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Influence of Von Mises Stress on the Deformation behaviour of a Pinion Spur Gear under Cyclic Loading in a Bottling Machine: An Approach for predicting surface Fatigue failure in Gears

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Abstract:

Fatigue failure predictions using analytical method have become cumbersome due to the types and mode of load applications on the gear teeth. The study employed a simulation approach to predict the fatigue behaviour of a pinion gear under cyclic loading by the determination of the Von Mises stress which can result to Surface deformation. The simulation was carried out on the gear component with emphasis on the teeth at different interval of 60, 90, 120 and 150 seconds using SolidWorks program. The result showed that increased stress resulted to increased deformation. Thus a minimum and maximum Von Mises stress of 1.303e+001 N/mm^2 and 7.370e+001 N/mm^2 were observed at 60 seconds against the fracture strength of the chosen material, gray cast iron (276 MPa). Further to this, the equivalent minimum and maximum deformation at 60 and 90 seconds were observed to be 7.192e-004 mm, 2.304e-002 mm at 60 seconds and 1.594e-003 mm,2.365e-002 mm at 90 seconds at the tooth respectively. This implies that deformation increases as stress increased and they are both functions of time. Based on the results of these analysis, Von Mises stress and the cyclic loading played an important role in predicting the deformation behaviour of the pinion gear. Thus, it is worthy of note to say that this concept has reduced the rigorous calculations in analytical method of failure predictions.

Keywords: Spur Gear, Stress, Deformation, Fatigue Failure

I. INTRODUCTION

Gears undergo torque during rotation which cause severe elastic deformation of the teeth and the entire gear body. Cyclic loading results in bending fatigue of the teeth, this requires the attention of the gear analyst on the need to investigate the stresses resulting in deformation [1]. In addition to the deformation on the gear teeth, heat and frictional losses from the integral component like bearing increases the thermal expansion of the drive [2]. Also, the pinion gear in operation undergo higher number of rotation compared to the gear wheel, hence it experiences increased heat with no room for adequate convection [3]. Based on this problem a non- linear variation in temperature occur which contribute to the highest stress that can cause total gear tooth deformation [4-6]. Mehta et al. [7] focused on reducing the dynamic variation of the gear component rotation due to stiffness resulting from tooth to tooth contact deformation. However, from the study of Dooner [8], critical design of gears which can carry high load and speed simultaneously with smaller size and lighter weight remain a major challenge. Off course with such design, stress and contact pressure causing deformation can be determined, but mostly impossible in ideal gear design. In view of this challenge, a fundamental approach for determination of stress and deformation of gear tooth is the simulation technique. Compared with the analytical, and experimental method, it has proven very reliable [9]. Simulation technique provides insight on the gear tooth endurance limit and even factor of safety [10]. Further to this, certain questions like the exact endurance limit beyond which fatigue of gear tooth occurs are left unanswered. Gear tooth fatigue is what can be used to determine the capacity of load, hence this is possible via simulation method [11]. Weibring et al. [12] simulated the various stages of fatigue failure of gears with a focus on crack initiation resulting to micropitting. The result showed the interaction between micropitting and pitting process that could cause gear failure. More so, it is important to establish relationship between the mesh stiffness and the probable errors before accurate gear dynamic simulation can be run for effective spall determination [13-15]. Consequently, stress regime by finite element simulation will give better prediction of fatigue failure [16, 17]. However, this depend on contact fatigue and the variation in the tooth load [18-20]. According to Octrue et al. [21], it is possible to predict the fatigue failure via modelling approach by careful study of the phenomenon resulting into crack initiation at different region on the gear tooth. Thus, the developed model can be employed to study the friction on the cracked regions as well as determining the thickness of the fractured tooth [22]. However, simulating the contact zone to determine stress and determination will give a better prediction compared to the numerical modelling approach [23-28]. Therefore, the aim of this research is to determine the actual Von Mises stress that could cause a deformation of gear tooth at the contact zone using a time function simulation approach. Hence, it becomes easy to study the fatigue behaviour of the component in real life applications.

