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Generation of Helical Gears With New Surfaces, Topology by Application of CNC Machines

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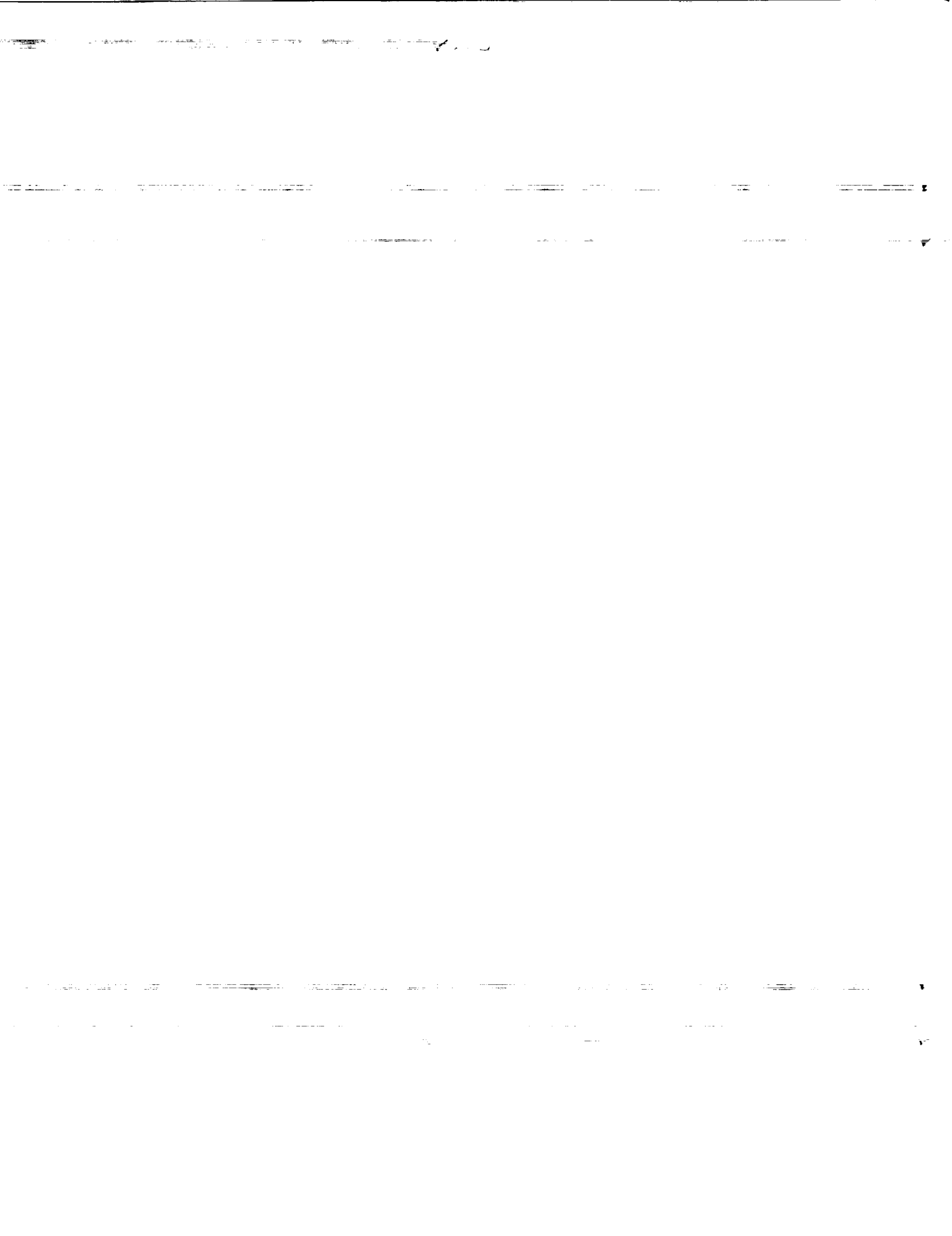*Lewis Research Center*
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GENERATION OF HELICAL GEARS WITH NEW SURFACES
TOPOLOGY BY APPLICATION OF CNC MACHINES

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Abstract

Analysis of helical involute gears by tooth contact analysis shows that such gears are very sensitive to angular misalignment that leads to edge contact and the potential for high vibration. A new topology of tooth surfaces of helical gears that enables a favorable bearing contact and a reduced level of vibration is described. Methods for grinding of the helical gears with the new topology are proposed. A TCA program for simulation of meshing and contact of helical gears with the new topology has been developed. Numerical examples that illustrate the proposed ideas are discussed.

