FAILURE ANALYSIS AND MODIFICATIONS OF CARBURIZED GEARS

BY

Eng.: **Raafat Ibrahim Mohamed Goher**

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In a Partial Fulfillment of the
Requirements for the Degree of

DOCTOR OF PHILOSOPHY

In

MECHANICAL DESIGN AND PRODUCTION ENGINEERING

FACULTY OF ENGINEERING, CAIRO UNIVERSITY

GIZA, EGYPT

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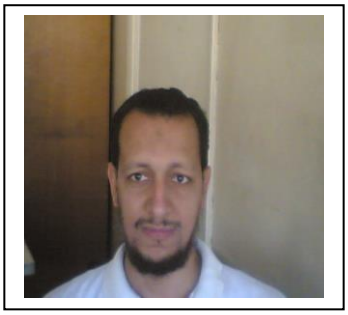

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Key Words: Gears failure; Carburizing; Decarburization; Case depth; 17NiCrMo 7-6; 14NiCr18

Summary:

The mechanical failure mainly concentrated in; material selection errors, design errors, production error and heat treatment errors with about 79 % of the total failure causes.
Gear failure is one of the most important problems facing the gears' designers, manufacturers and maintenance team. Gear failure may occur due to the errors in design, manufacturing, operating conditions or maintenance. Design errors may also come due to errors in stress analysis, material selection, geometry analysis or heat treatment specifications. Manufacturing errors may be result from the machining accuracy and/or errors, geometrical errors, heat treatment errors, finishing errors or assembly errors.
In this work, three industrial gear failure cases were studied and analyzed. It was found that the most failure cases were resulting from the heat treatment specifications, implementation or design analysis. So, the study was aimed to analyzing the failure cases searching for its causes and introducing solutions to the discovered failure causes. The failure studied cases, were made of carburized materials so; the carburization technique of surface hardening was applied. The studied cases material was DIN 1.6587 (17NiCrMo 7-6). The failure reason of the first and second cases were due to errors of; the carburizing depth either less or more than the correct values and decarburization. Those errors were studied and solved. Whereas, the third failure case was due to the high applied stress to the gears. For this reason, the study aims to find a high strength material which can help in overcome more stresses than the above-mentioned material and it was found that the material DIN 1.5860 (14 Ni Cr 18) could do this. But since this material is coded as aerospace material and it has a shortage of, data and researches so, this material is subjected to a variety of heat treatment conditions for discovering the best conditions which verifying high strength, toughness and wear resistance. Sets of specimens were manufactured, heat treated under variable conditions and mechanically tested. For material 18CrNiMo7-6 the relation between, carburizing time and case depth was correlated. For material 14NiCr18, it could obtain high tensile and impact strengths at a certain carburizing and tempering conditions for both oil and water quenching media. Also, wear resistance was tested where good results are obtained.

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ABSTRACT

The mechanical failure responsibility mainly concentrated in; material selection errors, design errors, production errors and heat treatment errors with about 79 % of the total mechanical failure causes. Gears are important items of the mechanical components.

Gear failure is one of the most important problems facing the gear designers, manufacturers and maintenance team. Gear failure may occur due to the errors in design, manufacturing, operating conditions or maintenance. Design errors may also come due to errors in stress analysis, material selection, geometry analysis or heat treatment specifications. Manufacturing errors may be result from the machining accuracy and/or errors, geometrical errors, heat treatment errors, finishing errors or assembly errors. Maintenance errors may happen if the maintenance is not proper or is not carried out corresponding to the standards recommendations.

