SVU-International Journal of Engineering Sciences and Applications (2022) 3(2): 131-136
Print ISSN 2785-9967| Online ISSN 2735-4571
DOI 10.21608/svusrc.2022.156724.1065

Stress Analysis of Gear Pair Faults Using FEM

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Abstract: Gear Fault Detection is a significant issue with many rotating machines that are connected to a gearbox. Damage that is not detected in a timely manner can result in serious machinery damage, catastrophic injuries, and significant financial losses. The purpose of this paper is focused to study the stress generated on the contact surfaces of gear pair. The case study of a gear (with 75 teeth) and pinion (with 25 teeth) from Alloy steel are analyzed using theoretical Von-Mises's equation using finite element method under static conditions using software package SOLIDWORKS. The contact stress between the gear tooth pair's engagement impacts the gear's ability to transmit power. So, the thesis studies the stresses on different faults on the same boundary condition.

Keywords: Condition monitoring, Gearbox, Gear fault, Stress analysis, Simulation.

1 Introduction

In power transmission system, a gear drive is performed when the distance between the driver and the driven shafts is very small. In precision machines, in which low slipping effect leads to reduce the velocity ratio of the system. The standard meshing and the ideal installation of the gears has not produced any vibration pluses. Fluctuations from these standards generate distinctive vibration signals whose help in monitoring the gearbox malfunctions. The main sources of these fluctuations are crack tooth, chipped tooth, missing tooth, the surface wear during heat treatment or gearbox assembly, and the geometrical errors, resulting from the gear cutting process and wear [1], [2].

Condition monitoring can help to save money by increasing maintenance efficiency and lowering the risk of serious accidents through the prevention of breakdown [3], [4]. Gear transmissions system is one of the most common in rotating machinery, which are used to transmit torque between shafts. Failure in gears could affect the overall operation of the machine [5]. The monitoring is carried out for several purposes to characterize the emitted sound, diagnose faults in running machinery's gearboxes and check correctness of gearbox assembly after manufacturing for identifying problems if any, before clearing it for use in any vehicle or machine [6], [7]. Also, the effect of bearing defects on vibration is modeled using simulation method [8]. Diagnosis of an antifriction bearing malfunction is a major factor in transmission system validity condition, especially the fault must be discovered in its initial stages [9], [10]. The localized and distributed defects are likely to be produced from manufacturing processes and abrasive debris. A mathematical model was established to detect the defect on the bearing. The results showed that, the amplitude level of vibration signals was produced from outer race defect is more than that for the inner race defect [11], [12]. FE Dynamic model considers a suitable method used to diagnosis the bearing defects of different sizes in the bearing [13].

A model-based gear fault detection method is preferable

Received: 16 August 2022/ Accepted: 3 September 2022
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to identify the gear defects using transmission error. A parametric model of a gear model was established to estimate the transmission error [14]. Finite element analysis via ABAQUS is created to estimate the influence of shaft misalignment and backlash on the stress generated on the spur gear [15]. Malfunction belt drive system monitor and detect using vibration analysis techniques [16]. The belt drive experimental equipment was performed to obtain realistic vibration signals under different operating conditions. The pulley-belt system faults like unbalance, misalignment and mis-cogs, that dedicated by vibration analysis technique [17], [18]. The unstable belt transmission was studied via the perturbation solution under assumptions of the forces applied is the same on the stick-slip regions. It can be observed that the results showed a good agreement with numerical solutions [19], [20]. The results of statistical parameters explained the effect of each type of faults comparing with the ideal system conditions. A numeric model of the belt drive system is established using ABAQUS to study the system transmission error under unsteady operating conditions [21]–[23].

Complete machine shutdown and disassembly is often required [24]. Another disadvantage of scheduled maintenance, or predictive maintenance, is that it tends to replace machines that may continue to function for several years [25]. Generally these structural alterations are the result of mechanical or thermal stress that has been applied either internally or externally [26]. Gear defects can be detected using a process called AE analysis, which requires the transmission signal path to be as short as possible. In order to make sure an accurate assessment of the short-time excitations in the frequency domain, we must do additional analysis by using wavelet techniques [27]. Acoustic emission (AE) has long been recognized as a highly effective method for non-destructive monitoring and damage detection. To control the wear process, an early detection system must be used as well as a system to monitor the size, amount, and appearance of wear debris particles in the machine's lubricating oil [28], [29]. A variety of on-line methods are available for oil debris monitoring [30], [31]. Some of the principles of the various methods are Ferrography [32], [33]. ultrasonic [34]. and X-ray fluorescence (XRF) [35]. Temperature monitoring is comprised of the measurement of the operational temperature as well as the temperature of component surface temperatures. It is possible to think of monitoring operational temperature as a subset of the operational variables for performance monitoring [36], [37].

