Design and Stress Analysis of Face Gear Drive in Automobile

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ABSTRACT:

In automobiles, Gear drive failures are the major consequence which causes break downs; this can be optimized by newdevelopments in design, and stress analysis of gear drives. The main contents of the paper are: (i) identification of transmissionerrors for the reduction of noise, (ii) modifying the basic algorithm of tooth contact analysis, (iii) stress analysis of the modifiedfacegeardrive.

Keywords:Transmissionerrors,Localsynthesis,Bearingcontact,Toothcontact analysis,Stressanalysis.

INTRODUCTION:

Theory, design, simulation of meshing, generation and stressanalysis was the subject of research of many distinguishedscientists and leading gear companies. The extended list ofreferences relates the contents of the paperwiththe basicdevelopmentoftheoryofgearing,differentialgeometry,designandmanufacturingofgeardrives,and stressanalysis.

Thecontentsofthispapercoverconceptuallythelatestdevelopments accomplished by the authors that represent ateam of researchers united by the same methodology. Thedevelopedapproachisbasedonapplicationof(i)modificationofgeometryofgears,(ii)applicationofamodified toothcontact analysis (TCA) algorithm, and(iii)application of an enhanced approach for application of thefinite element method to stress analysis [1]. The main topicsofthepaperare:

Reduction OfNoiseOfGearDrives:

The reduction of noise is achieved by application of a predesigned parabolic functionof transmissionerrors. Suchafunctionisabletoabsorbdiscontinuedlinearfunctionsoftransmissionerrorswithalargemagnitudeofmaximaltransmissionerrors.Thediscontinuedfunctionsoftransmission errors are caused by errors of alignment such aschange of shaft angle, center distance of some spatial geardrives, errors of machine-tool settings, etc. The advantage ofapplicationofapredesignedparabolicfunctionoftransmission errors is confirmed by simulation of the noisecausedbytypicalfunctionoftransmissionerrorsofmisaligned gear drives [5]. This can be achieved ahead of themanufacturingofadesignedgeardrive.

Modified TCAApproach:

The proposed modification of TCA is based on an algorithmfordeterminationof guess values forthe starting point oftangencyofmatingsurfaces.Theguessvaluesmaybedeterminedconsideringonlyasknownatthestartofcomputationthemachine-toolsettingsusedforgeargeneration [1]. Then, it becomes possible to develop a TCAprogramforsimulationofmeshingofmanufacturedgears.

Enhanced Approach For Application Of FEM ToStress Analysis:

The enhanced approach for application of the finite elementmethodtostressanalysisisbasedonapplicationofacontactingmodelformatinggearsdevelopedbyusingan alyticalrepresentationoftoothsurfaces.Thisallowsavoidingcodesforthenumericaldevelopmentofthecontacting model[2]. The stress analysis is complementedwith investigationof formationof the bearing contact andEnhanceddesignof,face-geardrives.

Theappliedenhanceddesignofgeardrivescovers:

(i) Design of low noise spiral bevel gears that is based onapplicationof:(a)combinationoflocalsynthesisandTCA;
(b) modified roll and modification of geometry of generatingtool;(c)anapproachforreductionofnoise.

(ii) Basic concepts of design and analysis of face-gear drives,and a new approach for generation of face-gears by grindingandcutting(applyingforthispurposeawormofspecialshape).

(iii) Modification of geometry of helical gears with parallelaxes thatisbasedon:

(a)Localizationofbearingcontactby substitutionof linecontact of tooth surface by point contact; (b) generation ofgears by a plunging disk or bya worm (hob) that enables toreducethenoiseandimprovethebearingcontact;

(c)ApplicationofTCAforanalysisofmisalignedgeardrives.

2.0FUNCTIONSOFTRANSMISSIONERRORS:

It has been already recognized by researchers that the mainsource of noise and vibration are transmission errors. Sucherrorsarecausedby misalignmentof geardrivessuchaschange of shaft angle, change of center distance (for somespatialgeardrives),errorsofinstallmentofmachine-toolsettings,etc[5].TheresultsofTCAshowthattherealtransmissionfunctionofamisalignedgeardriveisapiecewiselinearfunctionof transmissionerrors.