In this work, three industrial gear failure cases were studied and analyzed. It was found that the most failure cases were resulting from the heat treatment specifications, implementation or design analysis. So, the study was aimed to analyzing the failure cases searching for its causes and modifying the heat treatment operation to ensure optimal heat treatment specifications regarding the mechanical and tribological properties which led to the case of gear failure. The failure studied cases, were made of carburized materials so; the carburization technique of surface hardening was selected to apply the modifications. The studied cases material was DIN 1.6587 (17NiCrMo 7-6). The failure reason of the first and second cases were due to an error of the carburizing depth either less or more than the recommended values. This material heat treatment was studied to correlate the carburizing time with the carburizing depth in order to correctly validate the required case depth. Whereas, the third failure case was due to the high applied stress to the gears. For this reason, the study aims to find a high strength material which can help in overcome more stresses than the above-mentioned material and it was found that the material DIN 1.5860 (14 Ni Cr 18) could do this. But since this material is coded as aerospace material and it has a shortage of, data and researches so, a contribution of discovering its heat treatment procedure is done in this work. This material is subjected to a variety of heat treatment conditions for discovering the best conditions which verify high strength, toughness and wear resistance. Sets of specimens were manufactured, heat treated under variable conditions and mechanically tested. The results of the experimental work of both materials were satisfied concerning the objectives of each material experimental. For material 18CrNiMo7-6 the relation between, carburizing time and case depth was correlated. Two specimens were used to approve the resultant relation and it was satisfied with good accuracy. For material 14NiCr18, it could obtain high tensile and impact strengths at a certain carburizing and tempering conditions for both oil and water quenching media. Also, wear resistance was tested where good results are obtained.

Finally, the results of the industrial failure cases and the other experimental work could be applied in the gear design process and heat treatment practice. Moreover, more efforts and investigations are needed to reveal the mechanical and tribological properties of material: 14 Ni Cr 18 needs.

CHAPTER 1
INTRODUCTION

Designers face many problems during the design process of mechanical systems like performance, strength, life, wear, manufacturing considerations, maintainability, shape, cost, etc.

Failure problem is so highly affected factor of many design considerations that it must be studied and solved perfectly for the design success. One of the common parts in most mechanical systems is the gear box. Gear designers and manufacturers have to solve many problems through the design and manufacturing operations; one of those problems is the failure problems. The present work manipulates in details how to solve this problem by achieving, certain procedure to evaluate; the design, heat treatment, the mechanical & tribological properties, stress analysis, and manufacturing compared to standard recommendations.

1.1 DESIGN CONSIDERATIONS FOR GEARS

Many design considerations must be taken into account during the design of gears as; performance, strength, life, space, precision, noise, manufacturability, assemble ability, maintainability, cost, etc.

To verify those demands, gears must be optimally designed and manufactured for high performance depending on the geometry, accuracy, material selection and heat treatment. The design must follow the design rules of standards' specifications; as ISO, AGMA, DIN, etc.

Accuracy is obtained by selecting the efficient manufacturing operations and the production technique as hobbing, shaping, broaching, extruding, forming, powder sintering, etc.

Each production technique has its accuracy which may be suitable to some applications and not for others. So, the selection of gear production technique is important for verifying the design requirements.

1.2 GEAR FAILURE PROBLEMS

Failure can occur in gears due to many reasons such as; design errors, manufacturing errors, assembly errors and maintenance errors.

Failure due to design errors can be classified into performance analysis errors, geometrical analysis errors – Figure (1.1) shows the main nomenclatures of gears' geometries [1]- or manufacturing consideration errors. Performance analysis errors include strength, material and heat treatment specifications, which is carried out to increase the strength and the wear resistance of gear teeth.

The gear teeth wear is considered as one of the most important problems facing the designers and manufacturers of gear boxes. They have to reduce the effect of this phenomenon by engineering solutions.

Since the gear teeth are subjected to a high wear due to the sliding motion, pressure stress, fatigue stress and impact, the teeth surface must possess high wear resistance, whereas the core must be tough and strong enough to overcome the impact and the applied loads. Wear could be improved by controlling; hardness, lubricants, surface coatings, materials alloying elements.