Introduction

Computations by tooth contact analysis (TCA) has shown that involute helical gears are sensitive to errors such as the crossing of gear axes (instead of being parallel) and lead errors. The above errors cause the shift of the bearing contact to the edge and transmission errors of an undesirable shape (figs. 1 and 2). The transfer of meshing of gears with such transmission errors is accomplished with a jerk, producing high vibration and noise.

A new topology of tooth surfaces has been proposed [1-3] that provides for a more favorable bearing contact and transmission error motion even with misalignment present. The generation of the proposed gear tooth surfaces was based on application of existing equipment for generation of helical gears that provided linear relations between the rotations and displacements of the tool and the gear being generated. The modified gear tooth surfaces proposed in the works above could be generated as formate cut by a tool of large dimension or generated point by point if computer controlled. These methods of generation have some difficulties for manufacturing but may be overcome by the new approach.

The new approach that is discussed by the authors is based on application of CNC machines with five degree-of-freedom that enable to provide : (i) computer controlled nonlinear functions that relate the motions of the tool and the gear being generated, (ii) a varied plunge of the tool along the shortest center distance between the axes of the tool and the pinion, and (iii) a point contact of tooth surfaces that is spread over an elliptical area of controlled dimensions. This approach allows to avoid an edge contact and reduce the sensitivity of the gears to misalignment. The generation of gear tooth surfaces may be accomplished by form-grinding.

The new form-grinding method for helical gears that is proposed provides : (i) a stabilized bearing contact, (ii) better conditions of lubrication, and (iii) a predesigned parabolic function of transmission errors that is able to absorb an almost linear function of transmission errors caused by gear misalignment. It is expected that the new topology of the gears will eliminate edge contact and substantially reduce noise and vibrations.

The proposed form-grinding requires the application of a computer numerical controlled (CNC) machine with five degrees-of-freedom, but only four require control by computer. Each tooth space is generated separately, and indexing is required.

1. Bearing Contact and Transmission Errors of Misaligned Involute Helical Gears

The authors have developed a TCA program for conventional involute helical gears that permits the investigation of the impact of misalignment. Figs. 1 and 2 show that due to the crossing angle $\Delta\gamma = -5$ arc-min, the contact is shifted to the edge and the transmission errors have the shape shown in fig. 2. Similar results are caused by the lead error $\Delta\beta_1 = -5$ arc-min.

The edge contact reduces the load capacity of the gears. The transmission errors of the type shown in fig. 2 will inevitably cause premature failure along with an increased vibration and noise.
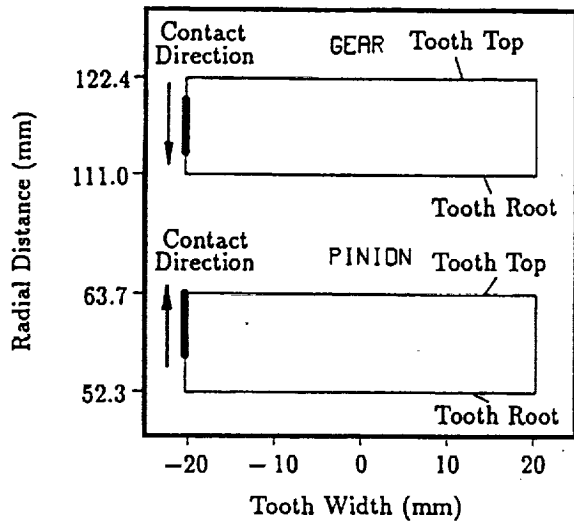
Fig. 1. Edge Contact Due to Axis Misalignment (Crossing Angle, $\Delta\gamma$, −5 arc-min).
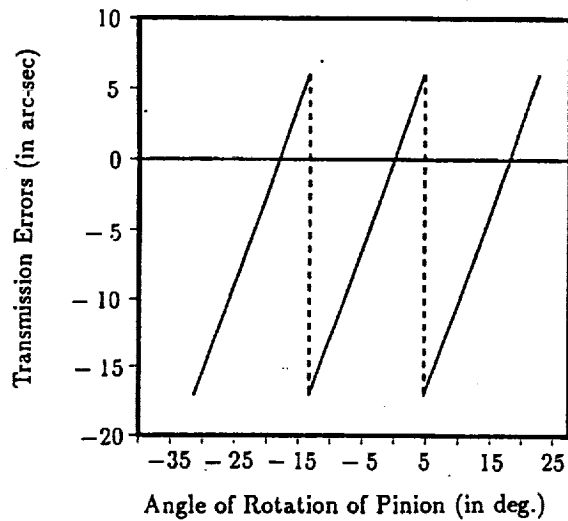

