Failure Analysis of Hydraulic Torque Wrench (Drive Shaft) - A Review

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Abstract— In this paper the essential factors required for failure analysis of square drive shaft of hydraulic torque wrench are taken into consideration and discussed in brief. This failure of square drive shaft is taken place due to twisting force acting on the area of square drive shaft during testing of this tool. Hydraulic torque wrenches are designed to handle the toughest bolting jobs accurately and quickly. All models provide a torque accuracy of +/- 3%. All models incorporate an easily reversible high grade alloy steel (DMR 1700) square drive enabling the operator to quickly switch from tightening to loosening applications. DMR-1700 steel is a material used in hydraulic torque wrench for structural applications that has been recently developed at Defence Metallurgical Research Laboratory by changing the chemistry of alloying elements. On the basis of studies by different techniques, DMR-1700 steel is recommended for the manufacture of components used in various systems in conjunction with the application of various defence service and power tool manufacturing. So in this paper the essential factors for failure analysis of square drive shaft of hydraulic torque wrench are discussed in brief.

Key words: Chemical composition of steel, failure cause, design, failure analysis

I. INTRODUCTION

The purpose of failure analysis is entirely positive to prevent further failures. Failures occur when some system or part of a system fails to perform up to the expectations for which it was created. Square drive shaft is one of the component part of hydraulic torque wrench which get failed during calibration or testing of tool[1]. This failure occurs as because of the twisting force acted on shaft end area and it failed to sustain twisting force supplied by the hydraulic fluid from the hydraulic power pack system. Failure of shaft itself is a human concept. Materials do not fail in and of themselves. It follows the laws of nature perfectly. A drive shaft is loaded beyond its tensile strength and it gets breaks as the maximum stress level is reached. When a part fails in service, it was under-designed or poorly manufactured for the circumstances in which it was used.

Analyzing failures is a process in determining the physical root causes of problems. The process is complex, draws upon many different technical disciplines, and uses a variety of observation, inspection, and laboratory techniques. One of the key factors in properly performing a failure analysis is keeping an open mind while examining and analyzing the evidence to foster a clear, unbiased perspective of the failure. Collaboration with experts in other disciplines is required in certain circumstances to integrate the analysis of the evidence with a quantitative understanding of the stressors and background information on the design, manufacture, and service history of the failed product or system. Just as failure analysis is a proven discipline for identifying the physical roots of failures, root-cause analysis (RCA) techniques are effective in exploring some of the other contributors to failures, such as the human and latent root causes. Properly performed, failure analysis and RCA are critical steps in the overall problem-solving process and are key ingredients for correcting and preventing failures, achieving higher levels of quality and reliability, and ultimately enhancing customer satisfaction. This paper briefly introduces the concepts of failure analysis, root-cause analysis, and the role of failure analysis as a general engineering tool for enhancing product quality and failure prevention. The discipline of failure analysis has evolved and matured, as it has been employed and formalized as a means for failure prevention.

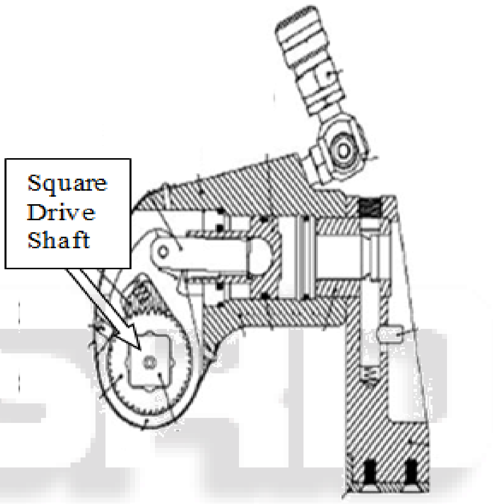

Fig. 1: Assembly of hydraulic torque wrench

A. *Material Failure Analysis:*

A failure analysis is much like the work of a detective. Important clues are discovered throughout the investigations that provide insight into what may have caused the failure and what contributing factors may have been involved. The failure analyst is aided by a broad knowledge of materials in general. Success is more likely if the analyst is aware of the failed material's mechanical and physical properties and its fabrication and historical performance characteristics.

