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Design And Analysis of Spur Gear for Steam Tube Dryer

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ABSTRACT

Gear design development rapid in the vicinity of parameters & become quite noticeable, due to effects on dynamic loads and stresses, and high working speed they required in industry to rotating components. Girth gears used in rotary dryers are critical components for power transmission and continuous operation in industrial processes. This study investigates the fatigue failure of a girth gear made from low-alloy cast steel used in a steam tube rotary dryer in a chemical plant after approximately 25 years of service. Cracks developed in the T-section web of the gear due to stress concentration and high stress intensity factors. Since the gear teeth surfaces remained in normal working condition and no spare gear was available, repair welding was adopted as a temporary solution. A nickel-based super alloy electrode was used for the repair, which successfully maintained operation until a replacement gear could be manufactured. The causes of fatigue failure and the effectiveness of the repair were analyzed using a cause–effect approach. Key contributing factors included the use of higher grade bolts than specified in the design, insufficient web stiffening, inadequate preparation before repair welding, and excessive weld bead sections. In addition, the study focuses on the design and stress analysis of spur gears used to rotate the steam tube dryer shell. The bending stress behavior of an involute spur gear tooth under static loading conditions was evaluated. The gear tooth profile was modeled in CATIA and analyzed using the Finite Element Method in ANSYS. Analytical stress calculations were also performed using established theoretical models, and the results showed good agreement with the numerical analysis. Keyword: - Involute Spur gear profile; Symmetric gear pair; Static stress analyses; Gear material selection; solar tracking

1.INTRODUCTION

Rotary dryers are widely used in many industrial sectors to reduce the moisture content of materials. In a rotary drying system, wet material is fed into a rotating cylindrical drum where it is continuously lifted and tumbled by internal flights while hot air flows through the drum. This direct contact between the material and heated gases promotes gradual evaporation of moisture and ensures efficient drying. Such dryers are commonly used in industries handling materials such as sand, limestone, fertilizers, coal, wood chips, ores, and sludge. The rotation of the dryer drum is usually driven by a gear mechanism that ensures steady and controlled movement during operation. In large rotary dryer installations, girth gears are used to transmit rotary motion and torque to the dryer shell. These gears are typically manufactured from low-alloy cast steel to withstand heavy loads and harsh operating conditions. The dryer drum is usually mounted at a slight inclination to facilitate the movement of material along its length while it rotates at a low speed. During operation, the material is gradually mixed with hot gases and dried before the humid air is extracted by a fan. Gears play a vital role in mechanical power transmission systems due to their reliability, compactness, and efficiency. Among various types of gears, spur gears are the simplest and most commonly used for transmitting power between parallel shafts with high efficiency. Gear systems are widely used in industrial machines, vehicles, elevators, and power generation equipment where smooth and reliable power transmission is essential. The increasing demand for quiet, durable, and efficient machines has created the need for more precise gear design and analysis techniques. Traditionally, gear design and stress evaluation were carried out using analytical calculations based on theoretical models. Finite Element Method (FEM) have become widely used for gear analysis. FEM allows detailed evaluation of stresses, including bending and contact stresses, under different loading conditions. Software tools such as ANSYS enable engineers to model gear geometry and simulate real operating conditions, providing more accurate and reliable results. By comparing numerical results with theoretical models, the accuracy and performance of gear designs can be effectively assessed.

2.BACKGROUND

Rotary steam tube dryers are widely used in chemical and process industries for drying large quantities of materials. These systems are typically designed to handle high production capacities and operate under demanding thermal and mechanical conditions. In many industrial dryers, the inlet temperature of the heating gases can reach very high levels depending on the fuel used. For direct-fired dryers, the inlet temperature generally ranges around 650°C and can increase to approximately 850°C in certain operating conditions. Such high temperatures enable efficient moisture removal from the processed material while maintaining continuous operation. The power requirement for rotary dryer systems varies significantly depending on the scale and capacity of the installation. Industrial dryers may require power ranging from approximately 75 kW to as high as 18,000 kW, and they may operate using either single or dual motor drive configurations. Due to the large size and heavy load of the rotating drum, power transmission is typically achieved through large girth gear systems. These gears are essential components responsible for transmitting rotational motion and torque from the drive system to the dryer shell. In large industrial dryers, girth gears can reach diameters of up to 14 meters with a face width of about 1.2 meters. Girth gears with diameters up to approximately 7.5 meters are commonly manufactured in two segments, whereas larger gears may consist of four to six segments depending on the casting capacity of the foundry or the size limitations of available forging processes. The design of large gear blanks also requires careful consideration of structural and operational factors. According to design guidelines such as those described in ANSI/AGMA standards, several aspects must be evaluated to ensure reliable gear performance. These include the potential shift of bending fatigue failure from the tooth root to the gear rim, the effect of rim deflection on load distribution, and the influence of the mating gear on load sharing. In addition, dynamic alignment techniques are often implemented to ensure proper gear meshing and to achieve uniform load distribution across the tooth surfaces.