Thus, this work aims to study the generated stresses on contact surfaces in case of healthy and defected spur gears. This step is important to help and illustrate the effect of defects on the generated stresses on the gear pair and stand on using validation of the defected spur gears. And the finite element model can predict contact stress.

2 FE Model Creation

Healthy and defected spur gears are performed using CAD (SOLIDWORKS 2020) software with specification as shown in **Table 1**. **Figure 1** presented the model of the used spur gears with its mate. The gear pair material properties are showed in **Table 2**.

Table 1 Specification of the gear and pinion

	Gear	Pinion
Number of teeth	75	25
module	2	2
Pressure angle	20°	20°
Face width	15 mm	15 mm
Centre distance	101.543	
Material	Alloy steel	

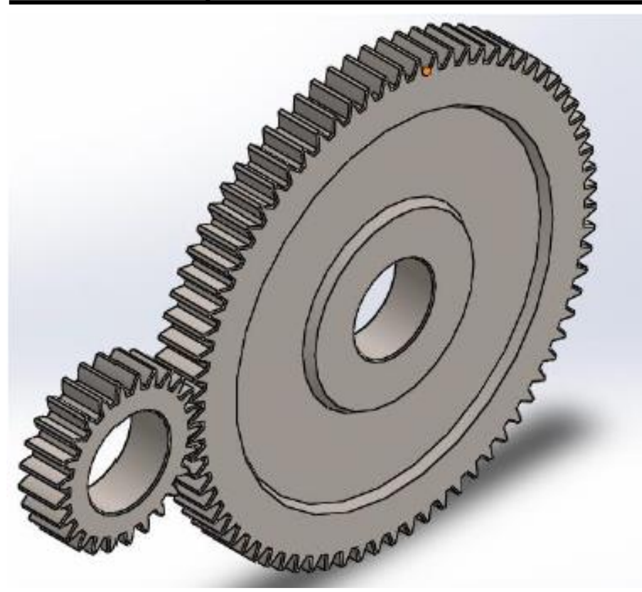

Fig. 1 Model of the healthy spur gear and Alloy steel properties

Finite element analysis of the healthy and defected spur gears is accomplished using SolidWorks simulation package. The static study analysis is performed on the models of the healthy and defected spur gears with turning the pinion 5° and boundary conditions as shown in **Fig. 2** set material Alloy steel to all bodies and set the connection between gear and pinion is no penetration this option allows two or more faces to touch and develop contact forces, as well as move away from each other. It does not allow the two faces to flow into each other and take up the same space together and set the gear as fixed geometry and the pinion on cylindrical faces with 5° clockwise. Solid mesh is used as meshing element types as **Fig.3** presented.

Table 2 Material Properties of the gear and pinion

Property	Value
Elastic Modulus (N/mm^2)	210000
Poisson's ratio	0.28
Shear Modulus (N/mm^2)	79000
Mass Density (kg/m^3)	7700
Tensile strength (N/mm^2)	723.83
Yield strength (N/mm^2)	620.42
Thermal Expansion Coefficient (/K)	1.3e-5
Thermal Conductivity (W/m.K)	50
Specific Heat (J/kg.K)	460

Moreover, node number and element number were 38017 nodes and 21514 elements, respectively. The model of defected gear and pinion are showed in **Fig 4**, which are created with same boundary condition. While the model 4 of defected gear and defected pinion. Moreover, finite element model of offset misalignment fault is performed. The model of negative offset misalignment is created with same boundary condition and center distance = 101.323 mm. The model of positive offset misalignment is created with same boundary condition and center distance = 101.848 mm. On the other side, finite element model of the angular misalignment showed in **Fig 5**, which is created with same boundary condition and with 30° between the gear and the pinion.

