NUMERICAL RESEARCH IN KISSSOFT FOR NOISE REDUCTION IN SPUR GEARS TRANSMISSIONS

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ABSTRACT

The main requirements for transmissions are a high load carrying capacity, a low sound excitation behavior and high efficiency, which become more and more important with the increasing environmental awareness.

Keywords: Spur gears, contact stiffness, noise reduction

1. Introduction

Depending on the project use, the main requirement for spur gear transmission beside from a long life time, high safety factor, reduction of losses in gear mesh, highest strength, low manufacturing costs it could find the sound behavior.

Due to the increasing environmental requests this aspect become more and more important. The limits for the allowable noise are given by the customer or by the existing regulation.

The design of gears can be done e.g. according to the ISO/DIN/ AGMA standards [1, 2, 3]. Besides these standards there are further possibilities of optimization in respect to excitation behavior and reduction of losses in a gear mesh i.e. using modern simulation soft like KISSsoft, IDZP, WTplus, etc.

With the support of suitable software, new possibilities open up for the calculation and the optimization of the gear with regard to operating noise, meshing and strength characteristics. In this way can be open new horizons to improve gears.

Main reason for noise is the excitation from the gear meshing because of variation of the mesh stiffness. First at all, the excitation starts from the gear meshing contact and it is transmitted to the rest of gears components like shafts, bearings and, at last, is transmitted to the environment through the housing system.

The excitation caused by the gear meshing is mainly the result of:

- The periodical change of the mesh stiffness;
- Engagement impact, the elastic deflection of the teeth under load at the beginning and the end of the line of action.

2.Issue

A helical gear pair is to be designed such that it has a service life of 8,000 h when transmitting 91,5 kW at 750 rpm (application factor = 1.50). The gears have 27 respectively 54 teeth, center distance 125, normal module 3, ratio shall be 1:2 (reducing speed) and 18MnCr10 (16 MnCr 5 –cf. DIN 17210-69) is to be used as the gear material.

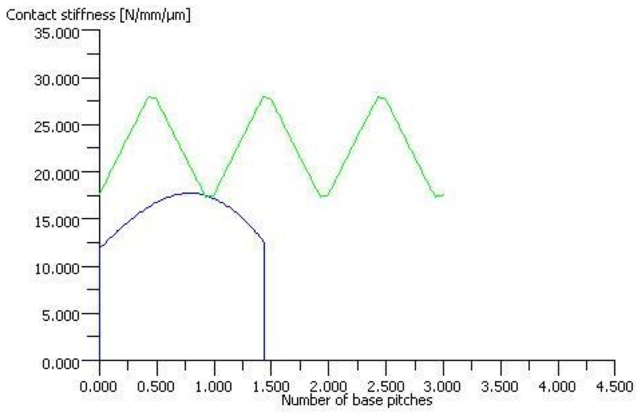

Fig.1 - Initial contact stiffness for considered gear transmission

3. Goal

In this paper, the goal is that the helical gear pair to be optimized to achieve the best possible noise/contact ratio. The variation of the tooth pair stiffness during a meshing cycle is a well known source for the generation of vibrations and noise.

The KISSsoft program is especially considered for the design of gear transmissions. A procedure is implemented in KISSsoft which determines the meshing stiffness:

1. A tooth form is calculated by simulating of the manufacturing process;
2. For every position of the two teeth during a meshing cycle, the single tooth stiffness is determined.
3. The overall stiffness it is obtained through superposing the single stiffness of all teeth in contact.

If the vibration reduction is very important for optimizing the gear geometry, after every solution was checked, the solution with lowest possible stiffness it should be selected.

Strength calculation is to be performed as specified in ISO 6336 Method B - Calculation of load capacity of spur and helical gears.

4. Optimizing gear geometry

Number of teeth

After having decided on a centre distance (imposed in this study case) for the gear transmission, selecting the proper number of teeth (without changing of the center distance) for a gear pair it is a next important step.