II. PROBLEM DEFINITION

Consider the assembly of spur gears in figure 1. The pinion is connected to the electric motor which provide the power source. The pinion gear drives the other gear components, thus making it possible for the other gears to provide drive for bottle movement. In addition, the pinion gear also provide drive for the worm (archimedian spiral) component resulting into intense pressure on the gear tooth. The mode of failure is characterized by initial crack propagation at the contact region and down to the material. Due to the involute geometry of the tooth and cyclic loading, pressure is set in at the tooth surface resulting into thermal stresses and eventual deformation of the material. This study investigated the stresses and deformation at a particular time which can actually cause gear failure.

III. SIMULATION PROCEDURE

The spur gear design and simulation work was done in SolidWorks program using gray cast iron material. Stress and displacement simulation were done at 60 seconds, 90 seconds, 120 seconds and 150 seconds to determine the Von mises nodal stress and static displacements. For safe design, factor of safety was also simulated. The technical view of these simulation results are presented in figures 2-5.

IV. RESULTS AND DISCUSSION

Figure 1 represent the assembly of the gears in operation with a speed of 100 revolutions per minute at constant speed of 90 seconds, while figures 2-3 showed the Von Mises stress and deformation result for a period of 60 and 90 seconds respectively. It can be observed from figure 2 that the minimum Von Mises stress on the gear teeth is 1.303e+001 N/mm^2 and maximum stress of 7.370e+001 N/mm^2. The Von Mises stress indicate the region of maximum and minimum stress on the whole gear teeth involute. Thus, it is expected that the gear component can safely function under the stress condition when compared with the standard yield strength or fracture strength of the material used which is 276 MPa. Further to this figure 2 showed the stress result for 90 seconds simulation period which indicate the operating time measurement in real life application. It can be depicted from the plot that the minimum Von Mises stress at the gear tooth was 1.3701e+001 N/mm^2, while the maximum was observed to be 7.150e+001 N/mm^2.

However, there are stress variations on other parts of the gear as the gear rotates overtime. For instance, the highest Von Mises stress was observed to occur at the contact between the shaft and the gear which contribute to overall fatigue behaviour of the material [29]. In addition, the equivalent minimum and maximum deformation at 60 and 90 seconds were observed to be 7.192e-004 mm, 2.304e-002 mm at 60 seconds and 1.594e-003 mm,2.365e-002 mm at 90 seconds at the tooth respectively. This implies that deformation increases as stress increased and they are both functions of time.

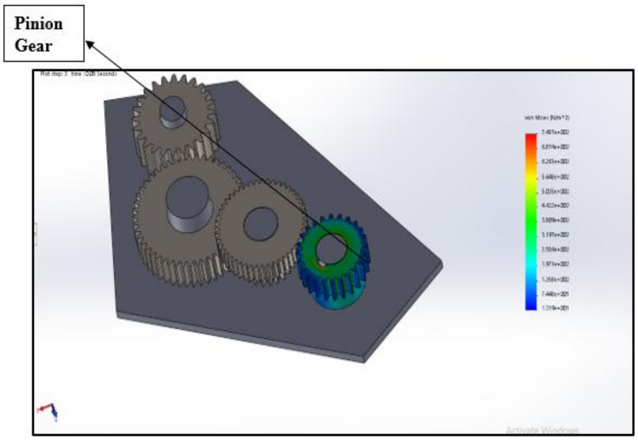

Fig.1: Spur Gear assembly in a typical Rinser machine (Bottling Machine)

