ANALYSIS AND IMPROVING THE HARDNESS OF En 353 STEEL USING CRYOGENIC TREATMENT

K.Sriharrish¹, M.Karthikeyan²

¹ M.E. (Manufacturing Engineering) Student, ² Assistant Professor
Department of Mechanical Engineering,
Karpagam University, Coimbatore, India.
E-mail addresses: ¹ sriharrish@gmail.com, ² mkarthi.karpagam@gmail.com

Abstract - Gears are used to transmit large amount of power in mechanical transmission system with compact layout. For this high loading they mostly prefer worm wheel because of its high torque capacity and strength. In this teeth fracture occurs due to the effect on metal of repeated cycle of stress called fatigue and due to improper hardness. Due to this improper hardness, fatigue occurs in the teeth end and hence it develops due to continuous heavy loading. Hence to rectify this, our investigation consists of visual examination, chemical composition analysis, hardness analysis, stress analysis, finite element analysis & cryogenic treatment on steel. The chemical design analysis results the gear is manufactured by En353. The hardness analysis shows the failure occur due to improper heat treatment. Cryogenic treatment is to increase the hardness of material. Hence I concluded by this project that we can reduce the fracture of teeth by providing the cryogenic treatment to it and to increasing the hardness of teeth.

Keywords – Cryogenic treatment; Gear failure; En353 Steel;

1. INTRODUCTION

This project describes the detailed study on the failed gear. The possible failure reasons are analyzed. Planetary gearing system is a system that consists of three planet gears. Typically the planet gears are mounted on a carrier which itself may rotate relative to sun gear. The planetary gearing system may also incorporate the use of an outer ring gear, which meshes the planet gears.

The material used for the manufacture of gears depends on the strength and service like wear noise etc. The steel is used for high strength gears and steel may be plain carbon steel or alloy steel. The steel gears are usually heat treated in order to combine properly the toughness and tooth material. In general, the steels selected for gear applications must satisfy the basic two requirements for ease of fabrication and processing.

Several researchers studied on the failures of the elements of power transmission system as there are many cases of the failures [1]. A failure investigation has been conducted on a diesel-engine gear-shaft used in truck which is made of EN353 steel [2]. He describes the detailed metallurgical investigation and careful fractographic study on the failed gear shaft, the carburized layer & the core zone were conducted [3].

Fig. 1. Structure of Two Stage Planet Gear

The possible failure reasons were assessed. A pinion which has a part of an air motor driving on a diesel generator (DG) of a power plants emergency power supply system, was found to be failed into three parts during a routine checkup of a dc.
A systematic failure analysis was carried out to find out the reasons for this unexpected fracture of the pinion during operation. The result indicates that the fracture was caused by fatigue with a fatigue crack initiating from the fillet of one of the pinion teeth. Due to misalignment that was present the pinion did not mesh properly with the ring gear during start up operation and this lead to a high stress concentration at the root of the pinion. Typical applications of En353 steel is being heavy duty gears, shaft, pinions, camshaft, & gudgeon pins.

The power transmission input is 22kw at 1440rpm and the final output power is 18rpm. For such huge reduction of three stage planetary gearbox is used. The gear reduction can be achieved by using the gear ratio \((1+R/S)\). The kind of gearing is occasionally used in tractors foundry division and construction equipments to give the high torque to the driving wheels.

2. METHODOLOGY

Failure analysis is the route of gathering and investigating statistics to conclude the cause of failure and how to avoid it from recurring. It is a significant control in manufacturing industry, where it is a very important tool used in the development of new products and for the upgrading of existing products.

\[
\text{En353 STEEL} \rightarrow \text{HARDNESS} \rightarrow \text{FEM ANALYSIS} \rightarrow \text{COMPARISON} \rightarrow \text{RESULT & CONCLUSION}
\]

Fig. 2. Flow Chart of Methodology

A. Properties of en353 steel

Gears

A gear is a rotating machine part having cut teeth, or cogs, which mesh with another toothed part in order to transmit torque. Two or more gears working in tandem are called a transmission and can produce a mechanical advantage through a gear ratio and thus may be considered a simple machine. Geared devices can change the speed, torque, and direction of a power source. The most common situation is for a gear to mesh with another gear, however a gear can also mesh a non-rotating toothed part, called a rack, thereby producing translation instead of rotation.

The gears in a transmission are analogous to the wheels in a pulley. An advantage of gears is that the teeth of a gear prevent slipping. When two gears of unequal number of teeth are combined a mechanical advantage is produced, with both the rotational speeds and the torques of the two gears differing in a simple relationship.