In the below figures, different solutions for a gear pairs with ration i=2 ± 5%, a=125 mm, P=91.5 kW, number of teeth (gear 1) between 21 and 30, are shown in Fig.2 and Fig.3.

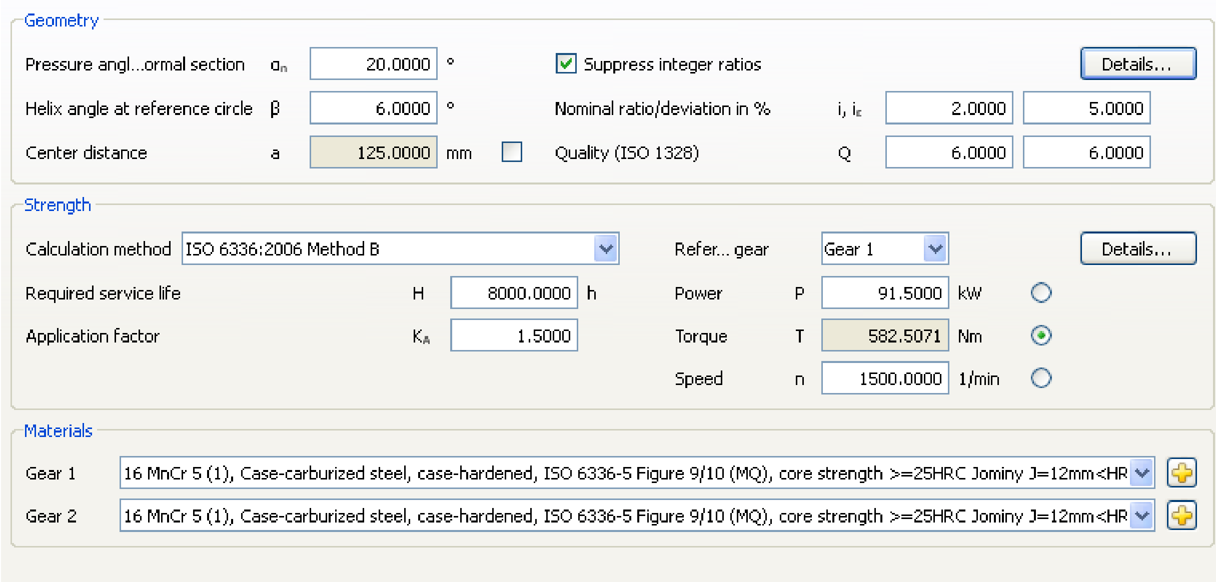

Fig. 2. Initial conditions for gears

b_1 [mm]	b_2 [mm]	m_n [mm]	β [°]	z_1	z_2	x^*_1	x^*_2	ε_α	ε_β	ε_γ	i	$T_{1\,max}$ [Nm]	P_{max} [kW]	W [kg]	Summary
55.000	55.000	2.750	6.000	29	59	0.549	0.777	1.415	0.665	2.080	2.034	532.243	83.605	12.664	0.837
47.591	47.591	2.750	6.000	30	61	0.101	-0.390	1.737	0.576	2.313	2.033	576.819	90.606	10.974	0.729
49.350	49.350	3.000	6.000	27	54	0.462	0.558	1.454	0.547	2.001	2.000	563.134	88.457	11.401	0.752
41.618	41.618	3.000	6.000	28	56	0.059	-0.594	1.770	0.462	2.231	2.000	586.001	92.049	9.602	0.636
40.427	40.427	3.500	6.000	23	47	0.341	0.208	1.509	0.384	1.894	2.043	578.697	90.902	9.519	0.676
42.883	42.883	4.000	6.000	21	41	0.211	-0.131	1.587	0.357	1.944	1.952	605.763	95.153	10.125	0.656