The main idea of the authors forthe designof geardriveswith reduced noise is based on application of a pre designedparabolicfunctionoftransmissionerrors.Apredesignedparabolicfunctionoftransmissionerrorsabsorbs linear functions of transmission errors caused by misalignment andthisisthemainconditionofreductionofnoise.

The analysis of meshing may be performed in the followingsequence:

(i) derivationof gear toothsurfaces by using of the basicmachine-toolsettingsappliedforsurfacegeneration;(ii)approximate determination of a contact point, used as a guessvalue forTCA; (iii) development of TCA and analysisofmeshing.

TOOTHCONTACTANALYSIS:

IntroductoryRemarks

Structure of Face Gear Tooth. The tooth surfaces Σ2 of theface-geargeneratedbyaninvoluteshaper.LinesSL2representtheinstantaneouslinesoftangencyofΣ2.andshaper Σ1 shown on Σ2. Investigation shows that the surfacepoints of the face-gear are hyperbolic ones. This means thatthe productof principalcurvaturesatthe surface pointisnegative.Thefilletoftheface-geartoothsurfaceofaconventional design is gene rate d by the edge of the shape r.The authors have proposed to generate the fillet by a roundededge of the shaper as shown in Fig. 4 that allows the bendingstresses to be reduced approximately in10%. The shape ofthe modified fillet of the face gear is shown in Fig. 1. Thelength of the face-gear teeth has to be limited by dimensionsL1 and L2: (i) undercut in plane A, and (ii) tooth pointing inplane B [9]. The permissible length of the face-gear tooth isdeterminedbytheunitlesscoefficientcrepresentedasm.

C=(L2-L1)Pd=L2-L1/m

Where Pd and mare the diametric pitchand the module,respectively. The magnitude of coefficient c depends mainlyonthegear

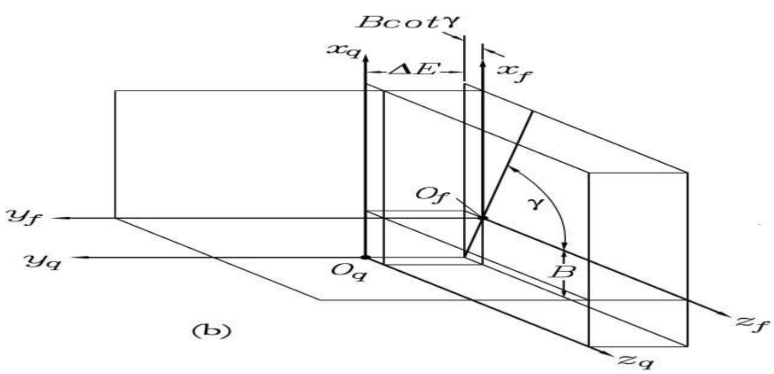

Fig.1Coordinatesystemsappliedforsimulationofmeshing:(a)CoordinatesystemsSq, Sd,Se

M12=N2/N1andisusuallyintherange 8< c <15.

Results of TCA (Tooth Contact Analysis): TCA is designatedfor simulation of meshing and contact of surfaces Σ1 and Σ2and permits the investigationof the influence of errors ofalignmentontransmissionerrorsandtheshiftofbearingcontact [9]. The TCA algorithm is based on observation ofcontinuous tangency of pinion and face-gear toothsurfacesΣ1 andΣ2. Application of the TCA program indicate s: (i)errors o f alignment do not cause transmission errors, but (ii)causetheshiftofbearingcontact.Theadvantageof zerotransmission errors is the result of application of an involutespinionthathasequidistantprofiles.Thesensitivity ofthebearing contact of the face gear drive to errors of alignmentrequires special corrections to obtain a central location of thebearing contact. It has been proven that this can be obtainedby axial displacement Δ q of the face-gear with respect to thepinion.Theinvestigationisbasedonapplicationofcoordinate systems. Coordinate systems S1 and Sf are rigidlyconnected to the pinion and the frame of the face-gear drive,respectively [19]. To simulate the misalignment of the face-gear, we use auxiliary coordinate systems S_q, S_d and S_e. Thelocation of q S with respect to f S is Parameters ΔE, B andBoth determine the location of the originO_q with respect toO_f. Here, ΔE is the shortest distance between the pinion andtheface-gearaxeswhentheaxesarecrossedbutnotintersected.

