Effects of misalignment error, tooth modifications and transmitted torque on tooth engagements of a pair of spur gears

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Abstract

In the last research [S. Li, Effects of machining errors, assembly errors and tooth modifications on load-carrying capacity, load-sharing rate and transmission error of a pair of spur gear, Mech. Mach. Theory 42 (2007) 698-726], effects of machining errors, assembly errors and lead crowning on tooth surface contact stresses (CS), root bending stresses, load-sharing ratios (LSR) and transmission errors of a pair of spur gears were investigated through performing loaded tooth contact analysis (LTCA) with developed finite element method (FEM) programs. But this research couldn't investigate the effects of tooth profile modification and lead reliving on tooth engagements. Also, the effects of machining errors, assembly errors and tooth modifications on tooth mesh stiffness (MS) couldn't be investigated. So, as a continuous study of the last research, this paper investigates the effects of tooth profile modification and lead reliving on tooth engagements of a pair of spur gears and the effects of misalignment error of gear shafts on the plane of action, tooth lead crowing and transmitted torque on tooth MS. An arc curve is used to modify tooth profiles of a pair of spur gears in this paper. This is because this method is used very popularly for the spur gears. Methods used in the last research are also used here to investigate the effects of the tooth profile modification, lead reliving and transmitted torque on tooth engagements. Based on the results, it is found that the tooth profile modification and lead reliving have significant effects on tooth CS, LSR and MS. It is also found that transmitted torque has a little effect on tooth MS, but has no effect on LSR of the gears. For the lead-relived gears, calculation results show that edge-loads happened at the joint parts of the relieved part and the non-relieved part of tooth lead when the lead is relived with straight lines. Since the edge-loads resulted in greater contact stresses at the joint parts and weakened tooth contact strength, an attention must be paid to the lead reliving. It is necessary to reduce the edge-loads as small as possible through making the joint part smooth when the lead relieving is made.

Keywords: Spur gears; Assemble errors; Tooth modifications; Mesh stiffness; Load-sharing ratios; Contact stresses

1. Introduction

It is well-known that machining errors, assembly errors and tooth modifications of a pair of gears have significant effects on vibration, noise and strength of the pair of gears. Though this problem has been well investigated by many researchers [1-20], many problems, such as how to estimate vibration, noise and strength levels of a pair of gears with the machining errors, assembly errors and tooth modifications exactly in theory, have not been solved completely.

Umezawa et al. [3-6] conducted researches on tooth MS calculations of a pair of gears with tooth surface deviations using an analytical method. In Umezawa's research, tooth deformation was divided into tooth deflection and tooth approach (resulted from Hertzian contact of contact teeth). The tooth deflection was calculated by a cantilever theory and the tooth approach was calculated by the *Sneddon* equation. Effect of the tooth surface deviations on rotational vibration of a pair of helical gears was also investigated [7].

Since it is a difficult thing to use *Umezawa*'s method to solve tooth contact problems of a pair of gears with complicated machining errors, assemble errors, tooth profile modifications and thin rims, *Li* [11-12] developed FEM software to do LTCA of a pair of gears with machining errors, assemble errors and tooth modifications based on the principle of mathematical programming method presented by *Conry* and *Seireg* [13-14]. In the last research of the author [12], effects of machining errors, assemble errors and lead crowning on tooth surface CS, root bending stresses, LSR and transmission errors of a pair of spur gears were investigated using the developed FEM software. But this research couldn't investigate the effects of tooth profile modification and lead reliving on tooth engagements. Also, the effects of the machining errors, assembly errors and tooth modifications on tooth MS of a pair of spur gears couldn't be investigated. So, as a continuous study of the last research, this paper investigates the problems that have not been solved in the last research. The same methods and FEM programs are used to do LTCA of a pair of spur gears with tooth profile modification and lead reliving. The effects of misalignment error on the plane of action, tooth lead crowing and transmitted torque on tooth MS of the pair of spur gears are also investigated.

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Based on calculation results, it is found that tooth profile modification and lead reliving have significant effects on tooth CS, LSR and MS. It is also found that transmitted torque has a little effect on tooth MS, but has no effect on LSR of the gears. For the lead-relived gears, edge-loads happened at the joint parts of the relieved part and the non-relieved part of the tooth lead when the lead is relived with straight lines. Since the edge-loads resulted in greater contact stresses at the joint parts and weakened the tooth contact strength, it is necessary to reduce the edge-loads as small as possible through making the joint part smooth when the lead relieving is made.

2. Definitions of the misalignment error and tooth modifications

2.1 Definition of the misalignment error

In the last research [12], since the effect of assemble errors of a pair of spur gears on tooth MS couldn't be investigated, so this paper investigates this effect here. In the last research, it was found that the misalignment error of the gear shafts on the vertical plane of the plane of action of a pair of spur gears almost has no effect on tooth surface CS, so only the misalignment error of the gear shafts on the plane of action is used here to investigate the effect of it on tooth MS. The misalignment error of the gear shafts on the plane of action can be expressed by an inclination angle of the contact teeth on the plane of action as shown in Fig. 1.

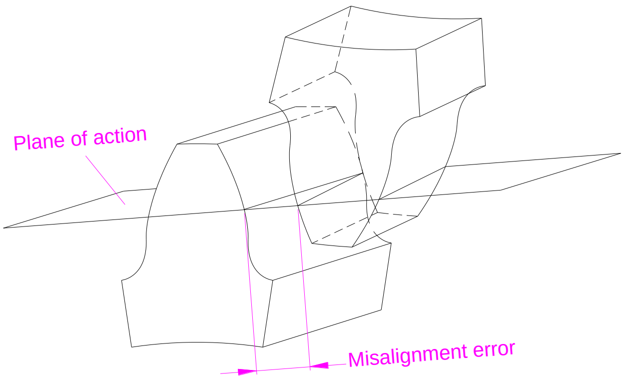


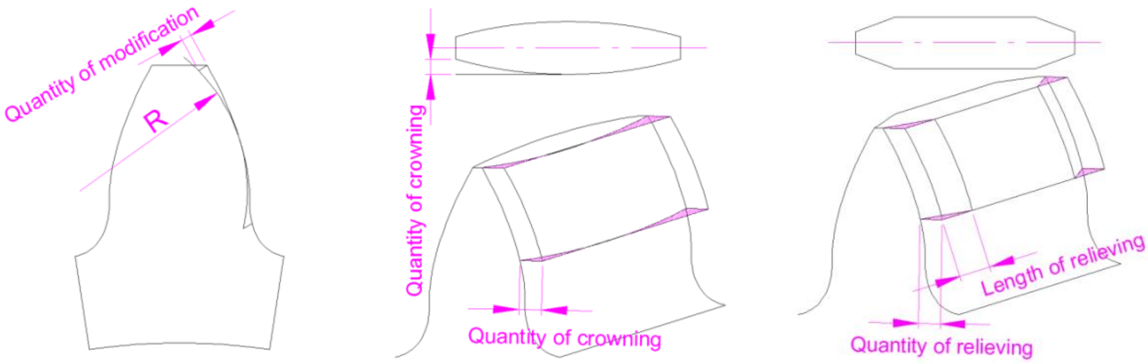
Fig. 1 Image of contact teeth with misalignment error on the plane of action