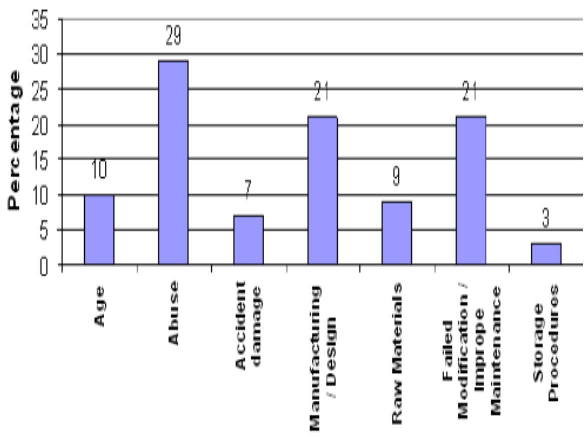

Fig. 2: The common causes of service failure.

The analyst must also possess a working knowledge of structural design and stress when it has deteriorated to the point at which it is unsafe or only marginally capable of performing its intended function. For an item to be classified as a failure it need not be completely broken. As an illustration, consider a fracture as a type of failure. A component is considered to have failed in materials when cracks are initiated and propagate to a greater or lesser degree. They may not go to completion. Cracks may be initiated by mechanical stresses or environmental or chemical influences, by the effects of heat, by impurities in the material or by a combination of these and many other factors [6].

B. Preliminaries: Determine when, where and how the failure occurred

Before beginning any failure analysis, it is vital to determine whether or not destructive testing is permitted or if the testing must be limited to non-destructive approaches.

As a part of this preliminary information gathering, it is also important to obtain the physical and chemical specifications for the product which failed, against which performance may be measured.

Fig. 3: Failure component (DMR 1700 steel) of hydraulic torque wrench by twisting force acting on it.

C. Laboratory Examination:

Samples selected should be characteristic of the material and contain a representation of the failure or corrosive attack. For comparative purposes, a sample should also be taken from a sound and normal section. Surface chemistry must not be contaminated by careless handling. Materials specifications and service history reveal much about the nature of failure. If submitting a sample for analysis, background information will need to be provided. Samples can be removed by acetylene torch, air-arc, saw, trepan, or drill. All cuts with an acetylene torch should be made at least six inches and cuts by air-arc at least four inches away from the area to be examined to avoid altering the microstructure or obscuring corrosive attack.

D. Identify Defects Non-Destructively:

Search for material imperfections with radiography, magnetic particle, ultrasonic, liquid/dye penetrant, eddy current, leak, and/or acoustic emissions non-destructive testing procedures.

E. Conduct Appropriate Chemical Analyses

Chemical analysis should be conducted on the original material to determine if the material was of proper type and grade, whether it met appropriate standards, and whether deviation from the specifications contributed to the fracture, wear, breaks corrosion and failure [3].

1) *Table I: Comparison of Chemical Composition*

Sample Identity		**DMR-1700**	
C %	0.349	C %	0.359
Si %	2.013	Si %	2.00
Mn %	0.467	Mn %	0.512
P %	0.015	P %	0.019
S %	0.007	S %	0.009
Cr %	1.097	Cr %	1.00
Ni %	3.409	Ni %	3.00
Mo %	0.429	Mo %	< 1
Al %	0.015	Al %	0.016
Cu %	0.009	Cu %	0.009
V %	<0.001	V %	<0.002
Nb %	<0.001	Nb %	<0.007
Ti %	<0.006	Ti %	<0.006

Table 1: Comparison of chemical composition between sample tested and standard material [3].

In this paper the sample of material is tested by ASTM E 415 method for the chemical composition test. Atomic Absorption, X-ray Photoelectron, Auger Electron and Secondary Ion Mass Spectroscopies are another potentially suitable methods of chemical analysis, depending on the particular need of the situation.

F. Confirm Material Composition and Identify Contaminants through EDS Analysis:

EDS (Energy Dispersive Spectroscopy) is an analytical method based on the differences in energy of the characteristic x-rays emitted by the various elements. It is used in conjunction with scanning electron microscopy (SEM) to identify the elements present at a particular spot on a sample. Advantages of EDS are that it is easily performed and is reliable as a qualitative method. Limitations are that it is only marginally useful as a quantitative method.

G. Analyze via Fractography:

Fractography is used to determine the mode of fracture (intergranular, cleavage, or shear), the origin of fracture, and location and nature of flaws that may have initiated failure. With this information, the answer as to why a part failed can usually be determined. The major use of fractography is to reveal the relationship between physical and mechanical processes involved in the fracture mechanism. The size of fracture characteristics range from gross features, easily seen with the unaided eye, down to minute features just a few micrometers across. Light and electron microscopy are the two more common techniques used in fractography. An important advantage of electron microscopy over conventional light microscopy is that the depth of field in the SEM is much higher; thus the SEM can focus on all areas of a three-dimensional object identifying characteristic features. The texture of a fracture surface, that is, the roughness and the colour, gives a good indication of the interactions between the fracture path and the microstructure of the alloy. For instance, at low stress a fatigue fracture is typically silky and smooth in appearance.