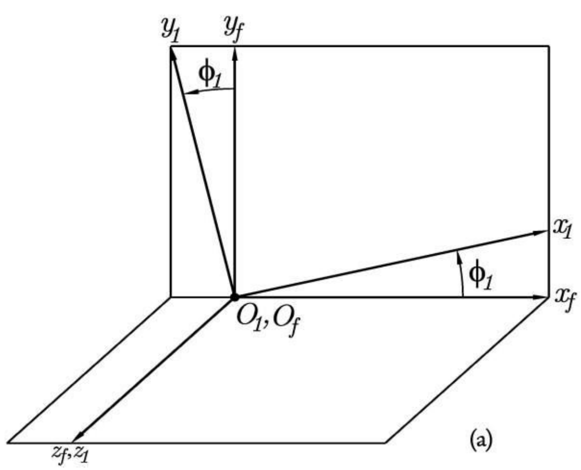

Fig.2Coordinatesystemsappliedforsimulationofmeshing:CoordinateSystems S_2,S_e

Auxiliary fixed coordinate systems S_q, S_d and S_e are shownTheface-gearperformsrotationabouttheezaxis.ThelocationofSewithrespecttoS$_d$simulatestheaxialdisplacementΔqofth eface-gear(Fig2).

ENHANCEDAPPROACHFORSTRESSANALYSIS

ApplicationOfTheFiniteElementAnalysis(FEA)Enables:

(1) Determinationofcontactandbendingstresses forthepinionandthegear.

(2) Investigationofformationofbearingcontacttakingintoaccountthatthemeshing

istransferred fromonepair ofteethtotheneighboringone.

(3) Detectionandavoidanceofareasofseverecontactstresses.

Applicationofthefiniteelementmethodrequiresthedevelopment of the finite element model formed by the finiteelement mesh, the definition of contacting surfaces, and theestablishment of boundary conditions to load the gear drivewith the desired torque. The authors apply a general purposecomputer program to perform the finite element analysis. Anenhanced approach for application of finite element analysishas been used for design of gear drives. One of the main ideasoftheappliedFEAapproachistheautoimmunizationofderivationof the contacting modelof gearteethby directapplicationoftoothsurfaceequations[7].Thisapproachenablestodeterminecontactandbendingstressesfort hewholecycleofmeshing,investigatetheformationofthebearing contact and determine, if they exist, hidden areas ofsevere contact wherein the contact stresses are substantiallyincreased.

5.0DESIGNOF FACEGEARDRIVES:

5.1.Introduction

A face gear drive is formed by a spur or helical gear and aconjugated gear with tooth located on the gear “face” (Figure13).Themanufacturingoffacegeardrivesbasedonapplicationofashaperhasbeeninventedbythe FellowCo rporation. The shaper is identical to the pinion of the drive,but the numberof shaperteethis increased in comparisonwith the pinion teeth for the purpose of localization of bearingcontact[5]. The contributions to the design, simulation ofmeshing,stressanalysis,andmanufacturingofface-geardrives. The contents of this section cover: (i) development ofnew geometry of face-gears, and (ii) generation of face-gearsby grinding or cutting (by application of a tool similar to aworm of a special shape.Results of TCA fortoothdrivingsideforpreviousdesign:(a)and(b)contactpatternandcontactpathonthegearandpiniontoothsurfa ces,respectively;(c) functionoftransmissionerrors(Fig.3).

