrelling.

Topological Modification for the Left Flank

After finishing the calculation for the right flank, we applied the same procedure for the left flank. Table 2 shows the topological deviation and modification template values according to the calculation steps for the left flank.

Step 1. In the first step the maximum distance of the left flank shows 570 μm at the position (0.965, 0.789).

Step 14 (final step). We could reach the final topological modification after 14 steps for the left flank. You can find the final modification as Modification 14 and the final deviation as Deviation 15. You can see all the deviation values are less than the maximum deviation of 5 µm, except the values at the border. The graphical comparison of the modification surfaces of Step 1 and the Step 14 (final step) are shown in Figure 8.

Conclusions

The developed method makes it possible to incorporate any desired flank form of a bevel gear given by grid points, and provides the model for the CAM machining in a very short time from the simplest way. That is, the macrogeometry is generally assumed by existing standards or data sheets, and the microgeometry is created by a difference of unmodified real flank-to-the-flank created by topological modifications with the help of *KISSsoft*. The results showed that the final flank with the topological modification gives the deviation of less than 5 µm, which can be ignored, considering the manufacturing tolerance in practical situations.

The method presented here has considerably high potential for practical usage because it allows not only the modeling of all existing flank forms into 3-D models, but also can be applied for various other purposes, such as to compensate hardening distortions and cutting deviations of 5-axis milling models. These are very important features in practice, and were unresolved issues in the 5-axis milling process.

Table 2 Topological deviations and modifications according to iteration steps (left flank, values in µm)

Deviation 1	1	-1	0	0.089	0.193	0.297	0.399	0.5	0.599	0.696	0.789	0.879	1
Modification 1	2	1	110	199	287	365	434	493	538	568	578	569	559
	3	0.965	145	225	306	375	438	490	531	558	570	564	558
	4	0.744	181	252	324	386	441	488	524	549	561	559	556
	5	0.522	219	281	344	397	444	484	515	537	548	549	549
	6	0.301	269	320	372	416	454	487	513	531	541	543	545
	7	0.08	342	382	423	456	486	511	531	544	552	555	559
	8	0	415	444	473	497	518	535	548	557	563	568	572
Deviation 2	1	-1	0	0.089	0.193	0.297	0.399	0.5	0.599	0.696	0.789	0.879	1
	2	1	63	62	60	63	67	70	77	87	105	120	135
	3	0.965	34	38	43	53	63	73	84	96	112	125	138
	4	0.744	4	15	27	44	59	77	92	106	119	130	141
	5	0.522	33	38	43	53	63	75	87	100	114	127	140
	6	0.301	35	40	46	57	68	80	91	105	118	132	145
	7	0.08	65	66	66	73	81	90	100	113	126	140	154
	8	0	95	91	87	90	94	100	109	121	135	149	163
Modification 2	1	-1	0	0.089	0.193	0.297	0.399	0.5	0.599	0.696	0.789	0.879	1
	2	1	188	262	349	428	501	563	615	654	682	689	698
	3	0.965	189	263	349	428	501	563	615	654	682	689	698
	4	0.744	195	267	351	430	500	565	616	655	680	689	701
	5	0.522	261	319	387	450	507	559	602	637	662	676	695
	6	0.301	310	360	418	473	522	567	604	636	659	675	697
	7	0.08	413	448	489	529	567	601	631	657	678	695	718
	8	0	514	535	560	587	612	635	657	678	698	717	743
Deviation 3	1	-1	0	0.089	0.193	0.297	0.399	0.5	0.599	0.696	0.789	0.879	1
	2	1	49	33	16	-2	1	16	30	36	36	34	32
	3	0.965	27	20	12	3	5	14	22	27	30	31	33
	4	0.744	6	7	7	7	9	11	14	18	23	28	33
	5	0.522	6	6	6	7	9	11	15	19	24	28	33
	6	0.301	1	3	5	8	11	15	18	22	26	30	35
	7	0.08	18	17	16	15	16	18	21	25	29	34	39
	8	0	35	31	27	23	21	21	23	27	33	39	44
Modification 3	1	-1	0	0.089	0.193	0.297	0.399	0.5	0.599	0.696	0.789	0.879	1
	2	1	218	284	361	427	500	577	638	682	713	720	730
	3	0.965	216	283	361	428	501	577	637	681	712	720	731
	4	0.744	202	274	358	437	509	576	630	673	703	717	736
	5	0.522	267	325	393	457	516	570	617	656	686	704	728
	6	0.301	310	360	418	481	533	582	622	658	685	705	732
	7	0.08	431	465	505	544	583	619	652	682	707	729	759
	8	0	548	566	587	610	633	656	680	705	731	756	790
Modification 14	1	-1	0	0.089	0.193	0.297	0.399	0.5	0.599	0.696	0.789	0.879	1
(Final step)	2	1	158	241	337	427	506	577	638	682	713	728	747
	3	0.965	166	246	340	428	506	577	637	681	712	727	747
	4	0.744	211	279	358	437	509	576	630	673	703	723	750
	5	0.522	267	325	393	457	516	570	617	656	686	710	742
	6	0.301	310	360	418	481	533	582	622	658	690	712	742
	7	0.08	436	474	518	546	583	619	652	682	714	738	770
	8	0	554	579	608	610	633	655	675	709	740	767	803
Deviation 15	1	-1	0	0.089	0.193	0.297	0.399	0.5	0.599	0.696	0.789	0.879	1
(Final step)	2	1	2	1	0	0	-1	2	5	6	5	0	-4
	3	0.965	0	1	2	1	1	2	3	4	4	1	-3
	4	0.744	-1	1	4	2	3	2	2	2	3	1	-2
	5	0.522	6	4	1	0	2	3	4	5	5	1	-4
	6	0.301	2	3	4	2	2	3	3	4	2	2	1
	7	0.08	6	3	1	3	4	3	4	5	2	3	3
	8	0	11	4	-3	5	5	3	5	5	2	4	5

References

1. KISSsoft AG. Calculation Program for Machine Design. *http://www.kisssoft.ch*.
2. ISO 23509 (2006). Bevel and Hypoid Gear Geometry. *http://www.iso.org*.
3. Bae, I. and J. Langhart. "Können 5-Achsgefräste 3D-Kegelräder mit Konventionell Hergestellten Kegelrädern Gepaart Werden?" 2013, *Dresdner Maschinenelemente Kolloquium* 2013, 135-152
4. ISO 21771 (2007). Gears: Cylindrical Involute Gears and Gear Pairs — Concepts and Geometry.
5. ISO/TR 10064-6 (2009). Code of Inspection Practice — Part 6: Bevel Gear Measurement Methods.
6. Klingelnberg, J. *Kegelräder*, 2008, Springer.
7. Breton S.p.A., *http://www.breton.it*

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