In transmissions which offer multiple gear ratios, such as bicycles and cars, the term gear, as in first gear, refers to a gear ratio rather than an actual physical gear. The term is used to describe similar devices even when gear ratio is continuous rather than discrete, or when the device does not actually contain any gears, as in a continuously variable transmission.

B. Types

External Vs Internal Gears

An external gear is one with the teeth formed on the outer surface of a cylinder or cone. Conversely, an internal gear is one with the teeth formed on the inner surface of a cylinder or cone. For bevel gears, an internal gear is one with the pitch angle exceeding 90 degrees. Internal gears do not cause direction reversal.

C. Spur Gear

![Fig. 3. External gear vs Internal gear](image-url)
Spur gears or straight-cut gears are the simplest type of gear. They consist of a cylinder or disk with the teeth projecting radially, and although they are not straight-sided in form, the edge of each tooth is straight and aligned parallel to the axis of rotation. These gears can be meshed together correctly only if they are fitted to parallel shafts.

![Fig. 4. Spur gear](image)

**D. Helical**

Helical or “dry fixed” gears offer a refinement over spur gears. The leading edges of the teeth are not parallel to the axis of rotation, but are set at an angle. Since the gear is curved, this angling causes the tooth shape to be a segment of a helix. Helical gears can be meshed in a parallel or crossed orientations. The former refers to when the shafts are parallel to each other; this is the most common orientation. In the latter, the shafts are non-parallel, and in this configuration are sometimes known as "skew gears".

A disadvantage of helical gears is a resultant thrust along the axis of the gear, which needs to be accommodated by appropriate thrust bearings, and a greater degree of sliding friction between the meshing teeth, often addressed with additives in the lubricant.

![Fig. 5. Helical Gears](image)

**E. Double Helical**

Double helical gears, or herringbone gears, overcome the problem of axial thrust presented by “single” helical gears, by having two sets of teeth that are set in a V shape. A double helical gear can be thought of as two mirrored helical gears joined together. This arrangement cancels out the net axial thrust, since each half of the gear thrusts in the opposite direction. Double helical gears are more difficult to manufacture due to their more complicated shape.

![Fig. 6. Double Helical Gear](image)

**F. Worm Gear**

Worm-and-gear sets are a simple and compact way to achieve a high torque, low speed gear ratio. For example, helical gears are normally limited to gear ratios of less than 10:1 while worm-and-gear sets vary from 10:1 to 500:1. A disadvantage is the potential for considerable sliding action, leading to low efficiency.

Worm gears can be considered a species of helical gear, but its helix angle is usually somewhat large (close to 90 degrees) and its body is usually fairly long in the axial direction; and it is these attributes which give it screw like qualities. The distinction between a worm and a helical gear is made when at least one tooth persists for a full rotation around the helix. If this occurs, it is a ‘worm’; if not, it is a ‘helical gear’. A worm may have as few as one tooth. If that tooth persists for several turns around the helix, the worm will appear, superficially, to have more than one tooth, but what one in fact sees is the same tooth reappearing at intervals along the length of the worm. The usual screw nomenclature applies: a one-toothed worm is called single thread or single start; a worm with more than one tooth is called
multiple thread or multiple start. The helix angle of a worm is not usually specified. Instead, the lead angle, which is equal to 90 degrees minus the helix angle, is given.

**G. Failed En353 Steel Gear**

A systematic failure analysis was carried out to find out the reasons for this unexpected fracture of the pinion during operation. The result indicates that the fracture was caused by fatigue with a fatigue crack initiating from the fillet of one of the pinion teeth. Due to misalignment that was present the pinion did not mesh proper with the ring gear during start up operation and this lead to a high stress concentration at the root of the pinion. Typical applications of En 353 steel is being heavy duty gears, shaft, pinions, camshaft, & gudgeon pins.

![Grinding Marks](image1)

![Wear Scar Edge](image2)

![Brittle fracture](image3)

**Fig. 7. cracks in En 353 steel Gear**

**H. Gear Nomenclature**

Number Of Teeth, N. How many teeth a gear has, an integer. In the case of worms, it is the number of thread starts that the worm has Gear, Wheel The larger of two interacting gears or a gear on its own. Pinion The smaller of two interacting gears.

Line Of Action, Pressure Line - Line along which the force between two meshing gear teeth is directed. It has the same direction as the force vector. In general, the line of action changes from moment to moment during the period of engagement of a pair of teeth. For involute gears, however, the tooth-to-tooth force is always directed along the same line that is, the line of action is constant. This implies that for involute gears the path of contact is also a straight line, coincident with the line of action as is indeed the case.