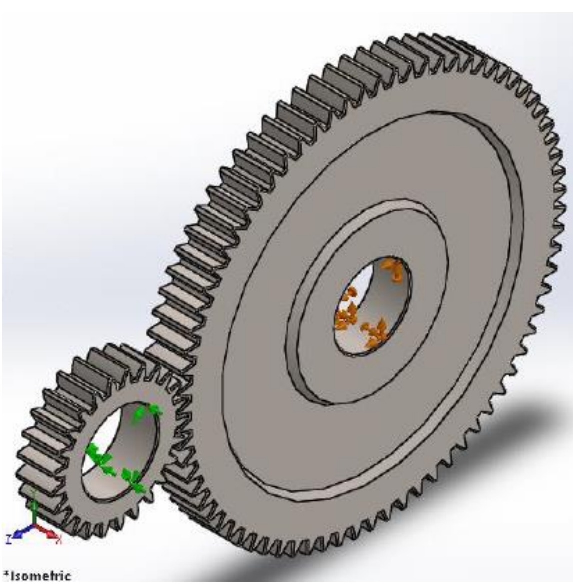

Fig. 2 The boundary condition of spur gear model.

Maximum distortion energy (Von-Mises) theory was studied on the selected model of the spur gear to find the generated stresses on the gear.

Von-Mises's theory formula:

$$\sigma' = \sqrt{\frac{(\sigma_x-\sigma_y)^2+(\sigma_y-\sigma_z)^2+(\sigma_z-\sigma_x)^2+6(\tau_{xy}^2+\tau_{yz}^2+\tau}{2}}$$

Where:
σ' = Von-Mises effective stress
σ_x = equivalent normal stresses in X axis
σ_y = equivalent normal stresses in Y axis
σ_z = equivalent normal stresses in Z axis
τ_{xy} = equivalent shear stresses in X direction
τ_{yz} = equivalent shear stresses in Y direction
τ_{zx} = equivalent shear stresses in Z direction