2.2 Definitions of the tooth modifications

Figure 2(a) is an image of tooth profile modification method. An arc curve with the radius R is used to modify tooth profiles of spur gears (tooth tip and root are modified with the same quantity). Since this method can be realized easily, it is used very popularly for spur gears. In Fig. 2(a), the maximum quantity of the tooth profile modification is illustrated. The effect of tooth profile modification on tooth engagements is investigated through investigating the effect of the maximum quantity of the profile modification on tooth MS, LSR and CS of the pair of gears when the pinion is modified.

Figure 2(b) is an image of tooth lead crowning. This method is used for tooth longitudinal modification. An arc curve is used to modify the tooth lead. Though the lead crowning was investigated in the last research, since the effect of the lead crowning on tooth MS couldn't be investigated in the last research, it is investigated here. The maximum quantity of the lead crowing is also illustrated in Fig. 2(b).

Figure 2(c) is also a method used for tooth longitudinal modification. It is called lead relieving. In Fig. 2(c), straight lines are used to relief the tooth lead. The maximum reliving quantity and reliving length of the teeth are illustrated in Fig. 2(c). The effect of the lead relieving on tooth engagements is investigated through investigating the effect of the reliving length on tooth MS, LSR and CS of the pair of gears under the condition that the maximum reliving quantity is fixed at 15μm.



(a) Tooth profile modification (b) Tooth lead crowning (c) Tooth lead relieving

Fig. 2 Image of tooth profile modification, tooth lead crowning and tooth lead relieving

3. LTCA of a pair of spur gears with misalignment error and tooth modifications

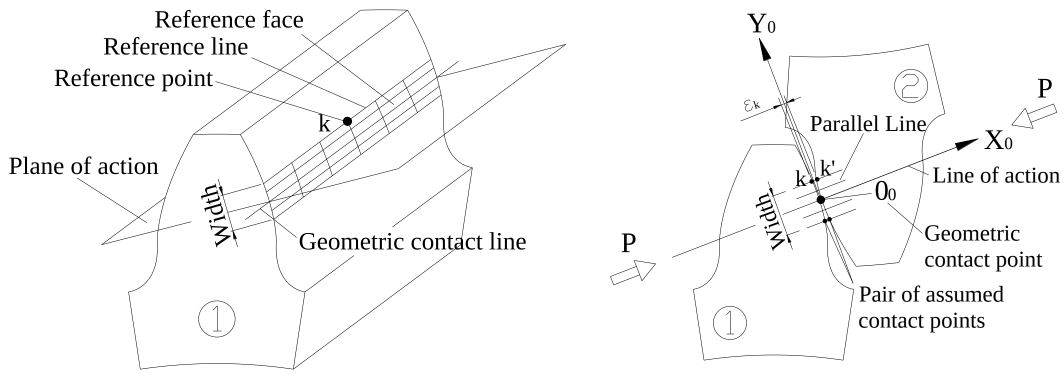
In previous research [11-12], a face-contact model of contact teeth and self-developed FEM software were used to conduct LTCA, MS, LSR and CS calculations of a pair of spur gears with machining errors, assemble errors and tooth modifications. But effects of these errors and modifications on tooth engagements couldn't be investigated completely. So, in the paper, the same FEM model and software are used again to finish the research that couldn't be finished in the last research.

It has been confirmed in the previous research [11-12] that the FEM model and software can make correct calculations of tooth MS, LSR and CS of a pair of spur gears with errors and modifications

Figure 3 is an image of the face-contact model used for LTCA of a pair of spur gears. This face-contact model is different from a line-contact model in that tooth contact is assumed to be on a reference face with a contact width "*Width"* on the contact tooth surfaces as shown in Fig. 3(a). The line-contact model only assumes that tooth contact is only on the geometric contact lines.

When FEM is used for LTCA, face contact of the contact teeth on the reference faces is replaced by the contact of many pairs of contact points on the reference faces as shown in Fig. 3. In Fig. 3(b), *(k-k')* is an optional pair of contact points on the reference faces. *k* is the point on the reference face of Gear ①, and *k'* is the responsive contact point on the reference face of Gear ②. ε_k is a gap between the pair of points *(k-k')*.

Loads between the pairs of the contact points can be calculated through conducting LTCA using the mathematical programming method [13-14] combined with FEM if the total load of the pair of gears along the line of action, gaps between the pairs of contact points and deformation influence coefficients of the pairs of contact points are known [11-14]. Then tooth MS, LSR and CS can be calculated when the loads between the pairs of contact points are known [11-12].



(a) Contact tooth of Gear 1 (b) Contact teeth of Gears 1 and 2

Fig.3 Face-contact model of a pair of spur gears used for loaded tooth contact analysis