Fig. 2. Transmission Errors of Involute Helical Gears with Axis Misalignment (Crossing Angle, $\Delta\gamma$, −5 arc-min).

2. New Method for Grinding, Modified Topology

Pinion Form-Grinding The form-grinding process for the pinion with the new topology is based on the following ideas :

(i) Consider initially that both tooth sides of the pinion are conventional screw involute surfaces. Using the approach developed in theory of gearing [4], it is possible to determine the surfaces of a disk-shaped grinding tool that will generate the conventional screw involute surfaces. The tool performs the screw motion with respect to the pinion being generated.

(ii) The grinding wheel surface is modified in the axial section. The deviations of modified tool surface from the conventional one is represented at the mean contact point by a parabolic function, which can be controlled to adapt to different applications. Both pinion tooth sides can be ground simultaneously. The surface of the pinion grinding wheel is a surface of revolution.

(iii) The modified grinding wheel must perform two motions with respect to the pinion : (a) the conventional screw motion, and (b) an additional but varied translational motion along the shortest distance between the axes of the grinding wheel and the pinion. This translational motion presents plunging of the grinding wheel into the space, being deeper at the edges and less in the middle of the tooth width.

(iv) Using the methods developed in the theory of gearing [4], it becomes possible to determine analytically the equations of the pinion generated as described above. These equations are necessary for the TCA that has to be applied for simulation of meshing and contact of helical gears with modified topology.

Gear Grinding Consider that a conventional involute helical gear is in mesh with the pinion whose tooth surface is modified as described above. Such a gear train if not misaligned will transform rotation with negligible transmission errors. The bearing contact of gear tooth surfaces is localized since the gear tooth surfaces are in point contact at every instant due to modification of the pinion tooth surface described above.

The goal is to keep the surface point contact but to provide a predesigned parabolic function of transmission errors. Such a function is able to absorb a linear discontinuous function of transmission errors caused by angular errors of misalignment. The goal above can be achieved by proper modification of gear tooth surface that is based on the following considerations:

(i) Consider that an imaginary rack-cutter is simultaneously in mesh with the pinion and gear provided with conventional screw involute tooth surfaces. The pinion and the gear perform rotational motions and the rack performs translational motion s_t described as follows

$$s_t = r_1\phi_1 = r_2\phi_2 \qquad (1)$$

$$\phi_2 = \phi_1 \frac{N_1}{N_2} \qquad (2)$$

where r_1 and r_2 are the pinion-gear centrodes, N_1 and N_2 are the tooth numbers.

Obviously, the transmission function $\phi_2(\phi_1)$ is a linear one, and the gears will be sensitive to angular errors of misalignment.

(ii) We may consider now that while the rack performs translational motion s_t, the pinion rotates through the angle $\phi_1 = \frac{s_t}{r_1}$, but the gear rotates through the angle

$$\phi_2 = \frac{s_t}{r_2} + \Delta\phi_2(\phi_1) \qquad (3)$$

where

$$\Delta\phi_2(\phi_1) = a\phi_1^2 , \quad -\frac{\pi}{N_1} \leq \phi_1 \leq \frac{\pi}{N_1} \qquad (4)$$

is a parabolic function of the period of cycle of meshing determined as $\phi_1 = \frac{2\pi}{N_1}$.