Fig.3 The result returned for gears

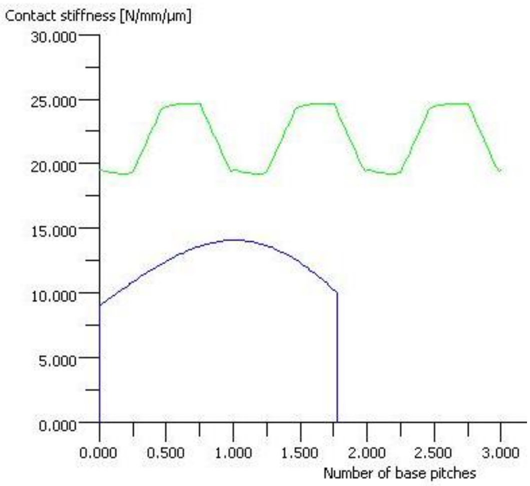

Fig. 4. The contact stiffness for rough sizing

Helix angle and profile shift

Measurements prove that a higher helix angle (higher overlap contact ratio) will result in lower noise level. Selecting the profile shift such that a lowest possible amount of sliding occurs is a highly efficient way to optimize gears in terms of high frequency noise. In the figures below (Fig.5 and Fig.6), different possible gearing solutions were found by variation of helix angle at reference circle and profile shift coefficient. Reference profile and centre distance were maintained for given values.

		Minimum	Maximum		Step		
Maximal no of solutions		100					
Nominal ratio/deviation in %	i, i_E	2.0000	2.0000				
Normal module	m_n	3.0000	3.0000	mm	0.0000	mm	☑
Pressure angle at normal section	α_n	20.0000	20.0000	°	0.0000	°	
Helix angle at reference circle	β	5.0000	7.0000	°	0.5000	°	
Center distance	a	125.0000	125.0000	mm	0.0000	mm	☐
Range for profile shift coefficient	x^*	-0.6000	1.0000				

		Gear 1		Gear 2		
Maximum tip diameter	$d_{a,\,max}$	999999.0000		999999.0000		mm
Minimum root diameter	$d_{f\,min}$	0.0000		0.0000		mm
Fix number of teeth	z	0	☐	0	☐	
Fix profile shift coefficient	x*	0.0000	☐	0.0000	☐	