4. Gears used as research objects

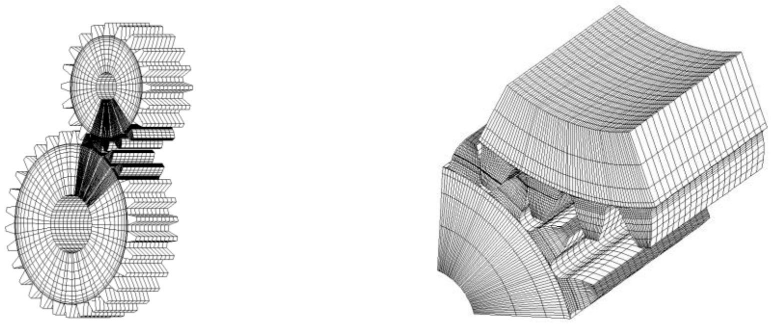
A pair of spur gears with the parameters given in Table 1 is used as research objects in this paper. Tooth dimensions, materials (JIS), heat-treatment and the transmitted torque are also given in Table 1. FEM models of the pair of gears used for LTCA are illustrated in Fig. 4. Figure 4(a) is a whole gear FEM model used for FEM analyses and Fig. 4(b) is used for an enlarged view of contact teeth. Figure 5 is a section view of the engaged teeth at three different engagement positions. They are named Positions 1, 6 and 12 respectively. In LTCA, one engagement period of the pair of gears is divided into 12 tooth engagement positions from engage-in to engage-out. Positions 1 to 7 are the double pair tooth engagement positions. It means that there are always two pairs of teeth in contact at these positions. Positions 8 to 12 are the single pair tooth engagement positions. It means that there is only one pair of teeth in contact at these positions. FEM mesh-dividing is made at these 12 positions separately when to conduct LTCA of the pair of gears. Also, tooth MS, LSR and CS are calculated separately at these 12 positions.

Based on above statements, it can be known that Fig. 5(a) is two pairs of teeth contacted at the double pair tooth engagement position. Since this position is also the beginning of tooth contact, it is named Position 1. Figure 5(b) is also two pairs of teeth contacted at the double pair tooth engagement position. At this position, the double pair tooth engagement position shall be ended. Figure 5(c) is one pair of teeth contacted at the single pair tooth engagement position. This position is also the last position of the single pair tooth engagement. It is named Position 12.

FEM Models in Figs. 4 and 5 are used to calculate deformation influence coefficients and gaps between the pairs of the contact points with FEM. Hubs of the gear and pinion are fixed as boundary conditions when the deformation influence coefficients are calculated using FEM.

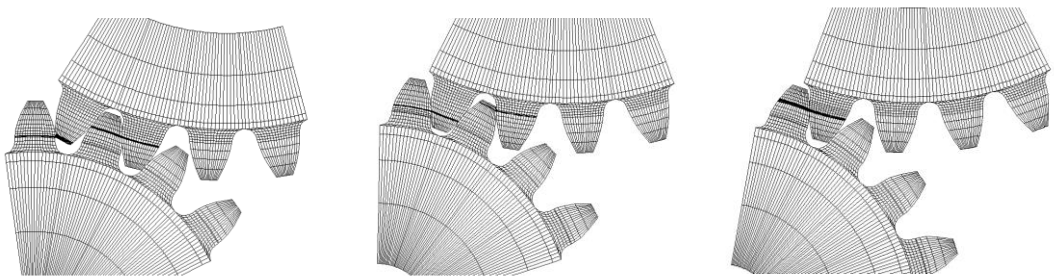
Table 1 Gear parameters

Pressure angle=20deg; module=4mm		
Involute Spur Gears	Gear	Pinion
Tooth number	30	20
Shifting coefficient	0	0
Face width (mm)	40	40
Tip diameter (mm)	128	88
Root diameter (mm)	110	70
Backlash (mm)	0.05-0.010	
Gear materials (JIS)	SCM415	SCM415
Heat-treatment	Carburized	Carburized
Torque load (Nm)	98	



(a) The whole gear FEM model (b) Enlarged view of contact teeth

Fig.4 Three-dimensional, FEM models



(a) Position 1 (b) Position 6 (c) Position 12

Fig.5 Engagement positions of the contact teeth

5. Tooth MS, LSR and CS of the ideal gears

LTCA are made for a pair of ideal gears without machining errors, assembly errors and tooth modifications at the first in order to make a comparison with the effects of tooth profile modification and lead reliving on tooth engagements. Tooth MS, LSR and CS of the ideal gears are given in the following.

Figure 6 is the calculated tooth MS curve of the ideal gears. In Fig. 6, the abscissa is tooth engagement positions of the pair of gears. In this paper, tooth engagement positions from engage-in to engage-out are expressed by contact ratio (=1.60) of the pair of the gears. In Fig. 6, the 12 engagement positions stated in Section 4 are indicated with numbers 1 to 12. As it was stated in Section 4, the numbers 1 to 7 stand for the double pair tooth engagement positions and the numbers 8 to 12 stand for the single pair tooth engagement positions. The ordinate of Fig. 6 is tooth MS. MS is calculated along the line of action of the pair of gears. Fluctuation of MS curve is also denoted by the letter "*D"* in Fig. 6. Since *D* is an important factor to affect vibration and noise behavior of a pair of gears, it is discussed in this paper.

Figure 7 is calculated LSR of the ideal gears. In Fig. 7, the abscissa is tooth engagement positions. It is also expressed by the contact ratio (=1.60) of the pair of the gears. The ordinate of the Fig. 7 is calculated LSR of the contact teeth.

Figure 8 is contour line graphs of tooth CS of the ideal gears at Position 6. Since the Position 6 is a double pair tooth contact position, Figure 8 (b) and (c) are CS on the first and the second pairs of contact teeth respectively.

In Fig. 8, the abscissa is tooth longitudinal dimension and the ordinate is the contact width "*Width*" as shown in Fig. 3. From Fig. 8, it is found that CS of the ideal gears are uniform distributions along the longitude. Geometrical contact lines of the first and the second pairs of contact teeth are also illustrated in Fig. 8. It is found that the maximum CS of the first and the second pairs of contact teeth happened on the geometrical contact lines. Also, the maximum CS of the first pair of contact teeth is about 2 times greater than that of the second pair of contact teeth.