H. Conduct appropriate mechanical and materials testing and analysis as necessary:

1) Physical Testing:

It may be necessary to conduct physical tests to determine if the mechanical properties of the materials involved conform to specifications [3]. Hardness, tensile strength, impact, fatigue resistance, wear, flexibility and many other physical tests are relatively common. These tests often compare the material in the failed component with standards.

2) Table II: Material Behaviour and Property

SN	Material Property	Laboratory Values	Industrial Values
1	Yeild Stress	$1530*10^{6}$ N/m^{2}	$1560*10^{6}$ N/m^{2}
2	Ultimate Stress	$1890*10^{6}$ N/m^{2}	$1920*10^{6}$ N/m^{2}
3	Elongations	12.6mm	13.4mm
4	Young modulus	200GPa	-
5	Poisons ratio	0.3	-

Table 2: Material behaviour and property

In general, structural members and machine parts can fail to perform their intended functions by:

- Excessive elastic deformation (deflection under applied loads),
- Yielding (permanent material deformation as a result of stress), or
- Fracture.

A study of the mechanical properties of the parts can provide information on load-bearing capabilities of the system and can minimize such failures.

3) Finite Element Analysis:

The finite element method is a powerful numerical tool for analysing mechanical components and systems. The representation of a component or system mathematically with finite elements generally involves a discretization of the structure into many small pieces, e.g. small brick-like elements (hence the name of the method).

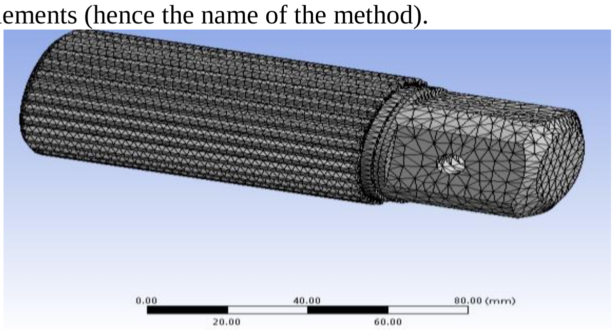

Fig. 4: Meshing component of square drive shaft in ANSYS software

The solution to the equations that govern the behaviour of the structure is approximated on each and every brick. The collective effect of all the bricks is taken into account during a step that synthesizes the solutions for each brick into one solution valid for the entire structure. This global solution represents the solution to the equations that govern the structure's behaviour. The finite element method provides a tool to predict and evaluate component response, elastic or non-linear plastic, subjected to thermal and structural loads[2]. Thermal analyses may include convection, conduction, and radiation heat transfer, as well as various thermal transients and thermal shocks. Structural analyses may include all types of constant or cyclic loads, mechanical or thermal, along with non-linearity's, such as opening/closing of contact surfaces, friction, and non-linear material behaviour.

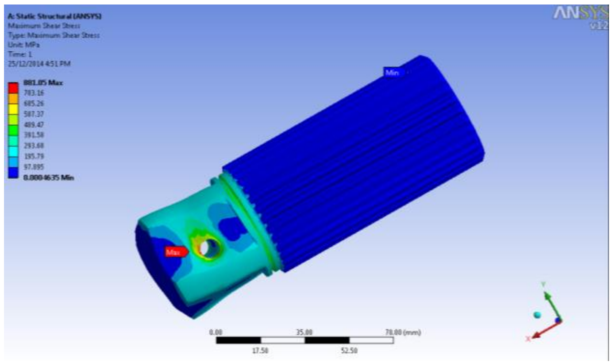

Fig. 5: Static srtuctural analysis by providing turning moment to left end of shaft in theANSYS software.

Finite element analysis can be used during a failure study in such ways as:

- Predicting the response of an existing component or assembly to stress
- Assessment of remaining life of a component or assembly
- Determining the failure mode of a failed component or assembly, e.g. fatigue, creep, and buckling.
- Designing of a new component or assembly as a part of recommendations for remediation of the problem.

4) Fracture Mechanics:

Fracture mechanics relates the size of flaws in a material, principally cracks, to the applied stresses on those cracks and to the "fracture toughness" of the material, or its resistance to cracking. Fractures include both initiation and growth phases. After initiation, perhaps at a pit or some other site of stress-concentration, the crack will only grow when the stresses at the crack tip exceed a critical value known as the "fracture toughness" or KIc. If KIc and the stress conditions are known for a given material, then it is possible to calculate the size of crack that can be tolerated in that material without having the crack grow further.