Pitch Circle, Pitch Line - Circle centered on and perpendicular to the axis, and passing through the pitch point. A predefined diametral position on the gear where the circular tooth thickness, pressure angle and helix angles are defined.

Module, M - A scaling factor used in metric gears with units in millimeters whose effect is to enlarge the gear tooth size as the module increases and reduce the size as the module decreases. Module can be defined in the normal ($m_n$), the transverse ($m_t$), or the axial planes ($m_a$) depending on the design approach employed and the type of gear being designed. Module is typically an input value into the gear design and is seldom calculated.

![Fig. 8. General Nomenclature](image4)
Pitch surface – In cylindrical gears, cylinder formed by projecting a pitch circle in the axial direction. More generally, the surface formed by the sum of all the pitch circles as one moves along the axis. For bevel gears it is a cone.

Pressure Angle, \( \theta \) - The complement of the angle between the direction that the teeth exert force on each other, and the line joining the centers of the two gears. For involute gears, the teeth always exert force along the line of action, which, for involute gears, is a straight line; and thus, for involute gears, the pressure angle is constant.

Outside Diameter, \( D_o \) - Diameter of the gear, measured from the tops of the teeth.

Root Diameter - Diameter of the gear, measured at the base of the tooth.

Addendum, \( a \) - Radial distance from the pitch surface to the outermost point of the tooth. \( a = (D_o - D)/2 \)

Dedendum, \( b \) - Radial distance from the depth of the tooth trough to the pitch surface. \( b = (D - \text{root diameter})/2 \)

3. CRYOGENICS PRE-PROCESSING PROCESS

A. Flame And Induction Hardening

Flame or induction hardening are processes in which the surface of the steel is heated to high temperatures (by direct application of a flame, or by induction heating) then cooled rapidly, generally using water; this creates a "case" of martensite on the surface. A carbon content of 0.3–0.6 wt% C is needed for this type of hardening.

Typical uses are for the shackle of a lock, where the outer layer is hardened to be file resistant, and mechanical gears, where hard gear mesh surfaces are needed to maintain a long service life while toughness is required to maintain durability and resistance to catastrophic failure.

B. Carburizing

Carburizing is a process used to case harden steel with a carbon content between 0.1 and 0.3 wt% C. In this process steel is introduced to a carbon rich environment and elevated temperatures for a certain amount of time, and then quenched so that the carbon is locked in the structure; one of the simpler procedures is repeatedly to heat a part with an acetylene torch set with a fuel-rich flame and quench it in a carbon-rich fluid such as oil. Carburization is a diffusion-controlled process, so the longer the steel is held in the carbon-rich environment the greater the carbon penetration will be and the higher the carbon content. The carburized section will have a carbon content high enough that it can be hardened again through flame or induction hardening.

It's possible to carburize only a portion of a part, either by protecting the rest by a process such as copper plating, or by applying a carburizing medium to only a section of the part. The carbon can come from a solid, liquid or gaseous source; if it comes from a solid source the process is called pack carburizing. Packing low carbon steel parts with a carbonaceous material and heating for some time diffuses carbon into the outer layers. A heating period of a few hours might form a high-carbon layer about one millimeter thick. Liquid carburizing involves placing parts in a bath of a molten carbon-containing material, often a metal cyanide; gas carburizing involves placing the parts in a furnace maintained with a methane-rich interior.

C. Nitriding

Nitriding heats the steel part to 482–621 °C (900–1150 °F) in an atmosphere of ammonia gas and dissociated ammonia. The time the part spends in this environment dictates the depth of the case. The hardness is achieved by the formation of nitrides. Nitride forming elements must be present for this method to work; these elements include chromium, molybdenum, and aluminium. The advantage of this process is it causes little distortion, so the part can be case hardened after being quenched, tempered and machined.

D. Cyaniding

Cyaniding is a case hardening process that is fast and efficient; it is mainly used on low carbon steels. The part is heated to 871-954 °C (1600-1750 °F) in a bath of sodium cyanide and then is quenched and rinsed, in water or oil, to remove any residual cyanide.

This process produces a thin, hard shell (between 0.25 - 0.75 mm, 0.01 and 0.03 inches) that is harder than the one produced by carburizing, and can be completed in 20 to 30 minutes compared to several
hours so the parts have less opportunity to become distorted. It is typically used on small parts such as bolts, nuts, screws and small gears. The major drawback of cyaniding is that cyanide salts are poisonous.