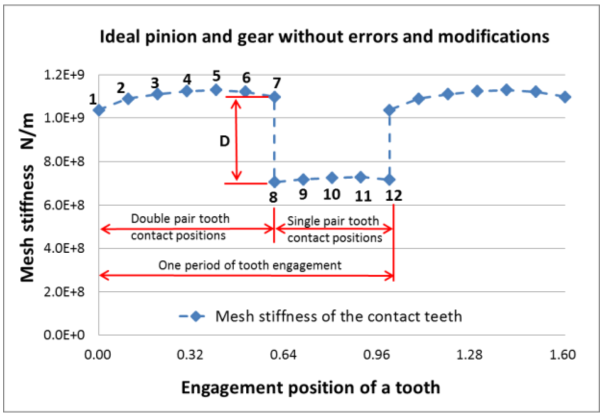


Fig.6 MS curve of the ideal gears

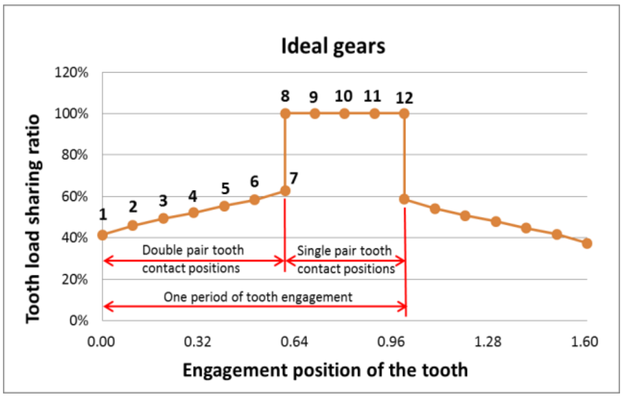
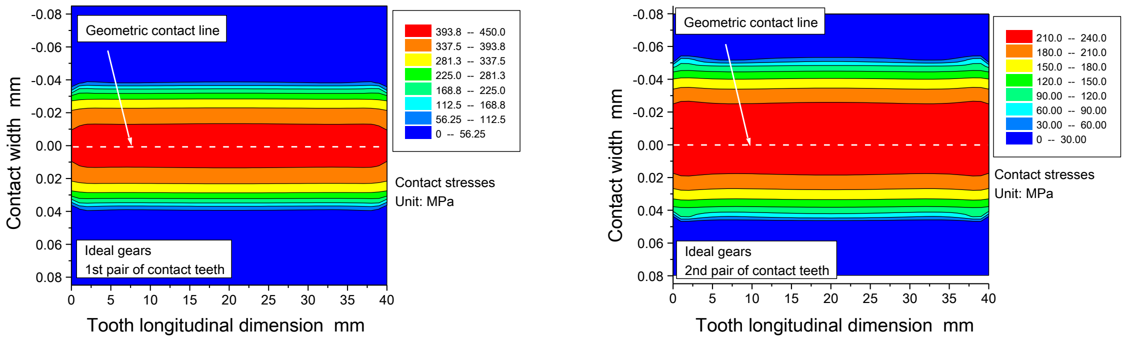


Fig.7 LSR of the ideal gears



(a) CS on the first pair of contact teeth

(b) CS on the second pair of contact teeth

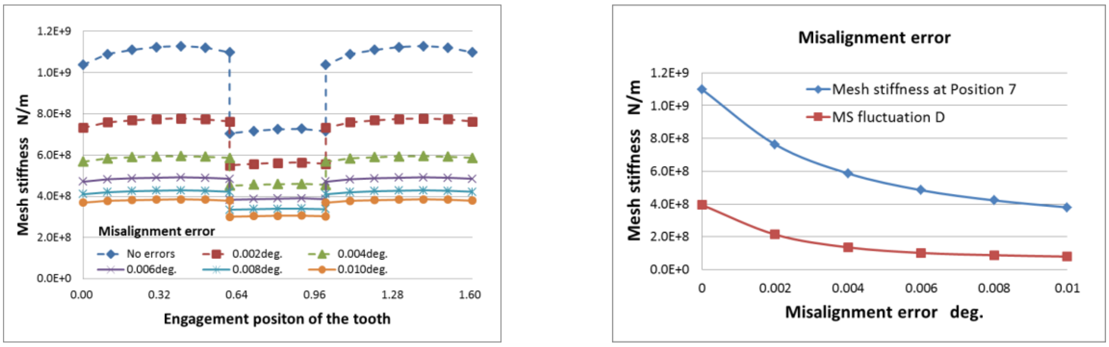
Fig.8 Contact stress distributions of the ideal gears at Position 6

6. Effect of the misalignment error of gear shafts on tooth MS

In the last research [12], effects of the misalignment errors of a pair of gears on tooth CS, root bending stresses and LSR were investigated. Since the effect of the misalignment errors on tooth MS was not investigated, this paper investigates it here. Tooth MS of the pair of gears in Table 1 are analyzed when the pair of gears has the misalignment error of the gear shafts on the plane of action. Calculation results are given in the following.

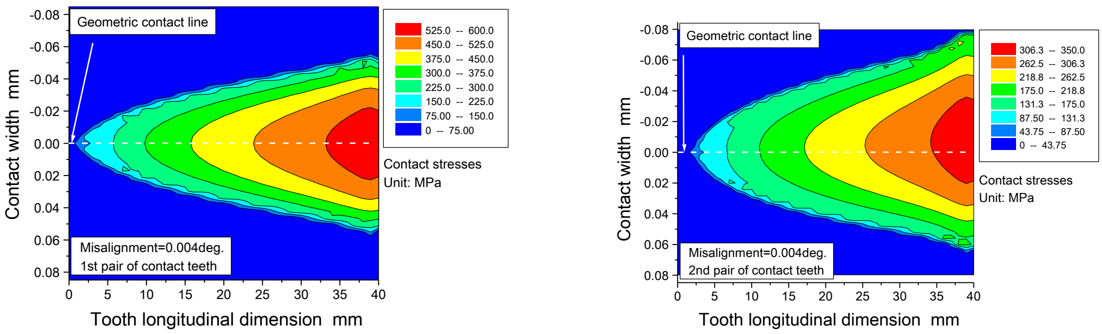
Figure 9(a) is a comparison of the tooth MS curves between the pair of ideal gears and the pair of gears with the misalignment errors. Figure 9(b) is relationships among MS value of the contact teeth at Position 7, the fluctuation *D* of MS curves and the misalignment errors. From Fig. 9, it is found that MS as well as the fluctuation *D* become smaller when the gears have misalignment errors and the misalignment errors become greater. This is because the tooth contact patterns have been changed by the misalignment errors from the a uniform contact as shown in Fig. 8 into a side heavier contacts on the right side of the contact teeth as shown in Fig. 10 when the misalignment errors exist. Since the tooth side heavier contacts make the tooth loads concentrate on the tooth side, greater contact deformation of the contact teeth shall happen than the uniform contact, then tooth MS becomes smaller than the uniform contact.

Figure 10(a) and (b) are tooth CS on the first and the second pairs of contact teeth respectively when the pair of gears engages at Position 6 and the misalignment error is 0.004 degrees.