Fig. 5. The conditions imposed for fine sizing

Nr.	a [mm]	m_n [mm]	α [°]	β [°]	z_1	z_2	x^*_1	x^*_2	ε_α	ε_β	ε_γ	Δc_γ [N/mm/µm]	η [%]	W [kg]	Summary
1	125.000	3.000	20.000	5.000	27	53	0.708	0.997	1.305	0.385	1.690	3.594	0.984	9.528	0.671
2	125.000	3.000	20.000	5.000	27	54	0.311	0.788	1.453	0.385	1.838	4.186	0.984	9.656	0.648
3	125.000	3.000	20.000	5.000	27	54	0.411	0.688	1.446	0.385	1.831	4.220	0.984	9.630	0.650
4	125.000	3.000	20.000	5.000	27	54	0.511	0.588	1.437	0.385	1.822	4.204	0.984	9.605	0.650
5	125.000	3.000	20.000	5.000	27	55	0.142	0.391	1.577	0.385	1.962	3.984	0.984	9.718	0.647
6	125.000	3.000	20.000	5.000	27	55	0.242	0.291	1.568	0.385	1.953	3.983	0.984	9.691	0.645
7	125.000	3.000	20.000	5.000	27	55	0.342	0.191	1.557	0.385	1.942	3.994	0.984	9.666	0.642
8	125.000	3.000	20.000	5.000	28	55	-0.016	0.024	1.694	0.385	2.079	3.190	0.984	9.635	0.604
9	125.000	3.000	20.000	5.000	28	55	0.084	-0.076	1.683	0.385	2.068	3.217	0.984	9.610	0.590
10	125.000	3.000	20.000	5.000	28	55	0.184	-0.176	1.670	0.385	2.055	3.433	0.984	9.586	0.595
11	125.000	3.000	20.000	5.000	28	56	-0.136	-0.335	1.796	0.385	2.181	2.395	0.984	9.659	0.561
12	125.000	3.000	20.000	5.000	28	56	-0.036	-0.435	1.782	0.385	2.167	2.564	0.984	9.634	0.541
13	125.000	3.000	20.000	5.000	28	56	0.064	-0.535	1.764	0.385	2.149	2.709	0.984	9.609	0.536
14	125.000	3.000	20.000	5.500	27	53	0.694	0.970	1.313	0.423	1.736	3.506	0.984	9.530	0.670
15	125.000	3.000	20.000	5.500	27	54	0.299	0.762	1.460	0.423	1.883	3.884	0.984	9.658	0.643
16	125.000	3.000	20.000	5.500	27	54	0.399	0.662	1.453	0.423	1.876	3.943	0.984	9.632	0.645
17	125.000	3.000	20.000	5.500	27	54	0.499	0.562	1.444	0.423	1.867	3.955	0.984	9.607	0.645
18	125.000	3.000	20.000	5.500	27	55	0.131	0.366	1.583	0.423	2.007	3.562	0.984	9.718	0.648
19	125.000	3.000	20.000	5.500	27	55	0.231	0.266	1.574	0.423	1.997	3.720	0.984	9.692	0.650
20	125.000	3.000	20.000	5.500	27	55	0.331	0.166	1.563	0.423	1.986	3.802	0.984	9.666	0.648
21	125.000	3.000	20.000	5.500	28	55	-0.025	0.000	1.699	0.423	2.122	2.990	0.984	9.635	0.599
22	125.000	3.000	20.000	5.500	28	55	0.075	-0.100	1.689	0.423	2.112	3.014	0.984	9.610	0.580
23	125.000	3.000	20.000	5.500	28	55	0.175	-0.200	1.675	0.423	2.098	3.119	0.984	9.585	0.586
24	125.000	3.000	20.000	5.500	28	56	-0.144	-0.358	1.800	0.423	2.223	2.231	0.984	9.658	0.548
25	125.000	3.000	20.000	5.500	28	56	-0.044	-0.458	1.786	0.423	2.209	2.312	0.984	9.632	0.529
26	125.000	3.000	20.000	5.500	28	56	0.056	-0.558	1.768	0.423	2.191	2.443	0.984	9.607	0.521
27	125.000	3.000	20.000	6.000	27	53	0.680	0.941	1.321	0.462	1.783	3.246	0.984	9.533	0.666
28	125.000	3.000	20.000	6.000	27	54	0.286	0.733	1.468	0.462	1.929	3.707	0.984	9.660	0.640
29	125.000	3.000	20.000	6.000	27	54	0.386	0.633	1.461	0.462	1.922	3.714	0.984	9.634	0.640
30	125.000	3.000	20.000	6.000	27	54	0.486	0.533	1.452	0.462	1.913	3.662	0.984	9.609	0.640
31	125.000	3.000	20.000	6.000	27	55	0.120	0.338	1.590	0.462	2.052	3.346	0.984	9.719	0.643