E. Carbonitriding

Carbonitriding is similar to cyaniding except a gaseous atmosphere of ammonia and hydrocarbons is used instead of sodium cyanide. If the part is to be quenched then the part is heated to 775–885 °C (1427–1625 °F); if not then the part is heated to 649–788 °C (1200–1450 °F)

F. Cryogenics

In physics cryogenics is the study of the production of very low temperature (below −150 °C, −238 °F or 123 K) and the behavior of materials at those temperatures [4]. A person who studies elements under extremely cold temperature is called a cryogenicist [5]. Rather than the relative temperature scales of Celsius and Fahrenheit, cryogenicists use the absolute temperature scales.

G. Etymology

The word cryogenics stems from Greek and means "the production of freezing cold"; however, the term is used today as a synonym for the low-temperature state. It is not well-defined at what point on the temperature scale refrigeration ends and cryogenics begins, but most scientists assume it starts at or below -150 °C or 123 K (about -240 °F). The National Institute of Standards and Technology at Boulder, Colorado has chosen to consider the field of cryogenics as that involving temperatures below −180 °C (-292 °F or 93.15 K). This is a logical dividing line, since the normal boiling points of the so-called permanent gases lie below −180 °C while the Freon refrigerants, hydrogen sulfide, and other common refrigerants have boiling points above −180 °C.

H. Cryogenic Processing

The field of cryogenics advanced during World War II when scientists found that metals frozen to low temperatures showed more resistance to wear. Based on this theory of cryogenic hardening, the commercial cryogenic processing industry was founded in 1966 by Ed Busch [6].

They originally experimented with the possibility of increasing the life of metal tools to anywhere between 200%-400% of the original life expectancy using cryogenic tempering instead of heat treating. This evolved in the late 1990s into the treatment of other parts (that did more than just increase the life of a product) such as amplifier valves (improved sound quality), baseball bats (greater sweet spot), golf clubs (greater sweet spot), racing engines (greater performance under stress), firearms (less warping after continuous shooting), knives, razor blades, brake rotors and even pantyhose. The theory was based on how heat-treating metal works (the temperatures are lowered to room temperature from a high degree causing certain strength increases in the molecular structure to occur) and supposed that continuing the descent would allow for further strength increases. Using liquid nitrogen, CryoTech formulated the first early version of the cryogenic processor. Unfortunately for the newly born industry, the results were unstable, as components sometimes experienced thermal shock when they were cooled too quickly. Some components in early tests even shattered because of the ultra-low temperatures. In the late twentieth century, the field improved significantly with the rise of applied research, which coupled microprocessor based industrial controls to the cryogenic processor in order to create more stable results.

4. APPLICATIONS

A. Some Applications Of Cryogenics:

MRI is a method of imaging objects that uses a strong magnetic field to detect the relaxation of protons that have been perturbed by a radio-frequency pulse. This magnetic field is generated by electromagnets, and high field strengths can be achieved by using superconducting magnets. Traditionally, liquid helium is used to cool the coils because it has a boiling point of around 4 K at ambient pressure, and cheap metallic superconductors can be used for the coil wiring. So-called high-temperature superconducting compounds can be made to superconduct with the use of liquid nitrogen which boils at around 77 K.

Electric power transmission in big cities It is difficult to transmit power by overhead cables in big cities, so underground cables are used. But underground cables get heated and the resistance of the wire increases leading to waste of power. Superconductors could be used to increase power throughput, although they would require cryogenic
liquids such as nitrogen or helium to cool special alloy-containing cables to increase power transmission. Several feasibility studies have been performed and the field is the subject of an agreement within the International Energy Agency.

B. Production

Cryogenic cooling of devices and material is usually achieved via the use of liquid nitrogen, liquid helium, or a cryocompressor (which uses high pressure helium lines). Newer devices such as pulse cryocoolers and Stirling cryocoolers have been devised. The most recent development in cryogenics is the use of magnets as regenerators as well as refrigerators. These devices work on the principle known as the magnetocaloric effect.

5. CONCLUSION

Visual examination of the crack surface specified that the gear tooth failed due to a fatigue crack which transmitted under a rotating bending load, pitting occur under repetition of loading. From the chemical analysis it’s clear that the gear material was En 353 alloy steel. From the stress analysis thus the failure of the gear tooth is mainly due to the improper heat treatment and the hardness of the steel is examined.

REFERENCES