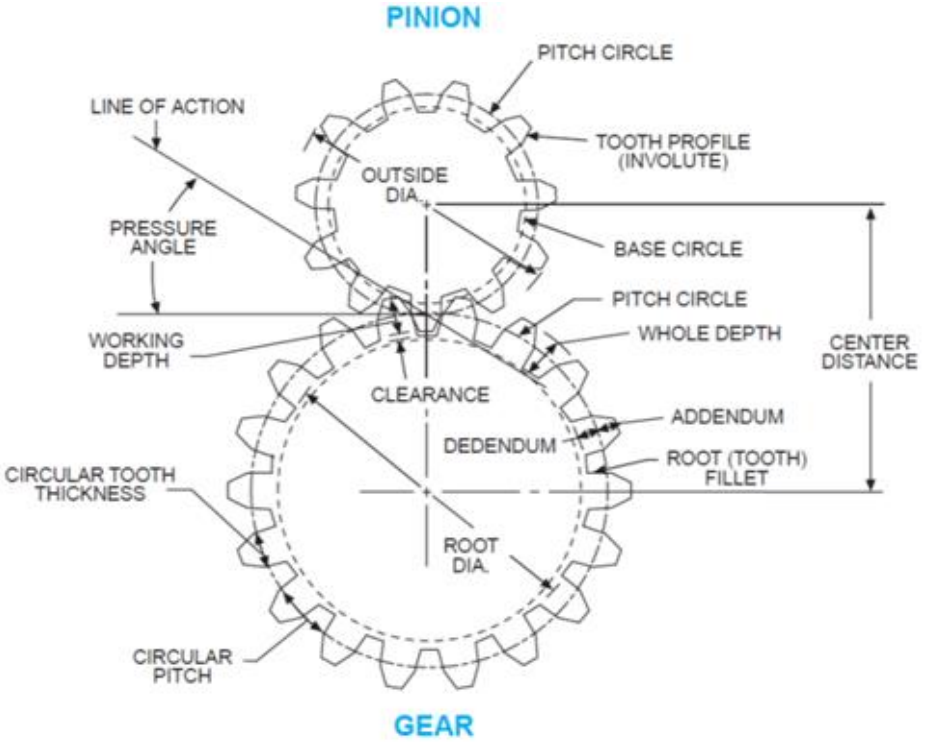

Fig. (1.1) Gear Geometry

1.3 GEAR MATERIALS

Material selection is one of the most important factor affecting the design of gears and performances. Material of gears must be selected depending on their applications (heavy, medium or light duty gears) and sizes. The ferrous base, cupper base, polymeric base materials, etc. are used for various engineering gears applications.

Most of gears used in mechanical applications are ferrous base materials which are strong, tough and suitable to case hardening, such as 16MnCr5, 18Ni Cr Mo 7-6, 14 Ni Cr 18, etc. The common used material for good strength gears is DIN No (1.6587) (18Ni Cr Mo 7-6) and one of the high strength carburized gears materials is DIN No (1.5860) (14 Ni Cr 18), which has very high strength and recommended for heavy-duty gears.

1.4 HEAT TREATMENT

The mechanical and tribological properties of gear steel can be modified and improved by heat treatment operation. The gear material strength, toughness and wear resistance must satisfy the applications' requirements. For these reasons, the gear steel is heat treated to increase its strength, toughness and wear resistance. If the plain carbon steel is compared to alloy steel with the same hardness concerning strength, they are alike. But from the point of view of toughness and wear resistance, the alloy steel could be modified by heat treatment to give more strength, toughness and wear resistance. So, the alloy steels have a wide range of gear applications in the industry especially for precision applications. In the industry applications, the designers and manufacturers are using over 90% of the gears made from alloy steels [2]. Heat treatment of gear materials is classified into through hardening and case hardening. Case hardening is classified mainly to flame, induction, nitriding, boronizing, carburizing and mixing of some of those methods as carbonitriding. The famous three techniques of carburizing are gas, salt bath and solid beside other methods as plasma. Every technique has its characteristics and advantages.