Table 2

"TOE"

$$\frac{V}{H} = \frac{1.024\ \text{mm}}{-1.356\ \text{mm}}$$

φ_1	φ_2	U_{12}	X mm	Y mm	$\Delta\varphi_2$ $\times 10^5$	$\Delta U_{21} \times 10^5$
−23°53′46″	12°54′01″	6.8112	−18.59	16.09	−19.82	47.41
−11°40′20″	14°41′39″	6.8159	−16.21	13.71	−11.12	37.29
0°32′17″	16°29′06″	6.8218	−14.35	11.35	−4.10	24.62
12°44′12″	18°16′20″	6.8291	−12.98	8.62	−0.52	9.10
18°49′53″	19°09′52″	6.8332	−12.47	7.29	0.	0.
24°55′26″	20°03′21″	6.8377	−12.06	5.94	−0.52	−9.48
30°59′21″	20°57′38″	6.8425	−12.15	4.68	−	−19.5

Table 3

"HEEL"

$$\frac{V}{H} = \frac{-1.182\ \text{mm}}{1.508\ \text{mm}}$$

φ_1	φ_2	U_{12}	X mm	Y mm	$\Delta\varphi_2$ $\times 10^5$	ΔU_{21} $\times 10^5$
−54°59′29″	6°36′35″	6.8258	6.54	17.09	−7.74	16.50
−42°43′38″	8°24′24″	6.8254	9.26	14.27	−3.95	16.87
−30°28′48″	10°12′03″	6.8281	11.21	11.34	−0.58	11.32
−12°08′16″	12°53′08″	6.8369	12.83	6.83	−0.12	−7.76
0°04′20″	14°40′13″	6.8460	13.13	3.79	−3.51	−27.20
6°10′20″	15°33′40″	6.8515	13.08	2.27	−6.85	−38.80
12°16′37″	16°27′02″	6.8570	13.04	0.69	−13.7	−50.59

Table 4

Helixform (9/43)

"MEAN"

$$\frac{V}{H} = \frac{0}{0} \quad \begin{matrix}\text{mm}\\ \text{mm}\end{matrix}$$

φ_1	φ_2	U_{12}	X	Y	$\Delta\varphi_2$	ΔU_{21}
−23°58′42″	14°43′05″	4.7816	−3.36	6.98	0.	−17.01
−15°56′18″	16°24′00″	4.7793	−2.91	6.24	−1.39	−6.74
−7°53′29″	18°05′02″	4.7776	−2.60	5.46	−1.87	0.
0°09′36″	19°46′10″	4.7761	−2.39	4.21	−1.37	5.61
8°13′08″	21°27′24″	4.7760	−2.39	3.77	−0.34	7.78
16°17′04″	23°08′44″	4.7764	−2.53	2.87	0.78	7.23
24°21′24″	24°50′08″	4.7774	−2.86	1.96	1.45	4.12
32°26′34″	27°22′20″	4.7780	−3.32	1.06	1.82	−1.41
40°31′08″	28°13′05″	4.7798	−3.98	0.16	0.94	−8.86

Discussion

R. C. Huston[1]. The paper is divided into three parts. In the first of these the authors propose a new method of determining the cutter machine settings for the manufacture of "Formate" and "Helixform" hypoid gears. They thus have extended the work of Pismanic (Reference [1]) which is restricted to Formate gears.

In the second part of the paper the focus is on determining the cutter machine settings for the manufacture of Formate and Helixform **pinions**. This analysis is based on local surface geometry conditions which insure conjugate action between the gear and pinion.

In the final part of the paper the authors examine the effects of mismatch. This analysis is developed globally in the sense that conjugate meshing is sought at all contact points along the tooth surfaces.

Although specific numerical examples are given in each of the three parts the reviewer believes that the analysis is probably too abstract and brief to be accessible to the average design engineer. Hence, it will probably be of most interest to gear theoreticians and kinematicians concerned with surface geometry.

