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Research on the meshing stiffness and vibration response of fault gears under an angle-changing crack based on the universal equation of gear profile

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A B S T R A C T

Tooth crack is a non-negligible issue that causes the vibration response of a gearbox. Therefore, the operating status of the gearbox is always detected to remove the presence of dangerous situations. Therefore, the effect of a gear tooth crack on the vibration response of the gearbox is important for the gear condition monitoring. The accuracy of meshing stiffness analytical model is the basis for effective dynamic simulation; for this account, a universal equation of a gear profile that is in reference to the actual process of manufacturing is presented to improve the meshing stiffness model for a cracked tooth. Based on the actual gear profile, in theory, two affecting lines, the parabolic-affecting line (PA) and the straight-affecting line (SA), are introduced to study the effect of an angle-changing crack on the gear mesh stiffness. Afterward, the influence of the angle-changing crack on the vibration response is investigated both in the time domain and in the frequency domain.

1. Introduction

The variation of meshing stiffness could have a significant effect on the dynamic response of a gearbox. For the meshing stiffness calculation, due to its accuracy, FEA (Finite Element Analysis) is a widely used approach to calculate stiffness for gear modeling. However, it could be a tedious and time-consuming undertaking to simulate the engagement process using FEA [1–3]. Therefore, the more effective analytical methods, which show close consequence compared with FEA simulations, are used in this paper to investigate the behavior of gear dynamics.

Considering the axial compressive, bending, hertz stiffness, shear stiffness and by using the principle of potential energy, the meshing stiffness calculation method was proposed by Tian [4]. The theoretically precise calculation method of fill-foundation deflection, was originally proposed by Lewicki and Ballarini [5]. They studied the behavior of tooth crack propagation under different rim thicknesses: whether the cracks passed through gear teeth or through gear rims under changing rim thicknesses.

By using a precise calculation of the distribution for stressing and loading over the gear profile at any meshing point, the effect of proper modification of tooth cracks is investigated to study the meshing stiffness by Zhang et al. [6]. Then, the effect of different types of cracks on the dynamic responses was investigated by Chen and Shao [7] by taking the fillet-foundation stiffness into

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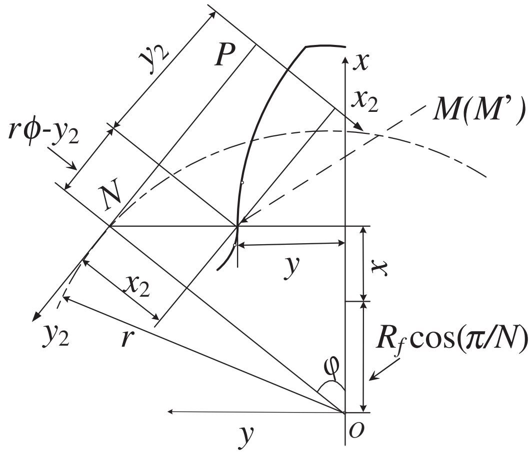

Fig. 1. Cutting process of gear tooth [15].

account. Nevertheless, the tooth profile between the base circle and the root circle was rarely considered. To solve this problem, an improved mesh stiffness calculating method was proposed by Wan et al. [8] by considering the misaligned behavior between the base circle and the gear root circle; however, the expression of equations should be changed by actual tooth numbers. Next, an improved method, which is in reference to the cutting process of a gear tooth, called the 'universal equation of gear profile', is proposed by Cui et al. [9] to calculate the stiffness between the root circle and the base circle precisely. In this paper, based on the rolling angle of cutting tools, the 'universal equation of gear profile' is also used to investigate the changing behaviors of meshing stiffness and vibration response of a gear system under different depths and angles of cracks in the tooth root.

For the calculation of the tooth thickness decrement, a straight line starting at the crack root which is parallel with the tooth midline was always applied by previous work [4]. This line can be defined as a 'straight-affecting line' (SA). The SA was modified by Mohammed et al. [10]. Using a parabola staring at the crack root and the end to tooth vertex, it can be defined as a 'parabolic-affecting line' (PA). Ma et al. [11,12] investigated the effect of three types of cracks on the meshing stiffness: (1. Straight crack and SA; 2. Straight crack and PA; 3. Parabolic crack and PA). The results of a type 2 and type 3 crack are very close to that of FEA. Therefore, PA is considered to be a correct path decrement calculation for tooth thickness. Although PA is demonstrated to be a correct path to simulate the influence of a tooth crack, SA is a universal method for most of the papers. To compare the different effects the two affecting lines have on the whole gear system, the PA and SA are both introduced to study the effect of a crack on the gear dynamics, and this proposed model could serve as a guide for the dynamic simulation of a cracked gearbox.

Many papers have examined the extraction of gear dynamic responses. Taking TVMS, friction forces, viscous damping and moments into account, the gear dynamic models with integrated periodic differential equations in 6-DOF(Degree of Freedom) is investigated in [13]. The vibration response of cracked, chipped, and broken local faults of the gearbox was investigated by Tian using an 8-DOF gearbox model. By considering the variations in meshing stiffness as the contacting number of teeth changes, the unstable parameter and significant vibration is investigated due to mesh stiffness variation in gear systems by using a two-stage gear systems in [14]. Then by considering the load, motor, couplings, shaft, bearings, gear, and pinion, a 16-DOF gearbox system was proposed by Wu [15] to study the major effects of a crack in the tooth root upon vibration response. To express

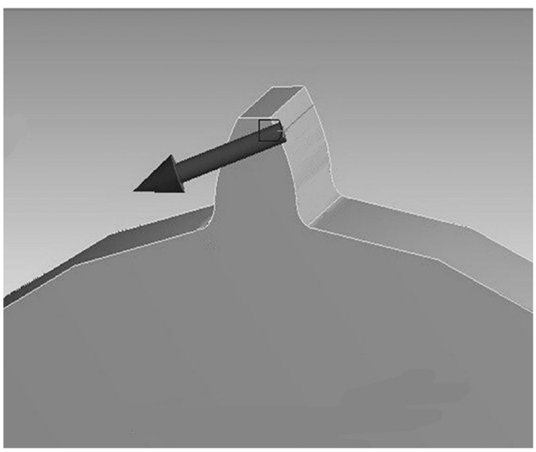

Fig. 2. Meshing simulation in Ansys.