Obviously, the transmission function of the pinion and gear generated as described above is determined as

$$\phi_2(\phi_1) = \phi_1\frac{N_1}{N_2} + a\phi_1^2 \qquad (5)$$

where $a\phi_1^2$ is the predesigned parabolic function of transmission errors.

(iii) The nonlinear transmission function (5) exists even in the case when the gear train is aligned. The advantage of such a function is the ability to absorb a linear but discontinuous function $b\phi_1(0 \leq \phi_1 \leq \frac{2\pi}{N_1})$ that is caused by gear misalignment. This is based on the fact [1,5] that the sum of functions represented as

$$\Delta\phi_2(\phi_1) = a\phi_1^2 + b\phi_1 \qquad (6)$$

can be transformed into the parabolic function

$$\Delta\phi_2(\phi_1^*) = a(\phi_1^*)^2 \qquad (7)$$

Parabolic functions $(a\phi_1^2)$ and $(a(\phi_1^*)^2)$ have the same slope. Transformation of function (6) into function (7) is equivalent to coordinate transformation when the coordinate system (ϕ_2, ϕ_1) is translated keeping the orientation of coordinates axes.

(iv) We have assumed above that the pinion tooth surface is a conventional involute screw surface Σ_1. In reality, the pinion tooth surface Σ_1^* is a modified one as mentioned above. However, a synthesized function of transmission errors of parabolic type exists in the case of modification of the pinion tooth surface as well. This statement is based on the fact that surfaces Σ_1 and Σ_1^* are in tangency at the mean point and only slightly deviate along the helix on Σ_1 that passes through the mean point.

(v) The described above methods of modification of tooth surfaces Σ_1 and Σ_2 enable to localize the bearing contact of Σ_1 and Σ_2 and provide a predesigned parabolic type of transmission errors to absorb the undesired linear function caused by gear misalignment.

(vi) There are alternative methods for grinding of the modified gear tooth surface other than the form-grinding method proposed here. The generation can also be achieved by either a grinding plane or by a grinding worm. However, a nonlinear function that relates the motions of the grinding wheel and the gear being generated is required for both alternative cases.

3. TCA for Helical Gears with New Topology

A TCA computer program to simulate the meshing and contact of the gears with the new topology has been developed.

The computations have been performed for a drive with the following design parameters:

$N_1 = 20$, $N_2 = 40$, $P_n = 0.19685\frac{1}{mm}$, $\alpha_n = 20°$, $\beta_p = 30°$, and tooth face width $F_w = 40.64$ mm.

Two types of path of contact can be provided as shown in figs. 3 and 4. These two types of path of contact can be obtained by the control of modification of the topology of pinion-gear tooth surfaces in the longitudinal and profile directions.
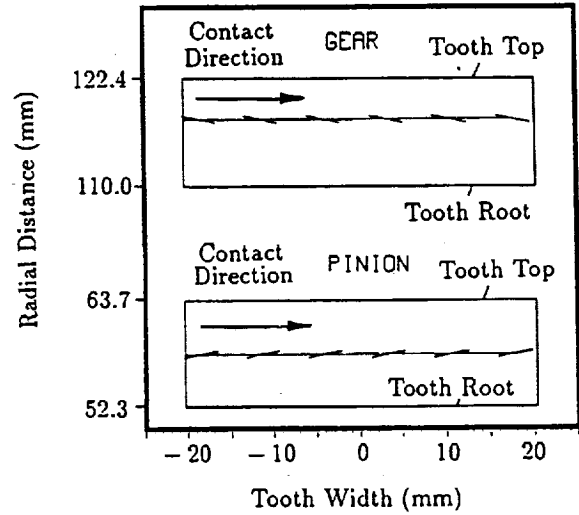