(a) MS curves under different misalignment errors (b) MS value versus quantity of misalignment errors

Fig.9 Effect of the misalignment errors on tooth MS



(a) CS on the first pair of contact teeth (b) CS on the second pair of contact teeth

Fig.10 Contact stress distributions of the pair of gears with misalignment error at Position 6

7. Effect of the tooth profile modification on tooth engagements

LTCA are made and the tooth MS, LSR and CS are calculated for the pair of gears with tooth profile modifications. Tooth profile modifications are made only for the pinion using arc curves as introduced in Fig. 2(a). Calculations results are given in the following.

Figure 11(a) is a comparison of the tooth MS curves between the ideal gears and the pair of gears with tooth profile modifications. The maximum quantities of the tooth profile modifications are also illustrated in Fig. 11(a). In Fig. 11(a), it is found that value of the tooth MS curves becomes smaller and smaller gradually when the maximum quantities of the tooth profile modifications are changed from 0μm into 1 and then 2μm. At this case, since the maximum quantities of the tooth profile modifications are not so large, these tooth profile modifications cannot change tooth contact states (from a double pair tooth contact into a single pair tooth contact), only changed tooth LSR of the double pair tooth contact as shown in Fig. 12. In Fig. 11(a), it is also found that there is a sudden change in tooth MS at tooth engagement positions 1 as well as 12 when the maximum quantities of the tooth profile modifications are changed into 3, 4 and 6μm. This is because the double pair tooth contact at Positions 1 and 12 becomes the single pair tooth contact as shown in Fig. 12 when the maximum quantities of the tooth profile modifications is equal to or greater than 3μm. Since the first pair of contact teeth does not contact more because of a larger quantities of the tooth profile modifications and only the second pair of contact teeth are remained to be in contact, there is a sudden change in tooth MS at Positions 1 and 12. It is also found that the double pair tooth contact becomes single pair tooth contact also at Positions 2 and 3 when the maximum quantity of the tooth profile modification is 4μm and at Positions 2, 3 and 4 when the maximum quantity of the tooth profile modification is 6μm as shown in Fig. 12.

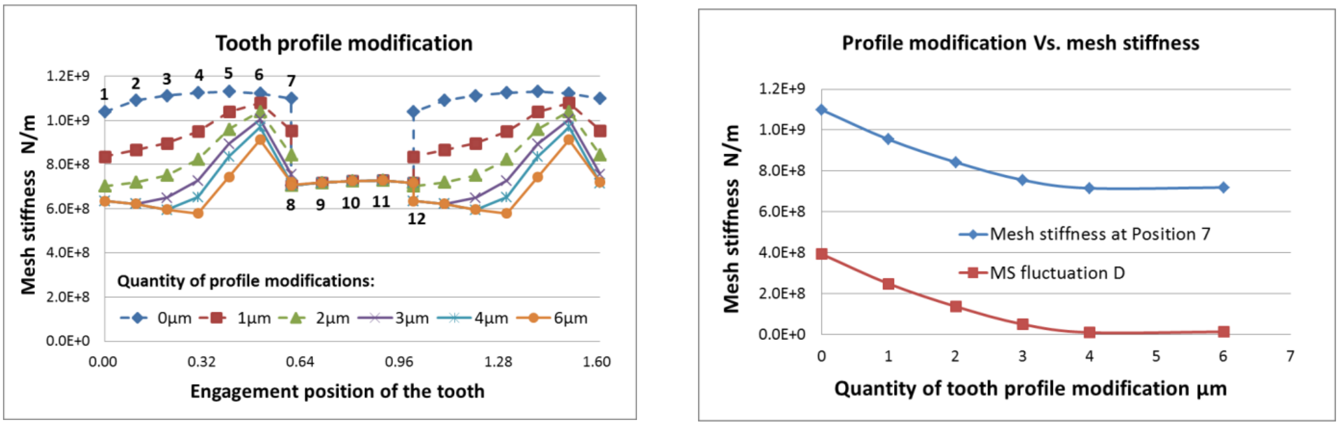
Figure 11(b) is relationships among MS value of the pair of gears at the Position 7, the fluctuation D and the maximum quantity of the tooth profile modifications.

From Fig. 11, it is found that the tooth profile modifications changed waveform of MS curves. It is also found that MS value at Position 7 as well as the fluctuation D become smaller when the maximum quantity of the tooth profile modifications become larger within 4μm. This is because the tooth profile modifications changed tooth engagement positions as shown in Fig. 13 and also changed tooth LSR as shown in Fig. 12.

The fluctuation D is often used by gear researchers as an evaluation index for gear vibration and noise and it is well known that tooth vibration and noise levels can be reduced when the tooth tip and root are relived. This phenomenon is agreement with the results in Fig. 11(b) in that the fluctuation D becomes smaller when the tooth profile is modified within 4μm. From Fig. 11(b), it is also found that the fluctuation D has no more changes when the maximum quantity of the tooth profile modification is greater than 4μm. This means that great tooth profile modifications have no meaning for tooth vibration and noise reduction.

Figure 12 is a comparison of LSR between the ideal gears and the pair of gears with the tooth profile modifications. Figure 12 indicates that the tooth profile modification has significant effect on LSR of the contact teeth. This is because the tooth engagements are affected directly by tooth profiles. When the tooth profiles are modified, contact states of the first and the second pairs of contact teeth shall be changed at once and then LSR shall be varied at once also.

Figures 13(a) and (b) are tooth CS on the first and the second pairs of contact teeth when the pair of gears engages at Position 6 and the maximum quantity of the tooth profile modification is 6μm. By comparing Fig. 13 with Fig. 8, it is found that the center positions of tooth contacts (the maximum CS positions) are changed by the tooth profile modifications from the geometric contact lines to other places away from the geometric contact lines along the tooth profile. It is also found that contact widths and the maximum CS on the first and the second pairs of contact teeth are also changed greatly when the tooth profile modifications are made for the pinion. This is because the tooth engagements are affected directly by the tooth profiles. When the tooth profiles are modified, tooth engagement states of the contact teeth shall be changed at once and the tooth CS shall be varied at once also.