32	125.000	3.000	20.000	6.000	27	55	0.220	0.238	1.581	0.462	2.042	3.374	0.984	9.693	0.642
33	125.000	3.000	20.000	6.000	27	55	0.320	0.138	1.569	0.462	2.031	3.401	0.984	9.667	0.642
34	125.000	3.000	20.000	6.000	28	55	-0.036	-0.026	1.705	0.462	2.166	2.682	0.984	9.634	0.589
35	125.000	3.000	20.000	6.000	28	55	0.064	-0.126	1.694	0.462	2.155	2.817	0.984	9.609	0.567
36	125.000	3.000	20.000	6.000	28	55	0.164	-0.226	1.680	0.462	2.142	2.915	0.984	9.585	0.574
37	125.000	3.000	20.000	6.000	28	56	-0.153	-0.382	1.805	0.462	2.266	1.940	0.984	9.656	0.534
38	125.000	3.000	20.000	6.000	28	56	-0.053	-0.482	1.790	0.462	2.252	2.090	0.984	9.630	0.517
39	125.000	3.000	20.000	6.000	28	56	0.047	-0.582	1.772	0.462	2.234	2.151	0.984	9.605	0.511
40	125.000	3.000	20.000	6.500	27	53	0.664	0.909	1.330	0.500	1.830	3.141	0.984	9.537	0.663
41	125.000	3.000	20.000	6.500	27	54	0.272	0.702	1.476	0.500	1.975	3.400	0.984	9.661	0.646
42	125.000	3.000	20.000	6.500	27	54	0.372	0.602	1.469	0.500	1.968	3.429	0.984	9.636	0.646
43	125.000	3.000	20.000	6.500	27	54	0.472	0.502	1.459	0.500	1.959	3.418	0.984	9.611	0.643
44	125.000	3.000	20.000	6.500	27	55	0.107	0.308	1.597	0.500	2.097	3.046	0.984	9.720	0.637
45	125.000	3.000	20.000	6.500	27	55	0.207	0.208	1.588	0.500	2.088	3.155	0.984	9.693	0.634
46	125.000	3.000	20.000	6.500	27	55	0.307	0.108	1.576	0.500	2.076	3.210	0.984	9.668	0.635
47	125.000	3.000	20.000	6.500	28	55	-0.047	-0.054	1.711	0.500	2.210	2.492	0.984	9.633	0.576
48	125.000	3.000	20.000	6.500	28	55	0.053	-0.154	1.700	0.500	2.199	2.623	0.984	9.609	0.550
49	125.000	3.000	20.000	6.500	28	55	0.153	-0.254	1.686	0.500	2.186	2.628	0.984	9.584	0.559
50	125.000	3.000	20.000	6.500	28	56	-0.162	-0.409	1.810	0.500	2.309	1.799	0.984	9.653	0.521
51	125.000	3.000	20.000	6.500	28	56	-0.062	-0.509	1.795	0.500	2.295	1.938	0.984	9.628	0.500
52	125.000	3.000	20.000	7.000	27	53	0.547	0.974	1.347	0.538	1.885	2.921	0.984	9.565	0.654
53	125.000	3.000	20.000	7.000	27	53	0.647	0.874	1.340	0.538	1.878	2.887	0.984	9.540	0.660
54	125.000	3.000	20.000	7.000	27	54	0.257	0.669	1.484	0.538	2.022	3.054	0.984	9.663	0.644
55	125.000	3.000	20.000	7.000	27	54	0.357	0.569	1.477	0.538	2.015	3.026	0.984	9.638	0.643
56	125.000	3.000	20.000	7.000	27	54	0.457	0.469	1.468	0.538	2.006	3.035	0.984	9.613	0.643
57	125.000	3.000	20.000	7.000	27	55	0.094	0.276	1.604	0.538	2.142	2.776	0.984	9.720	0.629
58	125.000	3.000	20.000	7.000	27	55	0.194	0.176	1.595	0.538	2.133	2.850	0.984	9.694	0.626
59	125.000	3.000	20.000	7.000	27	55	0.294	0.076	1.583	0.538	2.121	2.835	0.984	9.668	0.627
60	125.000	3.000	20.000	7.000	28	55	-0.059	-0.085	1.717	0.538	2.255	2.220	0.984	9.632	0.561
61	125.000	3.000	20.000	7.000	28	55	0.041	-0.185	1.706	0.538	2.244	2.326	0.984	9.608	0.528
62	125.000	3.000	20.000	7.000	28	55	0.141	-0.285	1.691	0.538	2.230	2.346	0.984	9.583	0.538
63	125.000	3.000	20.000	7.000	28	56	-0.171	-0.438	1.815	0.538	2.353	1.598	0.984	9.651	0.504
64	125.000	3.000	20.000	7.000	28	56	-0.071	-0.538	1.800	0.538	2.338	1.721	0.984	9.626	0.473

