Case study: Optimization of Case Depth in Induction-hardened 42CrMo Steel Shaft

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Abstract. Low alloyed high-grade chrome-molybdenum ferritic steel transmission output shaft was investigated. The medium-carbon steel which is commonly used induction hardened transmission components and drive shafts in the automotive industry. The aim of this experiment is achieve the case depth that spline shaft design requirement. The required case depth for design the proper induction hardening coil and varying the parameter of it has been achieved. The results agree well with literatures, that optimum case depth maximizing the strength and fatigue life of spline shaft.

1. Introduction

Heavy machinery splined shafts commonly used to transfer the high torque, choice of hardening process is crucial to achieve an optimal strength of the part[1]. Induction hardening heat treatment commonly applies for spline shafts, which enhance the torque capacity of the shaft. The strength of the spline connection mainly depends upon material strength and spline design. Last decade several researches published have defined spline shaft and non-spline shaft’s strength, hardness depth, fatigue life and failure. These parameters may be able to optimize by adjusting the parameters of induction hardened process parameter [2]–[8].

The process of induction hardening has been carried out for long time by several researchers. However, its application for studying the hardness profile sensitivity on the material or coil design and/or as a function of machine parameters are still rather rare. Furthermore, the effect of machine parameters and coil design on the hardness profile has limited studied and documented[2].

The analysis presented in this case study to optimize the hardness depth from hardening process of heavy duty machinery splined shaft by taking into account the detailed effect of the geometry of spline.

2. Geometry of the splined shaft

In this case study uses the transmission splined shaft 260 mm in length with both ends splined. Splined shaft parameters are tabulated in table 1. Figure.1 pictorial cross-section transmission splined shaft used in
this case study.

| Spline | No. of Teeth | Pressure angle | Major diameter (mm) | Minor diameter (mm) |
|--------|--------------|----------------|---------------------|---------------------|
| A      | 22           | 30'            | 72.28-72.25         | 65.633              |
| B      | 17           | 30'            | 63.73-63.7          | 56.134              |

**Figure 1.** Splined Shaft Cross-section View

3. Mechanical Properties of 42CrMoH
The 42CrMoH (SAE 4140) medium-carbon steel, it is commonly used in automotive industry. This material is suitable for induction hardened components [8], [9]. The chemical composition and mechanical properties tabulated in Table 2.

| Chemical Composition | C   | Si  | Mn  | P    | S    | Cr  | Mo  | Ni  | Ti  |
|----------------------|-----|-----|-----|------|------|-----|-----|-----|-----|
| Value                | 0.449 | 0.26 | 0.79 | 0.019 | 0.003 | 1.17 | 0.19 | 0.03 | 0.0019 |

| Hardenability | Technical Specification | J5 | J9 | J15 |
|---------------|-------------------------|----|----|-----|
| Value         | 56.99                  | 55.42 | 51.25 |

4. Experiment

4.1 Sample Preparation and Hardness profile
In this case study, medium carbon steel rods hardening & tempering to achieve the hardness (HRC 28.5, 28.7, 27.9, 28.9). These four samples were machined as per the print requirement. Samples simplified CAD model as shown in Figure 1, and detail of the spline tabulated in table 1.
Furthermore, the hardness profile requirement defined in the Figure 2 and required case depth tabulated in table 3 and finished part hardness requirement $\geq$ 48HRC.

**Table 3. Case Depth Requirement**

| Section | Speciation           | Value         |
|---------|----------------------|---------------|
| A       | Width                | 40.64-66.04mm |
| B       | Case Depth (CD)      | 7.525-11.7mm  |
| C       | Case Depth (CD)      | 7.525-11.78mm |
| D       | Case Depth (CD)      | 7.257-11.7mm  |
| E       | Case Depth (CD)      | 0.762-4.842mm |
| F       | Width                | 0-11.7mm      |

4.2. *Design and Process Considerations*

It is critical not only to meet the hardened depth requirement, but also prevent excessive heating in such area as, B, C, D, and E. Excessive heat in these regions may cause the crack on the surface and lead to excessive distortion.

The inductor needs to be designed carefully to prevent cracking possibility and excessive distortion issues. This part has a 0.762-4.842mm min pattern depth. Typically, it would use 10 KHz for anything up to 6.35 mm case depth. Heating beyond that depth loses the benefit of frequency penetration and requires heating by conduction. These results in slower travel that can lead to surface overheat. For effective heating at this depth would typically choose a machine with a nominal output frequency of 3 KHz. That frequency will effectively penetrate to the minimum depths required resulting in faster and minimizing the chance for surface overheat. With these deeper case depths quench capacity is also a concern. Due to the surface area parts like this are typically scanned due to power constraints with a machined Integral quench (MIQ) coil Figure 3.
5. Results and Discussion

The results from the experiment of the two samples are measured with a vernier caliper. These two samples of spline shaft result compare the case depth, which is defined in Figure 4 and data tabulate in Table 4.

![Figure 4. Hardness Profile and Depth, left side sample #1, and right side is Sample #2.](image)

### Table 4. Case depth Comparison

| Section | Specification | Value         | Sample #1 | Sample #2 |
|---------|---------------|---------------|-----------|-----------|
| A       | Width         | 40.64-66.04mm | 43.9 mm   | 43.75 mm  |
| B       | Case Depth (CD) | 7.525-11.7mm | 12.1-13.5 mm | 9.05-9.09 mm |
| C       | Case Depth (CD) | 7.525-11.78mm | 12.5 mm   | 8.6 mm    |
| D       | Case Depth (CD) | 7.257-11.7mm | 11.9 mm   | 9.2 mm    |
| E       | Case Depth (CD) | 0.762-4.842mm | 4.34-5.6 mm | 2.73-4.34 mm |
| F       | Width         | 0-11.7mm      | 0 mm      | 0 mm      |

The induction heat treatments were conducted to achieve required case depth by varying the frequency 4 KHz to 8 KHz and distance between coil and small diameter. The hardened surface layers (cases) of the undercut, spline and flat segment of these samples are presented in Figure 4. The non-transformed core and the transition layer between the case and the core can also distinguish. The higher case depths achieved by increased heating power.
In detail, the case layers of sample #2 (as it fulfills the requirement) have martensitic microstructure (Figure 5). The transition layers are characterized by microstructures composed of martensite and ferrite.

6. Conclusion

The current case study presents an induction hardening spline shafts by taking into account the case depth of spline shaft. It can be concluded that required case depth at vary area (undercut, under spline teeth, varying diameter and transition of diameter) achieved by 3 KHz to 8 KHz with help of special designed induction coil. The nominal required case depth value without surface crack has been achieved. The optimum hardness depth for hardened shaft obtained nearly to the half of the shaft radius. As the subsurface crack initiation with increase the hardness depth due to increase of residual stresses in the core, which is detrimental for fatigue life.

7. Reference

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**Acknowledgments**

This work supported by Research Program supported by the Science & Technology Bureau of Yuhuan, and the Taizhou city government, Zhejiang P.R. China.