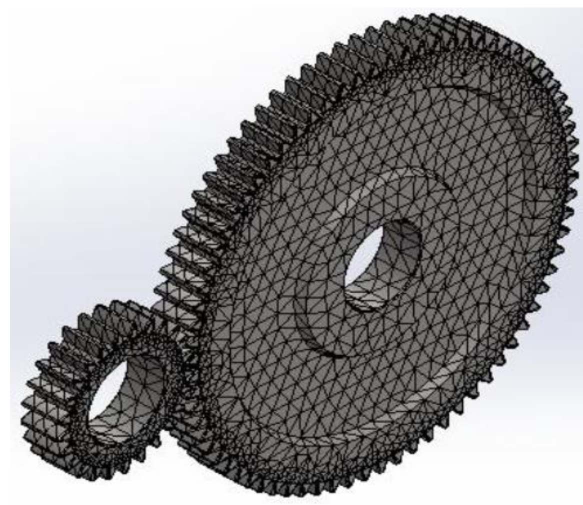

Fig. 3 The meshed model of spur gear

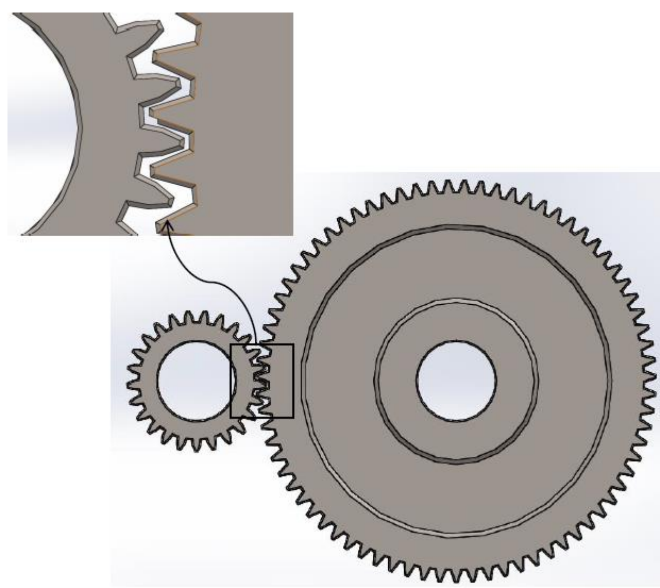

Fig. 4 Model of defected gear

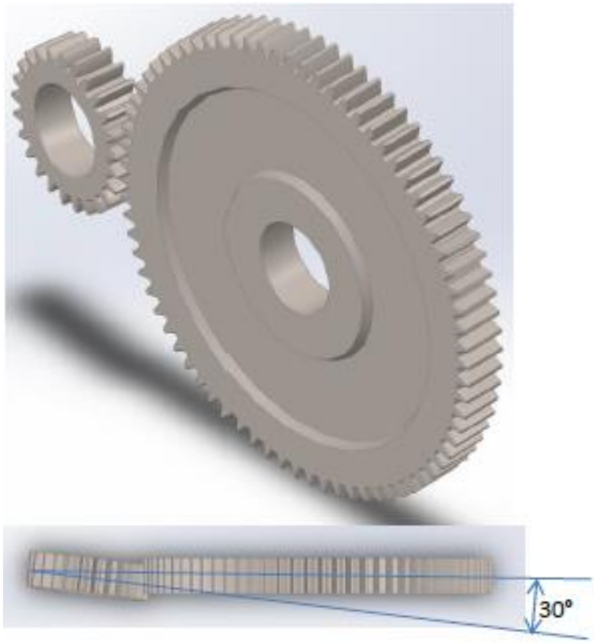

Fig. 5 Model of gears with angular misalignment

3 Finite element analysis

Via FEA, it was found that the maximum generated stress, in case of the healthy spur gears, was on the pinion tooth with value of 13430.438 MPa as shown in Fig. 6. In case of the defected gear, it was found that the maximum generated stress on the pinion tooth was 13522.573 MPa as shown in Fig. 7. FEA of defected pinion (pinion fault), it can be notice that the maximum generated stress on the pinion tooth was 14081.852 MPa as shown in Fig. 8. Moreover, in case of defected gear and defected pinion, the maximum generated stress on the pinion tooth was 14197.991 MPa as shown in Fig. 9.