(a) MS curves under different quantities of profile modification (b) MS values versus quantity of profile modification

Fig.11 Effect of the tooth profile modification on tooth MS

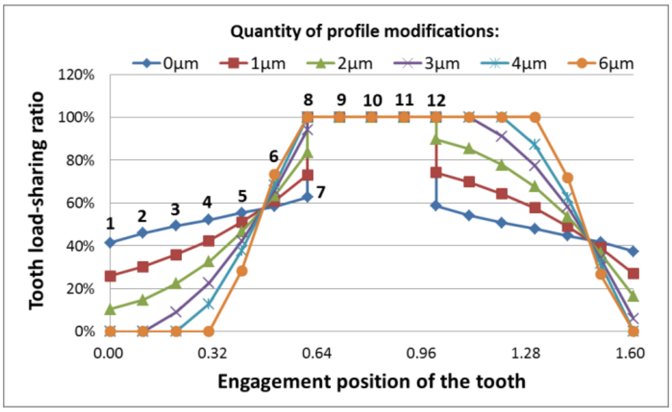
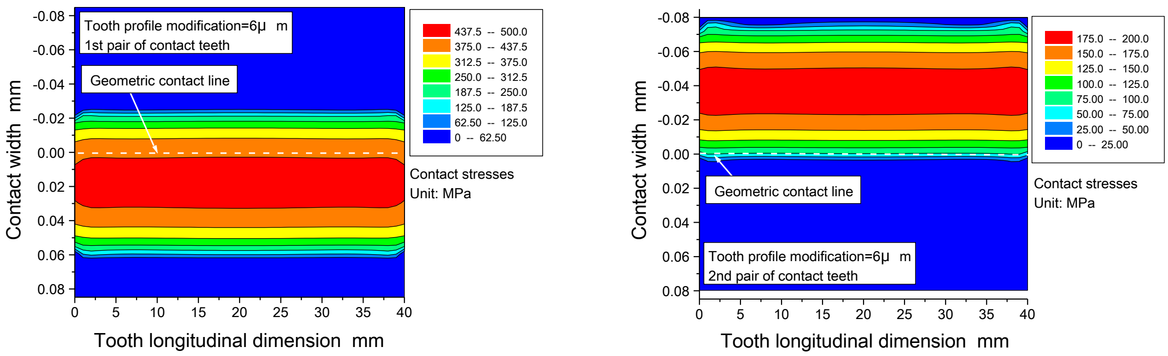


Fig.12 Effect of the tooth profile modification on the LSR



(a) CS on the first pair of contact teeth (b) CS on the second pair of contact teeth

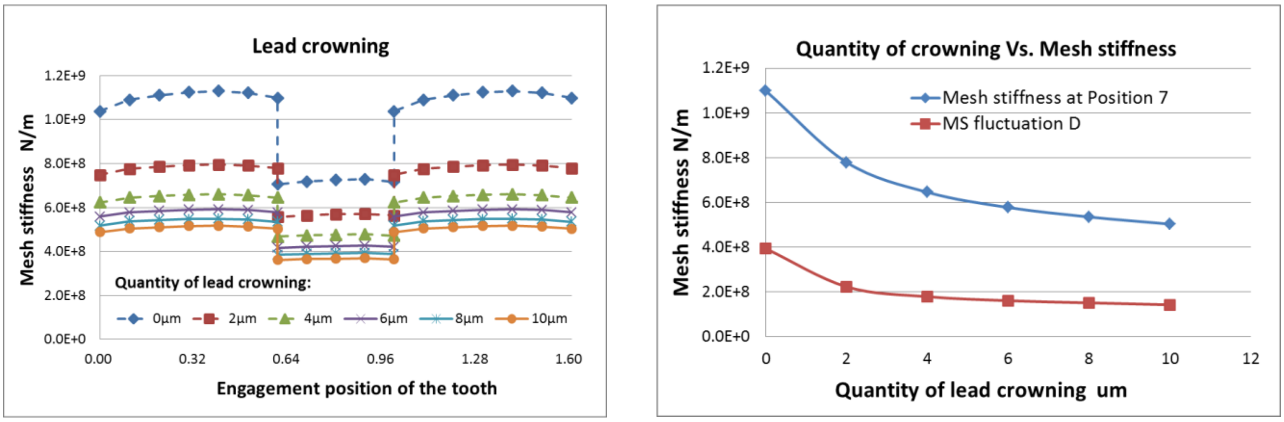
Fig.13 Contact stress distributions of the pair of gears with tooth profile modification at Position 6

8. Effect of the lead crowning on tooth MS

In the last research [12], effects of the lead crowning on tooth CS, root bending stresses and LSR were investigated. Since the effect of the lead crowning on tooth MS was not investigated in the last research, this paper investigates it here.

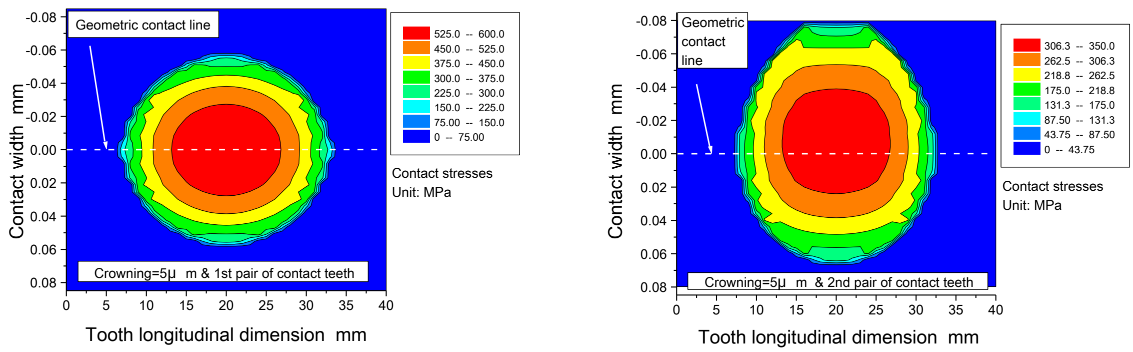
Figure 14(a) is a comparison of tooth MS curves between the ideal gears and the pair of gears with lead crowning. In Fig. 14(a), the maximum quantities of the lead crowning are also illustrated. In Fig. 14(b), the relationships among MS value at Position 7, the fluctuation *D* and the maximum quantity of the lead crowning are illustrated at the same time. From Fig. 14, it is found that MS value and the fluctuation *D* become smaller when the gears have the lead crowning and the maximum quantity of the lead crowning becomes larger. This is because tooth contact patterns are changed by the lead crowning from a uniform contact along the longitude as shown in Fig. 8 into a local contact at the tooth centers as shown in Fig. 15. The local contacts make the tooth loads concentrate on the local areas of tooth centers and then larger contact deformation happened than the uniform contact.