[1] Professor of Mechanics, Department of Mechanical Engineering, University of Cincinnati, Cincinnati, Ohio

Discussion

T. Krenzer[1]. This is another worthwhile paper on spiral bevel and hypoid gearing by Prof. Litvin and Dr. Gutman for which these authors are to be commended. The paper consists of three parts and I will present a short discussion on each of these parts.

Part 1: Calculations for Machine settings for Member gear Manufacture of the Formate and Helixform Hypoid Gears.

In this part of the paper, formulas for calculating Formate and Helixform gears are derived along with a sample calculation for each. Although the calculation procedures differ from those used at Gleason, they result in gear machine settings that are essentially the same. To demonstrate the point, calculations for the same gears were made using Gleason formulas. Table 1 shows the comparison of the basic machine settings using the two calculation methods. Small differences in values for the Formate gear are attributed to slight differences in selecting the mean calculation point. The larger differences for the Helixform gear result from the selection of the spiral angle. As explained in the paper, a nominal spiral angle must be assumed in the Helixform case. Gleason's procedure for making the assumption differs from

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that used in this paper and results in a slightly greater spiral angle. This difference is reflected in the machine spiral angle, the vertical setting and the horizontal setting. In either case the result has no effect on the final tooth contact since the pinion settings are calculated to match the gear.

Table 4

	FORMATE	HELIXFORM
Cutter Point Radius	151.73	77.58
Pinion Blade Angle	14°0′	10°0′

Table 1

	FORMAT*		HELIXFORM*	
Basic Machine Settings	Litvin/Gutman	Gleason	Litvin/Gutman	Gleason
Machine Root Angle	75°49′	75°49′	74°51′	74°48′
Vertical Setting	125.14mm	125.22mm	74.19mm	72.90mm
Horizontal Setting	73.03mm	72.90mm	30.64mm	29.69mm
Machine Center to Back - Mounting Distance	.06mm	.05mm	−7.62mm	−7.85mm
Helical Lead	0	0	39.48mm	38.99mm
Machine Spiral Angle	30°34′	30°33′	31°25′	32°48′

*Formate and Helixform are registered trademarks of the Gleason Works.

Table 2 contains the cutter specifications which are the same for both methods.

Table 2

Cutter Specifications	FORMATE	HELIXFORM
Nominal Cutter Radius	152.4mm	76.2mm
Blade Angles I.B.	22°30′	10°0′
O.B.	22°30′	28°0′
Point Width	2.54mm	2.03mm

In summary, Part 1 of the paper verifies, by using a completely different approach, the correctness of the present Formate and Helixform gear machine calculations.

Part 2: Machine Setting Calculations for the Pinions of Formate and Helixform Gears

This part of the paper presents a method for calculation machine settings to generate pinions that match Formate and Helixform gears [1]. First and second order contact characteristics are held to prescribed values. Several different pinion setups will satisfy these prescribed conditions. Gleason formulas were used to calculate the examples in the paper using the same set of conditions with the following exception. The meaning of the author's factor for contact pattern length was not fully understood. Therefore, we chose to hold the same cutter specifications as those used in the paper. Table 3 shows a comparison of the basic pinion machine settings for both the Formate and Helixform cases.

To evaluate and compare the meshing quality of sets calculated by the two methods, edge contact TCA's were calculated and plotted. The Formate comparison is shown in Fig. 1 with the TCA of the Litvin/Gutman settings on the left and the Gleason TCA on the right. Pattern length is the only significant difference between the TCA's. Since the same tool geometry was used in each case, the shorter length produced by the Litvin/Gutman setup is due to greater mismatch being introduced in the generation.