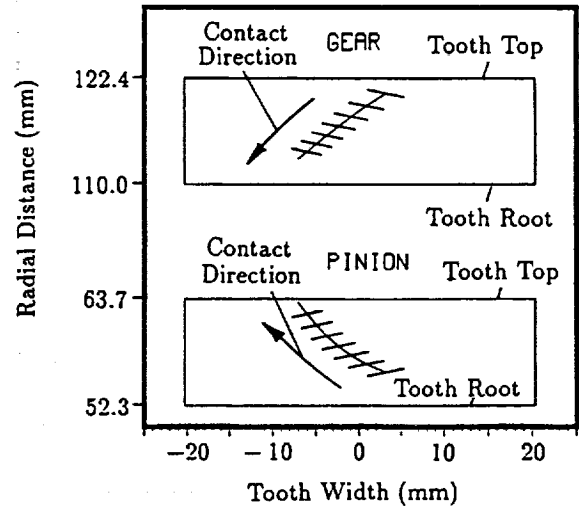Fig. 3. Latitudinal Contact Path with Shaft Misalignment $(\Delta\gamma = -5')$.

Fig. 4. Longitudinal Contact Path with Shaft Misalignment $(\Delta\gamma = 2')$.

The influence of the crossing angle $\Delta\gamma$ is shown for the above data in figure 5.

The results of investigation show that the almost linear function of transmission errors caused by misalignment of conventional involute helical surfaces (shown in figure 5) is indeed absorbed by the parabolic type of transmission errors for the modified surfaces (fig. 6).

The major axis of the contact ellipse, under an assumed light load, has been determined as shown in figs. 3 and 4. The undesirable displacement of the path of contact to the bottom and the top of the gear tooth can be controlled by the modification of the surface of the grinding wheel for the pinion generation.
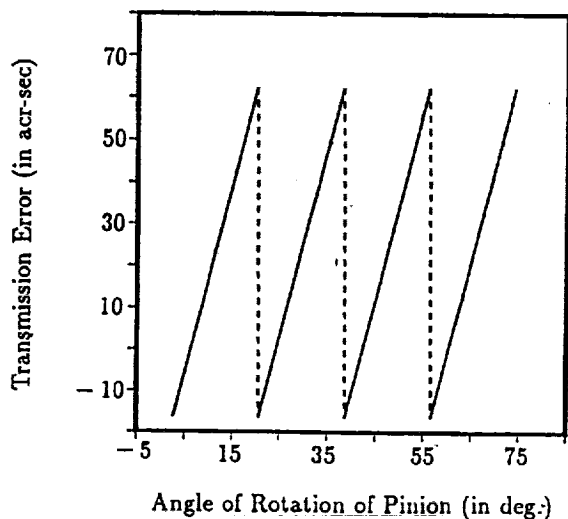

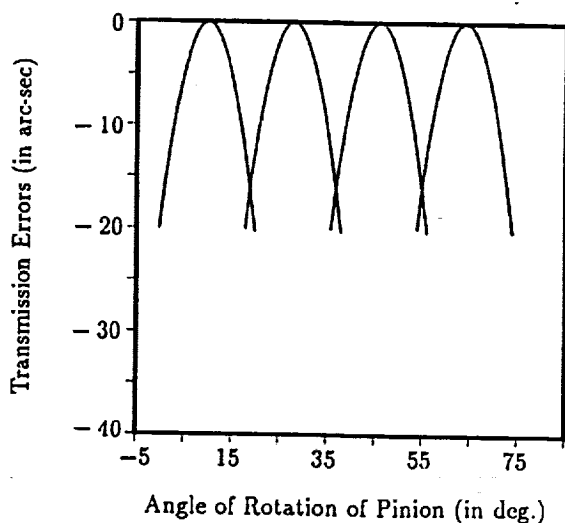Fig. 5. Influence of Misalignment on Transmission Errors ($\Delta\gamma = -5'$).

Fig. 6. Influence of Misalignment on Transmission Errors of Helical Gears with New Surface Topology ($\Delta\gamma = -5'$).

4. Conclusion

The following conclusions of the study conducted in this paper are as follows :

1. A TCA program for simulation of meshing and contact of conventional involute helical gears has been developed. This program has shown that such gears are very sensitive to angular misalignment and high vibration is inevitable.

2. A new topology of helical gear tooth surfaces has been developed. Methods for grinding tooth surfaces have been developed. The bearing contact of gears with the proposed topology is localized and the transmission errors are reduced.

3. The TCA program for helical gears with the new topology has been developed. The influence of crossing angle on the location of the path of contact and on the transmission errors has been investigated.

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13. ABSTRACT (Maximum 200 words)

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