Fig. 6. Possible gearing solutions

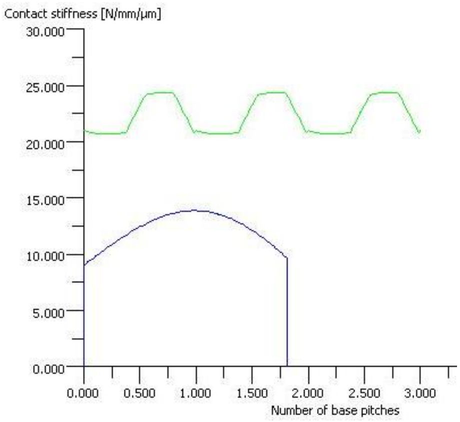

Fig.7. The contact stiffness for fine sizing

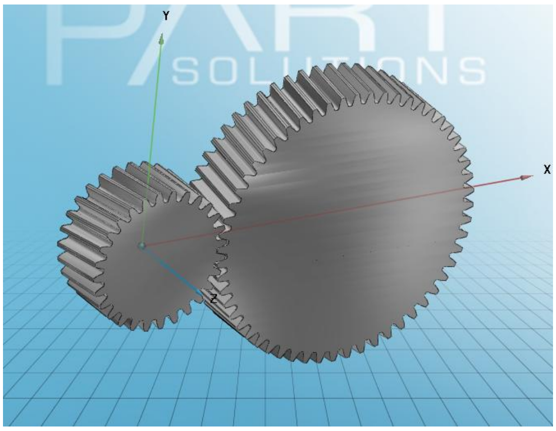

Fig.8 - Optimized gears

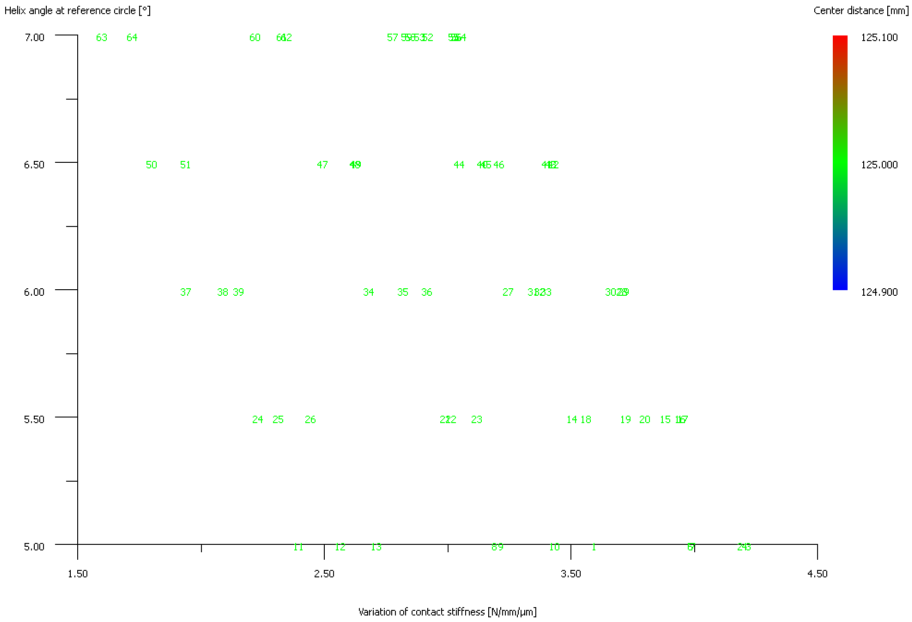

Fig.9. Variation of contact stiffness / helix angle

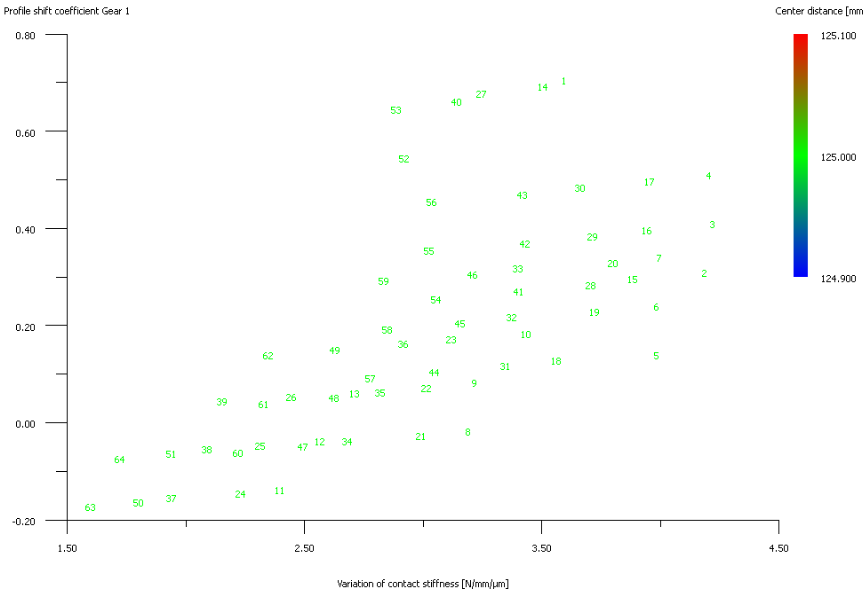

Fig.10. Variation of contact stiffness / profile shift coefficient

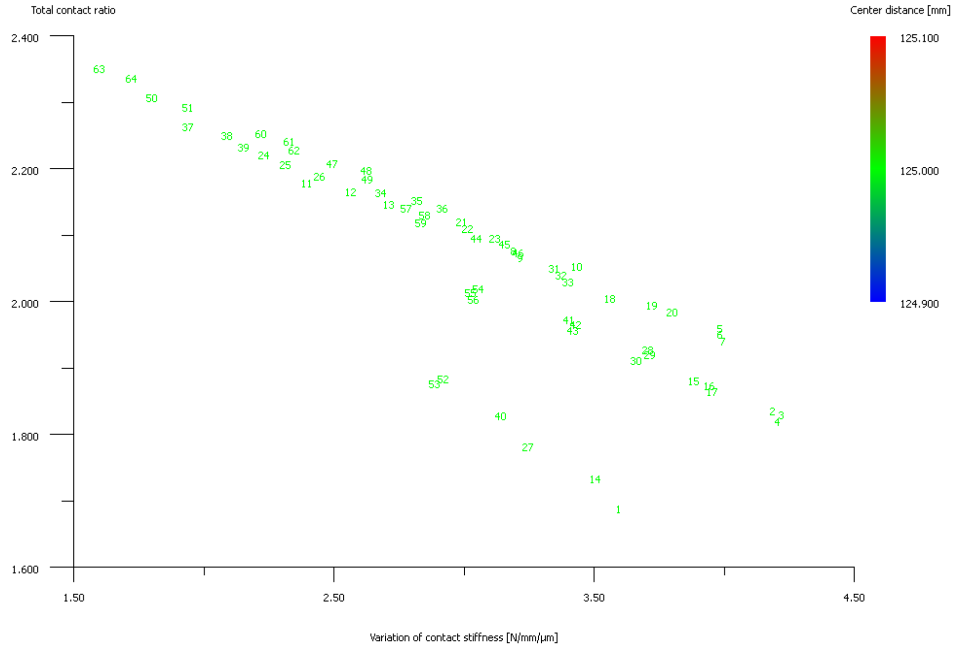

Fig.11. Variation of contact stiffness / total contact ratio

5. Conclusions

- The excitation from the tooth mashing has a main influence on the noise behavior of a gearing and should be taken measures to reduce this excitation.
- In the Fig. 9, Fig. 10 and Fig.11 it is presented three methods to reduce the noise of gear meshing.

References

[1] *** – *ISO 6336:2006 Method B - Calculation of load capacity of spur and helical gears*

[2] *** – *DIN 3990, method B - Calculation of load capacity of cylindrical gears*

[3] *** – *AGMA 2001-C95 - Fundamental Rating Factors and Calculation Methods for Involute Spur and Helical Gear Teeth*

[4] *** – *KISSsoft Release 03/2011 User Manual,* KISSsoft AG, Hombrechtikon Switzerland, 2011