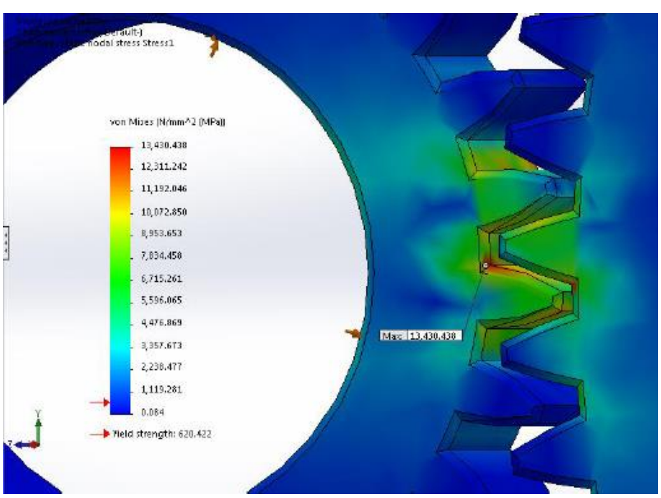

Fig. 6 generated stresses on healthy spur gears

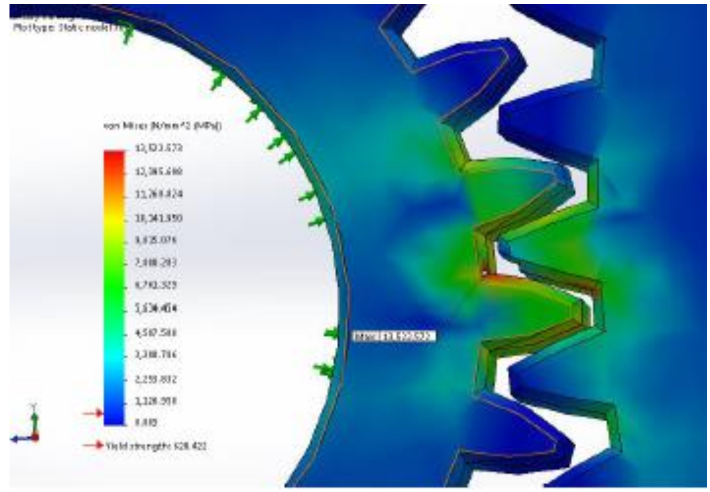

Fig. 7 generated stresses on the gear fault

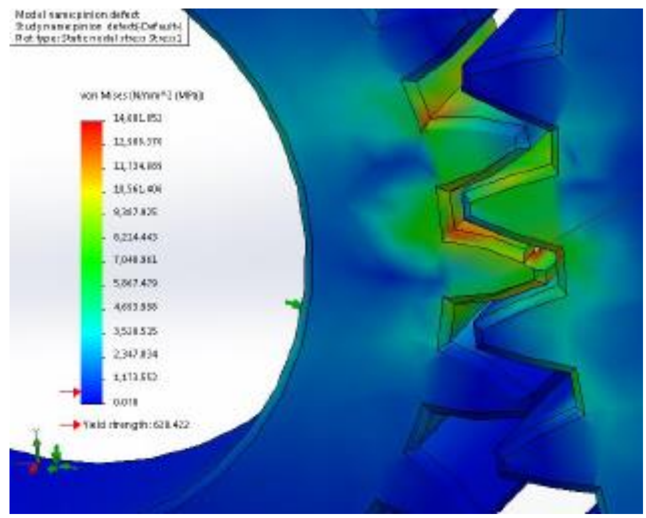

Fig. 8 generated stresses on the pinion fault

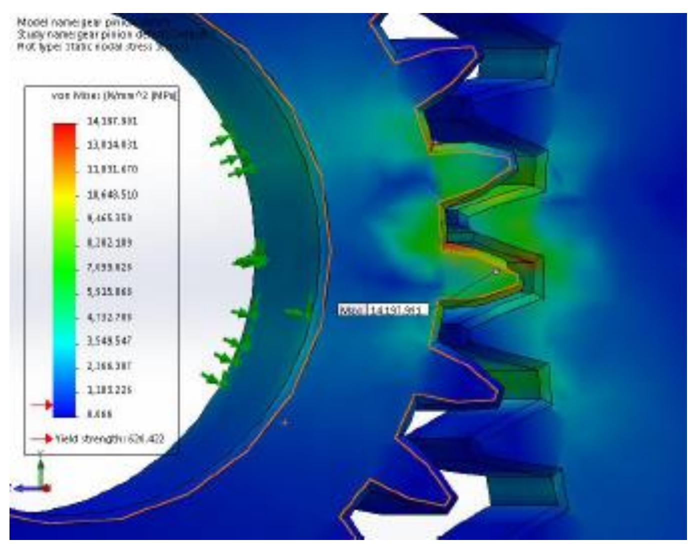

Fig. 9 generated stresses on the gear and pinion fault

Finite element analysis of negative offset misalignment fault is performed. It was observed that, the maximum generated stress on the pinion tooth was 14237.682 MPa as shown in **Fig. 10**. Also, finite element analysis of positive offset misalignment fault is applied. It was found that, the maximum generated stress on the pinion tooth was 12002.474 MPa as shown in **Fig. 11**. The generated stresses on the gears in the case of positive oddest misalignment were smaller than the generated stresses in the case of negative offset misalignment fault and smaller than healthy gear. However, finite element analysis of angular misalignment fault is performed. It was displayed that, the maximum generated stress on the pinion tooth was 15651.054 MPa as shown in **Fig. 12**.

The stresses of all defective cases are greater than those of healthy gears, except for the positive offset misalignment fault, as shown in **Fig. 13**, implying that all defected instances required higher energy to drive the gear system with its defects

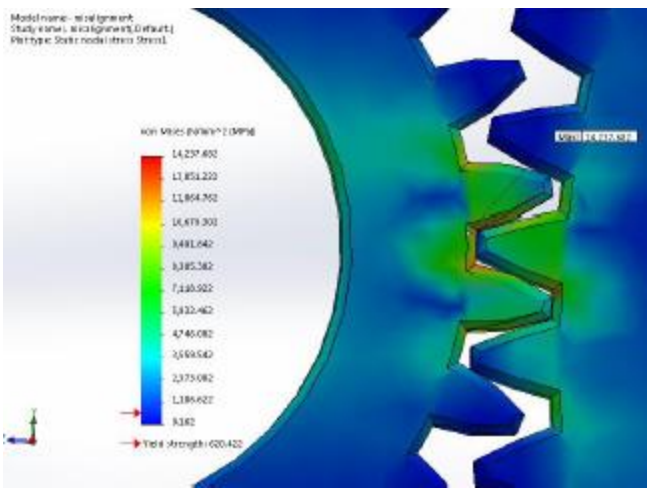

Fig. 10 generated stresses on the gears with negative offset misalignment fault.