The following equation shows those conditions. A crack will propagate if:

$$\sigma \geq \frac{K_{Ic}}{\beta \sqrt{\pi a}}$$

Where σ (sigma) is the fracture stress, β (beta) is a dimensionless shape factor and a is the crack length for a crack with only one tip (i.e., not an internal crack, but one opening at a surface). Handbooks for engineering calculations have tables of values for Beta for different geometries.

If the fracture toughness of the material is known, the fracture stress or critical crack size of a component can be calculated. This calculation will allow

- The determination of "permissible flaw size,"

- The determination of the load on a component at the time of failure.
- The determination as to whether adequate materials were used in manufacturing.
- The determination as to whether a part design was adequate.

These data can be used to calculate the toughness, given knowledge of the crack size at the time of final failure. If neither toughness nor stresses are known, toughness can be estimated from physical testing, using Charpy-impact tests on pieces of the material. Thus, fracture mechanics can be used to help us understand

- How a particular crack formed at a specific location and
- The stress conditions that caused the crack to propagate.

The design engineer will normally include "factors of safety" in his design to prevent stresses from reaching critical levels.

I. *Determine the type of Failure:*

The major types of failures likely to be encountered by metals in service are:

(1) Ductile,
(2) Brittle, and
(3) Fatigue fractures

1) *Ductile Fracture:*

Ductile fractures are characterized by tearing of metal accompanied by appreciable gross plastic deformation. The microstructure of the fracture surface is quite complex and may include both trans granular and inter granular fracture mechanisms. Ductile fractures in most metals have a gray fibrous appearance and may be flat-faced (tensile overload) or slant-faced (shear). The specimen usually shows considerable elongation and possible reduction of cross-sectional area as well. Most commonly seen characteristics of ductile failures are:

- Lateral contraction, or necking;
- Tensile stress.

Cylindrical specimens will have a "cup and cone" configuration.

2) *Brittle Fracture:*

Brittle fractures are characterized by rapid crack propagation without appreciable plastic deformation. If brittle fractures occur across particular crystallographic planes they are called Trans crystalline fracture. If along grain boundaries they are called inter granular fracture. Brittle fracture is promoted by:

- thicker section sizes,
- lower service temperatures, and
- Increased strain rate.

3) *Fatigue fracture:*

Fatigue is a progressive localized permanent structural change that occurs in a material subjected to repeated or fluctuating stresses well below the ultimate tensile strength (UTS). Fatigue fractures are caused by the simultaneous action of cyclic stress, tensile stress, and plastic strain, all three of which must be present. Cyclic stress initiates a crack and tensile stress propagates it. Final sudden failure of the remaining cross section occurs by either shear or brittle fracture. Striations on the crack surface are the classic sign of fatigue fracture.

Low cycle fatigue cracks occur under conditions of high strain amplitude (with failure in less than about 10^4 cycles) whereas high cycle fatigue occurs with low strain amplitude with failure after a large number of load fluctuations.

Thermal Fatigue cracking is caused by cycling the temperature of the part in the presence of mechanical constraint, e.g., rigid mounting of pipe. It could also be caused by temperature gradients in the part.

J. *Correcting the heat treatment process:*

This square drive shaft at the beginning were heat treated in the furnace along with the different material components and this method of heat treatment is found to be incorrect for DMR1700 (square drive shaft) alloyed steel material and it is required to be heat treated separately in the furnace with correct heat treatment process in order to meet the recommended hardness value of 50-55 HRC. The corrected heat treatment process for DMR1700 (square drive shaft) alloyed steel material as follows:

Material is placed in the furnace
↓
Material is pre heated at 760°C and Hold for 30 min
↓
Hardening at 925°C and hold for 2.5min/mm wall thickness
↓
Oil quenching till it gets cooled in the oil tank (Meta-quench 32 oil) until room temperature
↓
Tempering at 295°C and holding 5min/mm wall thickness
↓
Air cooling until room temperature
↓
Grind the surface before checking the hardness
↓
Required hardness between 50 to 55 HRC is obtained

II. CONCLUSION

From the observations it is concluded that there is no large variations in the chemical composition and the material of drive shaft is meeting the standard chemical values. Considering the data about yield strength, ultimate strength and elastic limit, the static structural analysis has been made in the ANSYS software. And by correcting heat treatment process for shat material it is found that the required hardness value of 50-55 HRC is obtained by which material able to sustain maximum stress and torque value.

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