Fig. 2 is the TCA comparison for the Helixform set. Again the Litvin/Gutman TCA is on the left. Only small insignificant higher order differences can be noted. This comparison provides the opportunity to make an interesting observation. The Helixform method in its simplest form is a conjugate method of generation. In the example used here only lengthwise mismatch was introduced. In the Gleason pinion setup: the machine root angle is equal to zero; the offset is equal to the running offset; the head setting is equal to zero; and the ratio of roll is equal to the ratio of the number of teeth in the members. The calculation method used in the paper gives a machine setup which is substantially different as shown in Table 3. Yet, the TCA's are not significantly different. It demonstrates that meshing quality is not a function of a conjugate calculation method but depends on the ability to define and hold contact characteristics.

In summary this part of the paper provides an alternate method for calculating machine settings which will produce pinions that match Formate and Helixform gears.

Part 3: Analysis and Optimal Synthesis Methods for

Table 3

	FORMATE		HELIXFORM	
Basic Pinion Machine Settings	Litvin/Gutman	Gleason	Litvin/Gutman	Gleason
Machine Root Angle	−2°30′	−4°16′	0°0′	0°0′
Sliding Base	26.77mm	23.70mm	9.39mm	7.46mm
Blank Offset	25.49mm	23.75″	34.33″	31.75″
Heat Setting	−10.98mm	−5.36mm	−.54mm	0.0mm
Radial	133.09mm	134.59mm	84.30mm	80.58mm
Cradle Angle	84°2′	76°58′	89°50′	86°35′
Tilt Angle	9°7′27″	11°18′	16°14′23″	15°16′
Swivel Angle	307°11′41″	319°53′	332°35′58″	340°17′
Ratio of Roll	6.051437	6.29527	4.856019	4.777778

Table 4 contains the pinion cutter specifications

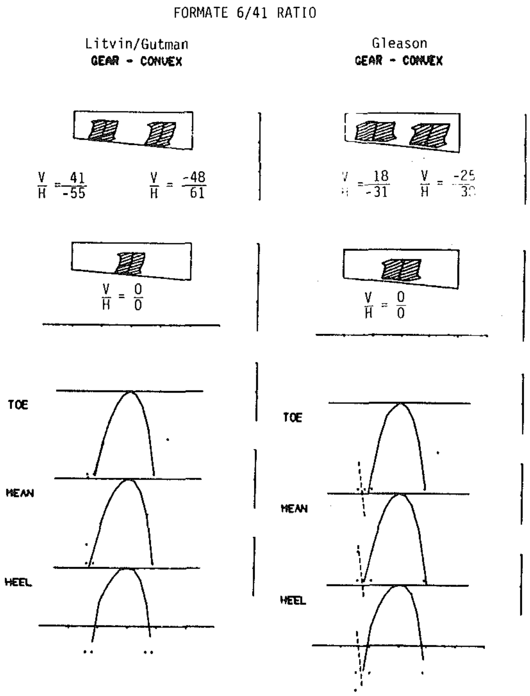

Fig. 1

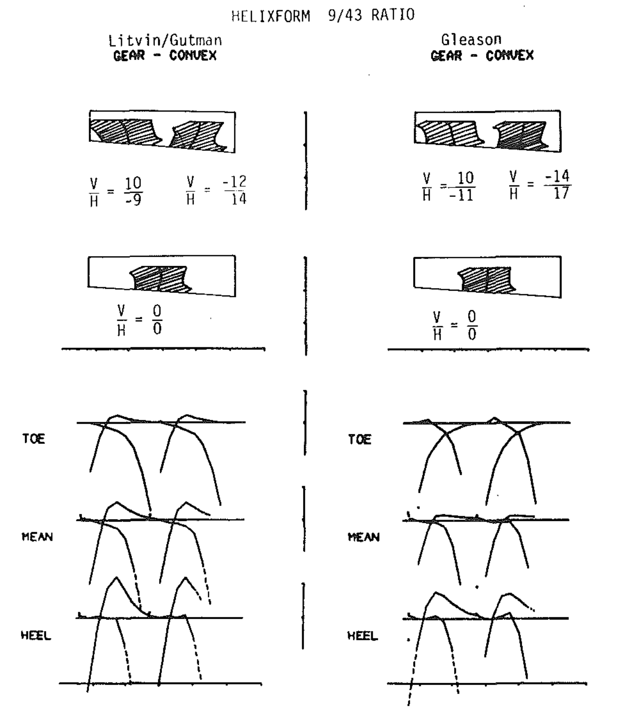

Fig. 2

Mismatch Gearing and It's Application for Hypoid Gears of Formate and Helixform.