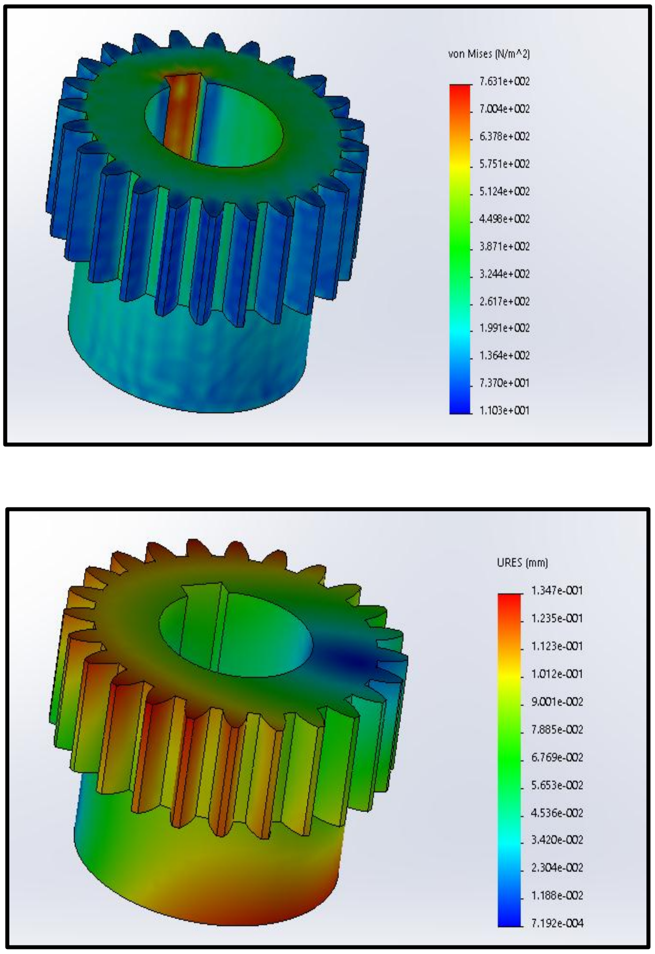

Fig.2: Stress and Deformation after 60 Seconds

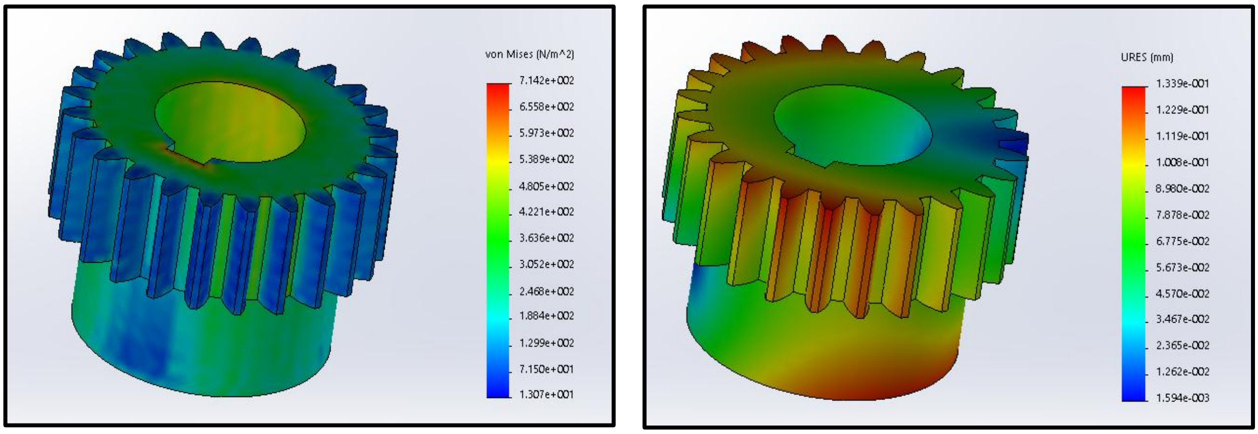

Fig.3: Stress and Deformation after 90 Seconds

More so**,** figures 4-5 displayed the Von Mises stress and deformation for a period of 120 and 150 seconds respectively. from fig 4, it can be depicted that the Von Mises stress has a minimum and maximum values of 1.330e+002 N/mm^2 and 1.116e+001 N/mm^2 respectively. this resulted to equivalent deformation of the gear teeth having minimum strain of 9.255e-004 mm and maximum strain rate of 2.331e-002 mm. In addition, variations in stress and deformation at various part of the gear body were equally observed.

Consequently, fig.5 showed the dynamic behaviour of stress and deformation for a period of 150 seconds. It indicates the minimum and maximum Von Mises stress of 1.32e+001 N/mm^2 and 7.90e+001 N/mm^2 and a corresponding deformation of 1.06e-003 mm and 2.342e-002 mm at the teeth surface respectively. The analysis of stress and deformation on the gear tooth geometry gave a better understanding of the fatigue behaviour of the pinion gear.