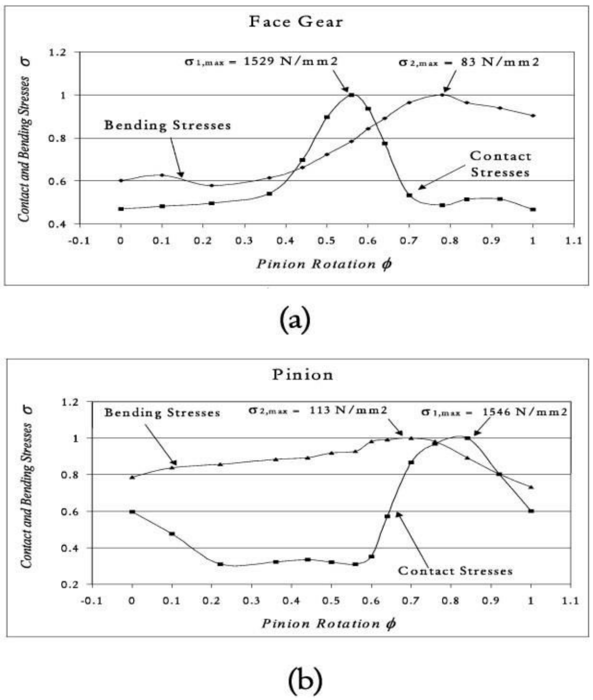

Fig3:Variationoffunctionsofcontactandbendingstressesduringthecycleofmeshingfor(a)theface-gearand (b)thepinion

Generation of Face-GearBy AShaper

For the purpose of localization of contact and even avoidanceofseparationofpinionandface-geartoothsurface(inamisaligned gear drive), the tooth number Ns of the shaper islargerthanthetoothnumberNpofpinionteeth,whereNs −Np=2/3.

5.3.ConventionalDesignofFace-GearDrives

Theconventionaldesignofface-geardrivesisbasedonapplicationofinvoluteprofilesofthepinionandtheshaper.[6]Thelimitationsofsuchdesignare:

(i) Appearance of singularities of tooth surface of the face-gear (it is the herald of the oncoming undercutting of the face-gear).(ii)Pointingofface-gearteeth.(iii)Limitationofparameters L1 and L2 to avoid undercutting and pointing,respectively(Fig4).

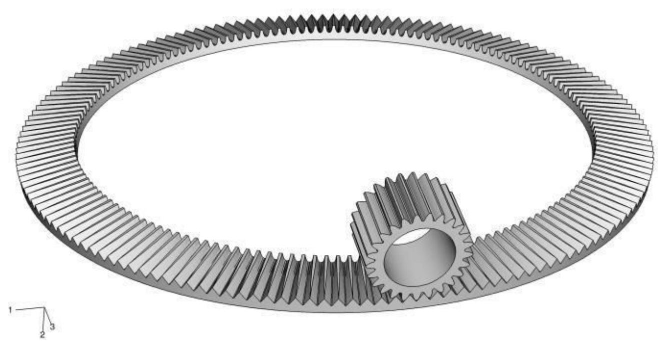

Fig4:Illustration ofWholegeardrivemodel

(iv) ResultsofTCAshowthat:(1)thepathofcontactisdirected across the tooth surface, and (2) errors of alignmentmay cause the shiftof the bearing contactand evenedgecontact.

(v) The advantage of application of involute profiles for theshaper and the pinion is that errors of alignment do not causetransmission errors. A new version of geometry of face-geardrives has been recently developed that enables to obtain alongitudinalbearingcontact.Aparabolicfunctionoftransmission errors of limited magnitude has to be providedfor a misaligned gear drive. The new version of geometry isbasedonapplicationof profiles (of pinionand shaper)thatare conjugated to parabolic profiles of imaginary parabolicrack-cutters [7]. Sb, and Sc are applied for illustration forinstallment of the worm with respect to the shaper. Axes zsand zw are the axes of rotation of the shaper and the worm,respectively,and they formacrossing angle of 90%.Theupper (and lower) sign correspond to application of a right-hand(left-hand)worm**.**

6.0CONCLUSION:

Based on the results of the performed research, the followingconclusionsmaybedrawn:

(1) Applicationofapredesignedparabolicfunctionoftransmission errors enables to reduce the noise and vibration.This statement is confirmed by computerization of noise of amisalignedgeardrive.

(2) Effectivemethodsof developmentofTCAhavebeendeveloped.

(3) Enhanced approaches for computerized design, simulationofmeshing,andstressanalysishavebeendevelopedfor:face-geardrives

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