Figures 15(a) and (b) are tooth CS on the first and the second pairs of contact teeth respectively when the pair of gears engages at Position 6 and the maximum quantity of the lead crowning is 5μm.



(a) MS curves under different quantities of lead crowning (b) MS values versus quantity of lead crowning

Fig.14 Effect of the lead crowning on tooth MS



(a) CS on the first pair of contact teeth (b) CS on the second pair of contact teeth

Fig.15 Contact stress distributions of the pair of gears with lead crowning at Position 6

9. Effect of the lead relieving on tooth engagements

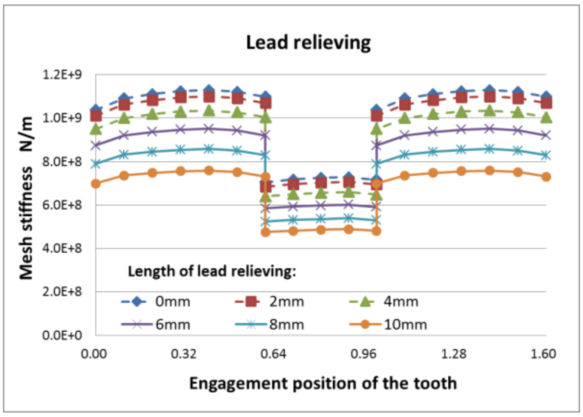
Lead relieving was used for spur gears very early in order to reduce tooth side heavier contacts resulted from the misalignment errors of gear shafts. So, effect of the lead reliving on tooth engagements is investigated here through performing LTCA, MS, LSR and CS calculations. When to do this investigation, the lead relieving is made only for the pinion using method illustrated in Fig. 2(c). Also, the reliving quantity of the pinion is fixed at 15μm and the relieving length is varied among 2 to 10mm. Calculation results are given in the following.

Figure 16(a) is a comparison of tooth MS curves between the ideal gears and the pair of gears with lead relieving. Figure 16(b) is the relationships among MS value at Position 7, the fluctuation *D* and the reliving length. From Fig. 16, it is found that MS value and the fluctuation *D* become smaller when the pinion is relived and the reliving length becomes longer. This is because the lead relieving changed the tooth contact pattern from a full length contact along the longitude as shown in Fig.8 into a partial length contact at the tooth center as shown in Fig. 18. The partial length contacts make tooth loads concentrate on the partial length area and then larger contact deformation happened than the full length contact.

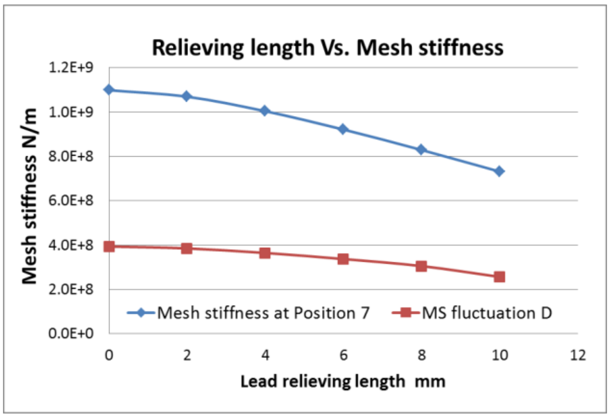
Figure 17 is LSR comparison between the ideal gears and the pair of gears with the lead relieving. In Fig. 17, the reliving length is also illustrated. From Fig. 17, it is found that the lead relieving length has no effect on LSR of the gears. This is because the tooth contact lengths both of the first pair of contact teeth and the second pair of contact teeth are changed at the same time by the lead reliving. Since the effects of the lead reliving on the first pair of contact teeth and the second pair of contact teeth are the same, the lead reliving cannot change LSR of the contact teeth.

Figures 18(a) and (b) are tooth CS distributed on the first and the second pairs of contact teeth respectively when the pair of gears engages at Position 6 and the relieving length of the pinion is 10mm. By comparing Fig. 18 with Fig. 8, it is found that tooth CS distribution patterns are changed greatly. Also, the maximum CS and the contact width of the contact teeth become much greater when the pinion is lead-relieved.

In Fig. 18, it is also found that edge-loads happened at the joint part of the relieved part and the non-relieved part of the tooth lead. Since greater contact stresses happened at the joint part, it is necessary to reduce the edge-loads as small as possible through making the joint part smooth when to relief the tooth lead.



(a) MS curves versus quantities of lead relieving



(b) Mesh stiffness versus length of lead relieving

Fig.16 Effect of the lead reliving on tooth MS

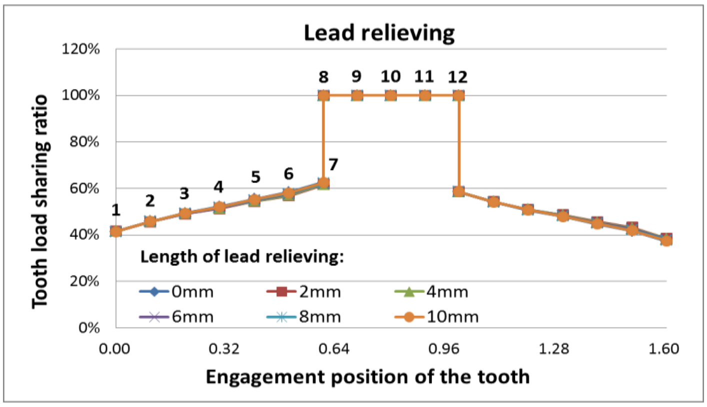
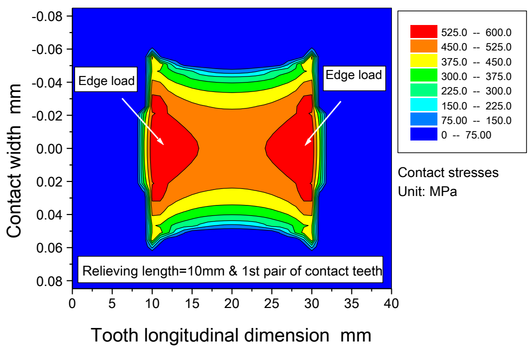
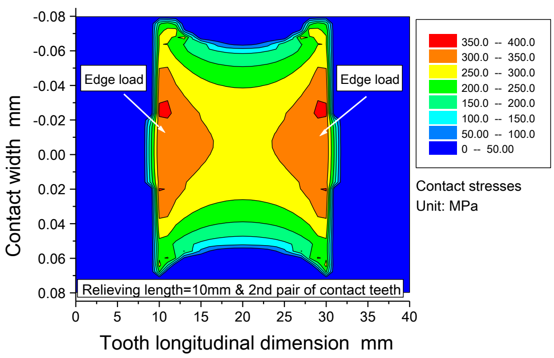