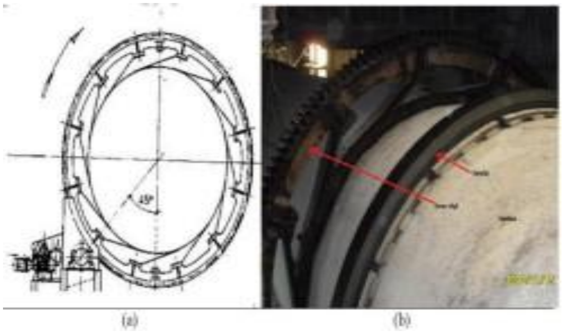

Fig -1: Name of the figure

3.MATERIAL CHOICES

Material selection for gear pairs is a critical aspect of design, particularly in applications where the gear system operates in open atmospheric conditions such as large rotary dryers. In such environments, gears are exposed to varying loads, temperature changes, and potential contamination, which makes the choice of material important for ensuring durability, wear resistance, and long service life. Generally, the pinion, which is the smaller gear in the pair, is selected with higher hardness than the larger gear. This is because the pinion teeth engage more frequently during operation and therefore experience greater cyclic stresses and wear compared to the mating gear. By using a harder material for the pinion, the wear rate can be reduced and the operational life of the gear pair can be improved. The final choice of material is also influenced by the manufacturing method used in the plant, as large gears are commonly produced either as fabricated structures or as cast components. Fabricated gear structures typically consist of a rolled rim made from materials such as SAE 1045 steel or a rolled ring forging of SAE 4340 steel, which is welded to a web plate made of ASTM A36 steel and supported with stiffeners for additional strength. In these fabricated designs, the hardness level is generally around 180 HBW for SAE 1045 and can reach up to 265 HBW for SAE 4340 steel plates. Cast steel is another widely used material for large gear blanks due to its strength and ability to be manufactured in complex shapes suitable for large-diameter gears. The hardness range for cast steel gears usually lies between 180 HBW and 335 HBW depending on the specific design and heat treatment conditions. Another alternative material is ductile iron, which provides similar advantages in terms of weight optimization when compared to cast steel. Additionally, ductile iron has the ability to reduce noise and vibration because of the presence of graphite particles within its structure, making it beneficial for certain industrial applications. Advanced material selection techniques such as Ashby's method can also be applied to evaluate different materials based on performance indices, allowing designers to compare options like steels, cast irons, bronzes, and polymer-based materials before choosing the most suitable one for the application.

4. CONSTRUCTION

Girth gears used in large industrial equipment such as rotary dryers, kilns, and mills are commonly designed using two main structural configurations known as Y-section and T-section designs. The Y-section structure is primarily associated with cast steel gears and, in some cases, ductile iron gears. This configuration provides strong structural support and is often selected when higher rigidity is required in heavy-duty applications. On the other hand, the T section design is more commonly adopted for both cast steel and ductile iron gears because of its relatively simple geometry and reduced overall weight. The lighter structure of the T-section design can simplify manufacturing and installation while still maintaining sufficient strength for transmitting the required torque. Another important aspect in the design of girth gear drive systems is the selection of the motor and transmission arrangement used to rotate the equipment. Designers must consider the overall cost and efficiency of the drive system when choosing between a low-speed motor that can be directly coupled to the pinion and a high-speed motor that requires a gear reduction unit. Low-speed motors typically operate around 200 rpm and can be directly connected to the pinion, while higher speed motors may run between approximately 740 rpm and 1170 rpm and therefore require additional gear drives to achieve the desired output speed. Analytical methods such as static analysis are commonly used to evaluate the mechanical behaviour of components by determining reaction forces at various joint locations under constant loading conditions. When the system is assumed to have zero velocity, the mechanism can be analysed at different positions throughout its range of motion to assess stress and load distribution. In addition to analytical evaluation, experimental analysis is sometimes carried out by developing a prototype and subjecting it to controlled testing procedures. Modern computer-aided design systems allow engineers to combine experimental data with numerical modelling to improve the reliability of design predictions, especially in cases where purely analytical methods may not fully represent the behaviour of complex mechanical systems. Furthermore, high-power drive systems that use motors exceeding 5000 kW require careful bearing selection to meet operational reliability requirements. Designers often specify bearing life using L10 life criteria, and when higher service factors are applied, larger input shaft bearings may be required to achieve the desired operational life span.

5. DESIGN RECOMMENDATION

For economical gear design, the designer should prioritize configurations that reduce manufacturing complexity and cost while still meeting functional requirements. One key recommendation is to select the coarsest pitch gear system that can adequately perform the intended function. Coarse-pitch gears generally require fewer teeth and allow easier machining, molding, casting, or forming, which lowers manufacturing cost compared with fine-pitch gears. Therefore, whenever operational conditions such as load capacity, speed, and space constraints permit, coarse-pitch gearing should be preferred. Another important consideration is the selection of appropriate dimensional tolerances and surface finish requirements. Tolerances specified by gear standards such as AGMA or DIN gear quality numbers should be kept as liberal as possible while still ensuring proper gear performance, because tighter tolerances significantly increase manufacturing cost due to the higher precision required in machining and inspection. By choosing a suitable coarse pitch and avoiding unnecessarily strict tolerances, designers can achieve a cost-effective gear design without compromising functional reliability.