In their first paper [2] Litvin and Gutman purposed a method for controlling the curvature of the path of contact. In the last part of this paper a method for minimizing the change in the motion variation as the contact is shifted on the face of the gear tooth is established. The concern which the authors are addressing in both of these papers is for control of third order contact characteristics in the manufacture of spiral bevel and hypoid gears. Gleason, as stated in the first discussion [1] has long been aware of the importance of these higher order characteristics. The approach we prefer is covered in that first discussion. It consists of a procedure to calculate the six third-order characteristics, a definition of a weighting function to establish their relative importance and an optimization technique to minimize the function by changing the machine setup.

In summary Litvin and Gutman in this last part of the paper have pinpinted an important contact characteristic and have set up a procedure for controlling it by changing pinion machine settings. Five other characteristics of equal rank exist and deserve equal treatment.

General Summary: This is an excellent theoretical paper in which alternative methods for calculating machine settings for manufacturing spiral bevel and hypoid gears are purposed. The calculation procedures and machine settings differ from Gleason's but TCA shows them to be correct. In calculations, where meshing contact is optimized, we look at all third-order characteristics as opposed to the one characteristic of motion variation along the tooth which is considered in the final part of the paper.

Author's Closure

We highly appreciate the thorough analysis of our four papers made by Mr. T. Krenzer (Gleason Works), Professor R. S. Husten and Mr. V. Simon.

In addition to his theoretical analysis, Mr. Krenzer calculated the machine settings and the tooth contact analysis with the Gleason Computer Programs and compared them with our results. We consider the coinciding of our results with the Gleason results as our important achievement, knowing the high theoretical and practical experience of Gleason collaborators.

Methods of our paper "A Method of Local Synthesis of Gears Grounded on the Connections Between the Principal and Geodetic Curvatures of Surfaces" are directed to improve the local synthesis in the neighborhood of the mean contact point. But this is only the first step. The second step must be to optimize the meshing over the entire area, as described in the third part of the paper titled "Analysis and Optimal Synthesis Methods for Mismatch Gearing and Its Application for Hypoid Gears of 'Formate' and 'Helixform'."

We think it is important to emphasize that the methods proposed in our papers may be applied not only for hypoid and spiral bevel gears but also for other types of gears. In our opinion some results, for instance, general relations between principal curvatures, principal directions and geodetic curvatures of contacting surfaces, are new not only in the field of theory of gearing but in the differential geometry too. Maybe the same can be stated for the methods of local and optimal synthesis of contacting surfaces and for the new method of tooth contact analysis.

We agree with Professor Husten that the topic of our papers is a complicated one, but this results from the nature of the problems to be solved. And then our papers are completed with practical results – with working equations and computer programs for the calculation of machine settings for the to-be-generated gears.

It is surprising for us that Mr. Simon, who favored his own methods to ours, did not mention that he applied methods and equations which were proposed in the book [*a*] and papers [*b*,*c*] by F. Litvin and published many years ago.

We are very thankful to ASME for the opportunity to present our papers at the Power Transmission and Gear Conference (San Francisco 1980) and for publishing them in this journal. We are very thankful to our reviewers.

Additional References

a *The Theory of Gearing* by F.L. Litvin, Russian Edition in 1968, Hungarian Edition in 1972.

b "The Synthesis of Approximate Meshing for Spatial Gears," *J. Mechanisms,* Vol. 4, 1968, pp. 187-191.

c "The Mathematical Modelling and Optimization of Approximate Meshing of Gears," (in Russian), *Proceedings of the Third World Congress for the Theory of Machines and Mechanisms,* Kupari, Yugoslavia, 1971.