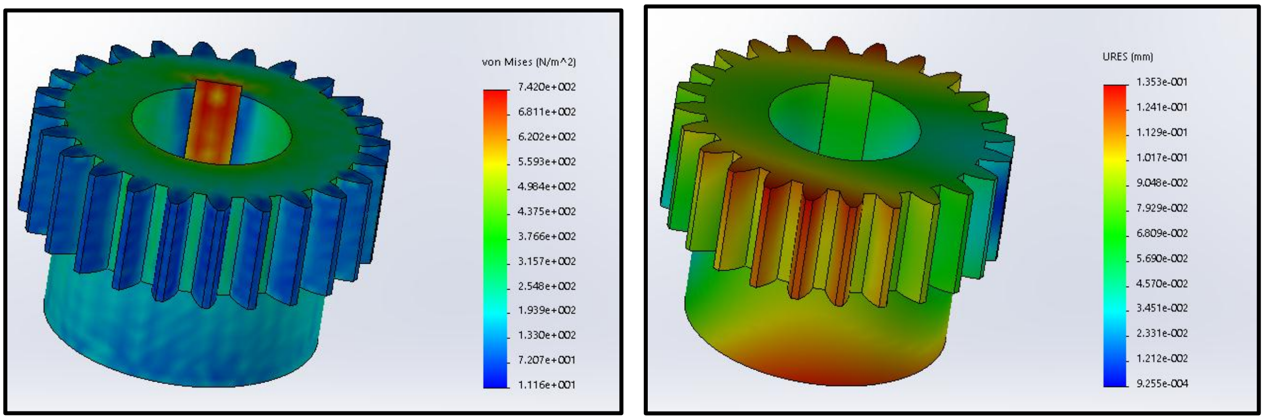

Fig.4: Stress and Deformation after 120 Seconds

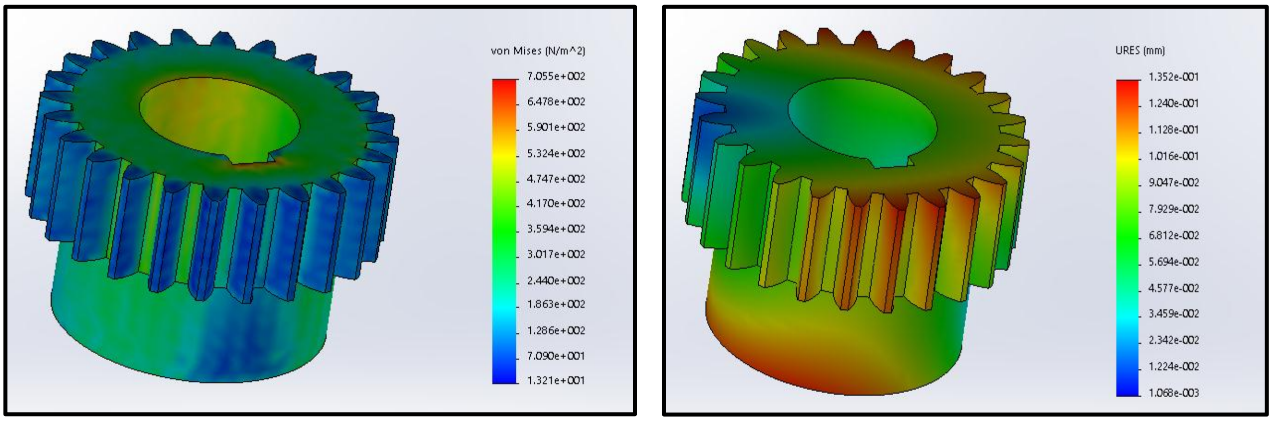

Fig. 5: Stress and Deformation after 150 Seconds

V. CONCLUSION

An effective method of predicting fatigue failures in spur gears have been proposed using the SolidWorks program. Stress and deformation at the teeth region were investigated via simulation approach at different time. The result of the stresses at various simulation showed that stress varies from minimum to maximum at the teeth, thus making it easy to understand the deformation trend of the pinion gear and simplified the prediction of surface fatigue per time. It was observed that stress increases significantly due to the cyclic loading at the surface during the period of simulation which consequently led to increased deformations at the point of contact. Based on the result of this analysis, Von Mises stress and the cyclic loading played an important role in predicting the deformation behaviour of the pinion gear. Thus, it is worthy of note to say that this concept has reduced the rigorous calculations in analytical method of failure predictions.

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