Fig.17 Effect of length of the lead relieving on the LSR



(a) CS on the first pair of contact teeth



(b) CS on the second pair of contact teeth

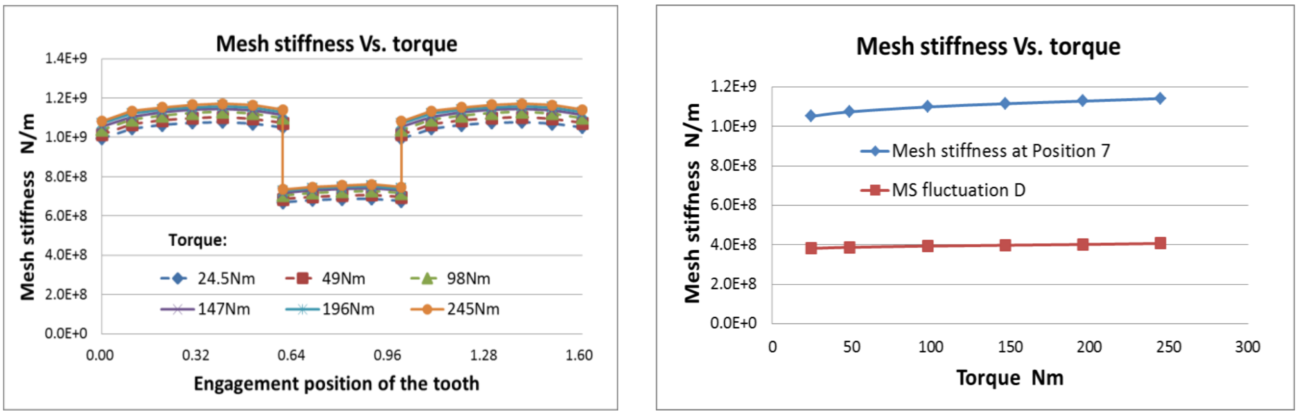
Fig.18 Contact stress distributions of the pair of gears with lead relieving at Position 6

10. Effect of transmitted torque on the MS and LSR

Tooth MS of a pair of gears is an important factor to affect dynamic behavior of the pair of gears. Of course, it is necessary to know value of tooth MS in advance if vibration analyses are made for a pair of gears or a geared mechanical system. Though there are many researches on tooth MS analyses of a pair of gears, very a few investigated the relationship between tooth MS and transmitted torque. This is because it is a difficult thing to do this investigation if a face-contact model of the contact teeth as shown in Fig. 3 is not used. So, this paper conducts this investigation here using the face-contact model of the contact teeth and FEM. Calculation results are given in the following. The similar research was also conducted by Kiekbusch et al [21]. Since different method was used by Kiekbusch, a different expression method is used for calculation results of tooth MS.

Figure 19(a) is MS curves of the ideal gears under several different torque loads. Figure 19(b) is a relationship between MS at Position 7 and the torque loads. The relationship between the fluctuation D and the torque load is also illustrated in Fig. 19(b). From Fig. 19, it is found that MS value is increased a little when the transmitted torque becomes larger. This is because contact area of the contact teeth becomes larger when a larger tooth load is applied. So, the load per unit area becomes smaller and then the total contact deformation of the contact teeth becomes smaller when the torque is enlarged.

Figure 20 is LSR curves calculated under several different torque loads. From Fig. 20, it is found that the torque load has no effect on LSR of the contact teeth. This is because the enlarged torque has the same effect on tooth contact of the first and the second pairs of contact teeth. So, the enlarged torque cannot change LSR of the contact teeth.



(a) MS curves under different torque loads (b) MS values versus torque loads

Fig.19 Effect of the transmitted torque on tooth MS

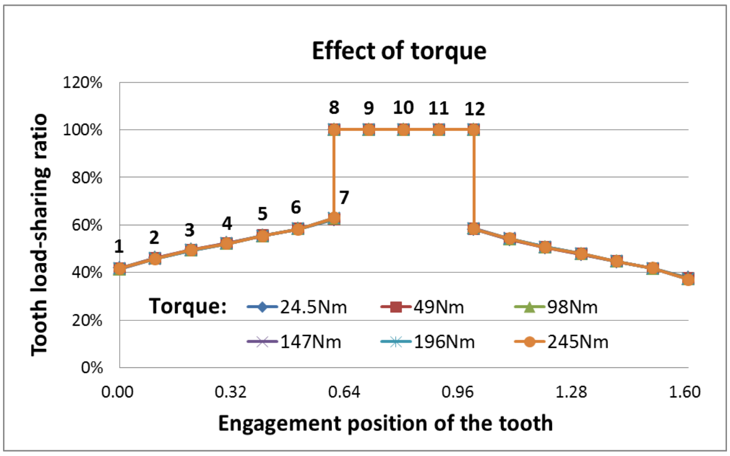


Fig.20 Effect of the transmitted torque on the LSR

11. Conclusions

The effect of tooth profile modification, lead relieving and transmitted torque on tooth contact stresses, load-sharing ratio and mesh stiffness of a pair of spur gears are investigated in this paper. The effect of misalignment errors of the gear shafts on the plane of action and lead crowning on tooth mesh stiffness are also investigated.

It is found that the tooth profile modification has significant effects on tooth load-sharing ratio and mesh stiffness. The contact of two pairs of contact teeth at the double pair tooth engagement positions can become the contact of one pair of contact teeth when the tooth profile modification is great.

It is found that the lead relieving has no effect on load-sharing ratio of the gears, but it shall reduce tooth mesh stiffness very much. The research results also show that though the lead relieving is used to reduce tooth side heavier contacts resulting from the misalignment errors, but it also brings edge loads at the joint parts of the relieved part and the non-relieved part of the tooth lead. It is necessary to reduce the edge-loads as small as possible through making the joint part smooth when the lead relieving is made.

Finally, it is found that tooth mesh stiffness of the contact teeth becomes a little great when the torque load is enlarged, but the fluctuation of the mesh stiffness curve has not been changed even if the torque load is enlarged greatly.

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