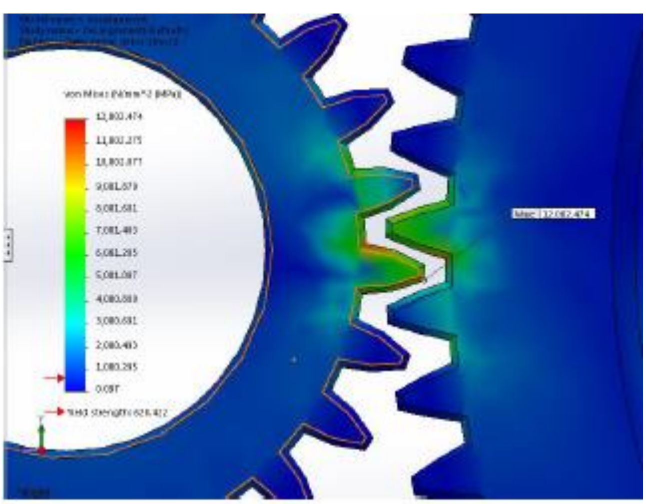

Fig. 11 generated stresses on the gears with positive offset misalignment fault.

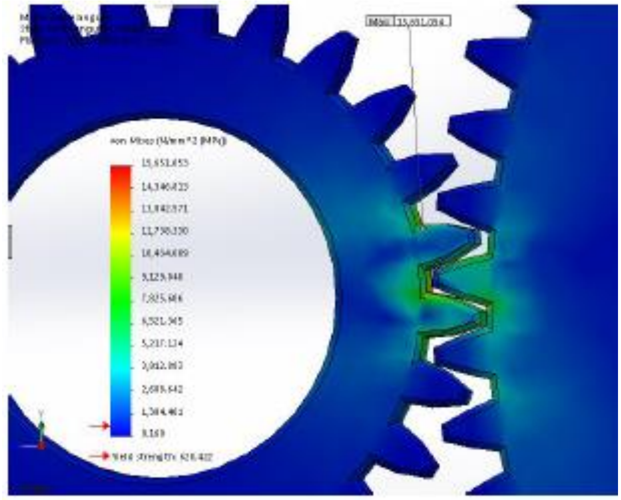

Fig. 12 generated stresses on the gears with angular misalignment fault.

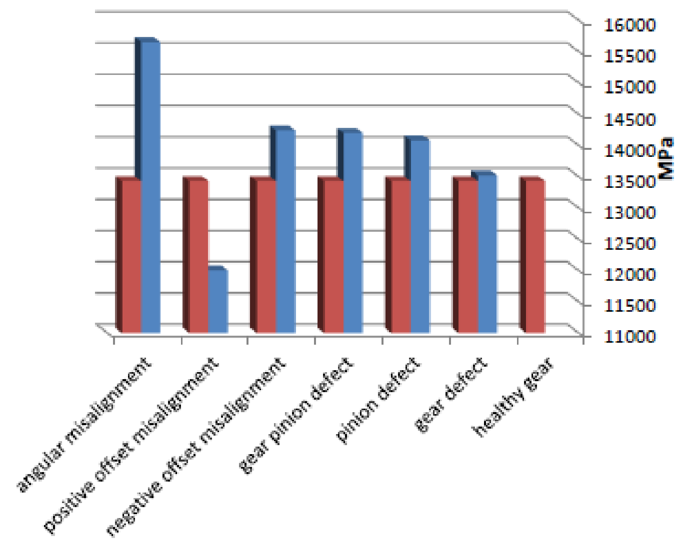

Fig. 13 Comparison stresses: the healthy gears with all pair of gears with faults.

Conclusions

Based on the results from the numerical treatment using SolidWorks, the following conclusions can be drawn:

- The finite element analysis can predict contact stress.
- The stress distribution along the gear flank can be achieved from simulation.
- The maximum stress decreases with the increase of the contact width.
- The peak of the maximum stress is positioned in

the tooth root, and it will be shifted with a certain value as the contact width increases due to shaft misalignment.

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