6. DESIGN PROCESS

The program assists the user in determining all the factors and variables of the above equations for a specific application. These input variables are determined from the tables, graphs, and figures shown in the program. The program then calculates the allowable bending stress and contacts stress for this application. This paper focuses on the procedure for sizing and selecting a spur gear using a specialized software program. Spur gears are widely used in machine design, and their proper selection requires numerous calculations and engineering decisions. The developed software simplifies this process by assisting users in determining the required parameters and variables for gear design. Input values are obtained from standard tables, graphs, and reference data within the program, after which the software calculates important design parameters such as allowable bending stress and contact stress for a specific application.The study also highlights the importance of engineering design skills, including technical knowledge, creativity, communication abilities, and effective planning. Modern engineers rely heavily on Computer-Aided Design (CAD) to create both two-dimensional and three-dimensional models of components such as machine parts, automotive and aircraft elements, and assembly systems. While initial ideas may be sketched manually, CAD tools allow designs to be modified and optimized more efficiently. During the design process, drafting and computer graphics techniques are integrated to develop detailed models of mechanical systems. The design workflow follows an “art-to-part” approach, which includes concept sketching, creation of accurate engineering drawings, realistic rendering of components, structural analysis to verify strength, and prototype development. Over time, CAD has evolved from a digital drafting board into an advanced modeling and simulation platform capable of representing solid components and entire manufacturing environments in three dimensions.Basic CAD capabilities include 2D drafting features for creating geometric entities such as lines, circles, and curves, which can be converted into 2.5D or 3D models through extrusion and wireframe modeling. Additional surface and face generation tools allow the creation of shell or solid models, while hidden line and surface algorithms help generate realistic visual representations. These capabilities make CAD an essential tool for modern engineering design and analysis..

7. MODELING

Modeling is the process of developing a simplified representation of a real system in order to understand its structure and behavior. A model reflects the essential features of the system it represents while remaining less complex than the actual system. The primary purpose of modeling is to allow analysts to study system performance and predict the effects of possible changes without directly altering the real system. An effective model maintains a balance between realism and simplicity so that it accurately represents important characteristics while still being easy to analyze and experiment with.In simulation studies, models are commonly developed using mathematical relationships and implemented with simulation software. These mathematical models can be categorized in several ways. Deterministic models use fixed input and output values, whereas stochastic models include variables that involve randomness or probability. Models may also be classified as static, where time is not considered, or dynamic, where interactions between variables change over time. Most simulation models are stochastic and dynamic because they more accurately represent real-world systems.Another important aspect of modeling is validation, which ensures that the model accurately reflects the behavior of the actual system. This is often achieved by testing the model with known input conditions and comparing the results with real system outputs. To improve accuracy and usability, simulation practitioners often recommend gradually increasing the complexity of a model through an iterative process. This approach helps create reliable models that effectively support analysis and decision-making.

8. SIMULATION

Simulation is the process of operating a model that represents a real system in order to study its behavior under different conditions. Through simulation, a model can be modified and tested repeatedly, which is often impractical, expensive, or impossible with the actual system. By analyzing the performance of the model, valuable insights about the behavior of the real system and its subsystems can be obtained. Simulation is widely used to evaluate both existing and proposed systems over extended periods of time and under varying configurations.This approach is particularly useful before implementing modifications to an existing system or constructing a new one, as it helps reduce the risk of design failure, identify potential bottlenecks, improve resource utilization, and enhance overall system performance. Simulation can also help answer critical design and operational questions, such as determining optimal system configurations, evaluating resource requirements, predicting the impact of increased workload, and assessing the effect of new algorithms or system failures.One important type of simulation is discrete event simulation, where system changes occur at specific moments triggered by events. For example, in queuing systems, the arrival of a customer immediately alters the system state. In contrast, continuous simulation models represent systems where variables change continuously over time, such as in flight or weather simulations. Although discrete event simulation provides a less detailed representation compared to continuous models, it is easier to implement and is therefore widely applied in many engineering and operational studies.A simulation study typically follows an iterative process involving model development, experimental design, analysis of results, and decision-making regarding system improvements. While simulation software efficiently performs the computational execution of models, human expertise is essential in problem formulation, model construction, and interpretation of results. Therefore, the success of a simulation study depends not only on the software used but also on the knowledge and experience of the analysts involved.

9. CONCLUSIONS

The design of spur gears involves several important factors such as calculations, material selection, strength, duty conditions, and manufacturing quality. In this study, the geometry of spur gears is developed using mathematical relationships and implemented through parametric design in Autodesk Inventor. CAD technology helps designers reduce manual drafting work and improves accuracy and efficiency during the design process. Simulation tools also allow engineers to test and evaluate designs quickly, saving both time and cost compared to physical testing. By using computer-based design and analysis, the overall product development process becomes faster and more reliable, making software-based design an effective approach for engineering applications and academic research.

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