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Physics Procedia 50 (2013) 103 – 112

Physics Procedia

International Federation for Heat Treatment and Surface Engineering 20th Congress
Beijing,China,23-25 October 2012

Study of effect of quenching deformation influenced by 17CrNiMo6 gear shaft of carburization

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Abstract

The 17CrNiMo6 steel is mainly used for the gear shaft of large modulus in many fields of heavy industry such as mining, transit, hoist, forging and so on[1]. The size of addendum circle and common normal line is changed a lot beyond the tolerance because of the long time of carburizing process and the out-of-step structural stress and thermal stress during the quenching process. And thus the posterior grinding efficiency and quality are influenced. In the paper comparison and analysis of the deformation affected by solid and hollow gear shafts were done and the methods of simulation and practice were both used. The results are as follows: the deformation of gear shaft was small before and after carburizing while that of gear shaft was large before and after quenching because of different cooling velocity, structure and hardness of each position. And the deformation of hollow was much smaller than that of solid. Therefore, if the hollow gear shaft is used, the waste of material will be decreased, and finishing cost will be reduced, and thus the technology of heat treatment will be optimized.

Selection and peer-review under responsibility of the Chinese Heat Treatment Society

Keywords: 17CrNiMo6 ;gear shaft ; quenching deformation ; simulation ; the optimization of structure

1. Background of study

Heavy haul gear is the gear used to transfer force and endure the larger load, and is mainly used in many fields of heavy industry such as mining, transmit, hoist, forging and so on. Heavy haul gear usually needs to endure working

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Selection and peer-review under responsibility of the Chinese Heat Treatment Society
doi:10.1016/j.phpro.2013.11.018

stress which is almost the allowed stress of the material. And thus it is supposed to have abilities of high impact resistance and anti-overloading besides good wear resistance, high contact fatigue strength and bending fatigue strength. Therefore, the material of heavy haul gear is structure steel of low carbon alloy steel. And enough strength and toughness can be kept at the heart position after carburizing, quenching, and tempering at the low temperature. And thus there is quite high hardness on the surface and then composite is formed so that it can endure very large impact load， contact stress and wear. There are relatively systematic standard limits on choices of steel because of differences of natural resources and traditional use of steel. And certainly the choices of steel for carburizing of heavy haul gears. However, the choices of Cr-Ni, Cr-Mo, Cr-(Men)-Ni-Mo are still used for large part of carburizing steel. With the proceeding of energy-saving tide all over the world and continuously using of new technologies, the potential of materials is excavated gradually. 17CrNiMo6 of Cr-Ni-Mo steel introduced by German (and that is17Cr2Ni2Mo in our country) is being widely used because of its good comprehensive properties. As the hardenability of 17CrNiMo6 steel is high, there will be large deformation during carburizing and quenching processes on condition that the gear shaft is made of the material. The posterior grinding depth will be increased, and the production cost will thus be improved because of large deformation. And it will also influence manufacturing accuracy of gears and decrease enduring ability and the service life of the gear shaft will be reduced largely. Therefore, the decreasing of deformation of gears during carburizing and quenching processes has already become an important subject. The deformation of gear shaft of carburizing is related to many aspects, such as structure, materials, technologies of heat treatment, cold processing technology and so on. The effect of deformation influenced by the structure of gear shaft was taken as an example in the paper, and the method of simulation combined with producing was used, and the study of factors leading to the deformation of carburizing and quenching gear shaft. And therefore the law of the deformation is expected to be found. And the bearing capacity and can be improved by reducing deformation using control measures.

2. Main research contents

2.1. The law of quenching deformation of gear shaft

The conclusion is that the deformation of large gear shaft is closely related to external diameter, width of gears, helix angle and so on. And that it is closely related with each other among deformations was obtained by measurement and analysis of carburizing and quenching deformation of large gear shaft during practical production. The two kinds of deformation as follows usually happened after carburizing and quenching of gear shaft by analyzing and study:

1) One kind of deformations was that the diameter of addendum circle was tend to become smaller, and it was lager or smaller at different position on the same ax. The external diameter on the two ends of gear was a little larger, but it was smaller at the middle of gear and the width of gear was larger and the deformation is more obvious.

2) The other kind of deformations was deformation in the direction of gears. Helix angle was larger and modulus was larger, and the depth of carburizing layer was tend to increase the deformation in the direction of gears. And the two kinds of deformations were showed as follows in Fig. 1.

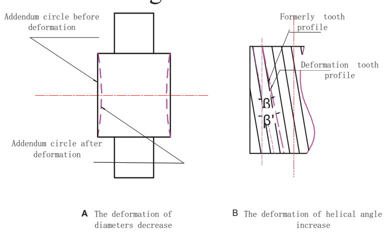


Fig. 1 schematic diagram of addendum circle and helix angle of large gears after quenching

(Solid line is before quenching and dashed line is after quenching)

2.2. The statistical and analysis of deformations of solid gear shaft

The chemical composition of 17CrNiMo6 (Standard of German) was showed in Table.1 as follows.

Table.1 the chemical composition of 17CrNiMo6

C	Si	Mn	P≤	S≤	Cr	Ni	Mo	others
0.14~0.19	0.17~0.37	0.40~0.60	0.035	0.035	1.50-1.80	1.40-1.70	0.25-0.35	Al≤0.05 Cu≤0.30

17CrNiMo6 concludes elements to form carbides which can reinforce the stability of austenite and elements which can reinforce ferrite, and both are influenced by each other, and thus the kind of steel has better hardenability, so that the hardness at heart position of large modulus-gear is guaranteed. The temperature at the critical point was showed in Table.2 as follows.

Table.2 the critical point of the phase transition（℃）of 17CrNiMo6

Ac1	Ac3	Ar3	Ar1	Ms
730	820	735		310

The representative law was analyzed by actual measurement and tracking intended for the change of size of addendum circle and common normal line of large modulus gear shaft during carburizing and quenching process in practical production.

The change of size of addendum circle and common normal line intended for solid gear shaft before and after quenching is showed in Table.3 and Table.4 as follows.

Table.3 The change of size of common normal line intended for Solid gear shaft before and after quenching (mm)

The kinds of forged piece	The measurement position	Before carburizing	Before quenching	After quenching	deformation before and after carburizing	deformation before and after quenching
A	up	324.15	324.02	323.78	-0.13	-0.34
	middle	324.10	324.00	323.51	-0.10	-0.49
	down	324.15	324.06	323.84	-0.09	-0.12
B	up	421.35	421.40	421.11	+0.05	-0.29
	middle	421.35	421.30	420.40	-0.05	-0.90
	down	421.40	421.50	421.50	+0.10	0
C	up	232.55	232.45	232.90	-0.10	+0.35
	middle	232.65	232.50	232.64	-0.15	+0.14

	down	232.55	232.60	232.88	+0.05	+0.28

Table.4 The change of size of addendum circle intended for Solid gear shaft before and after quenching (mm)

The kinds of forged piece	The measurement position	Before carburizing	Before quenching	After quenching	deformation before and after carburizing	deformation before and after quenching
A	up	651.51	651.45	650.97	-0.06	-0.48
	middle	651.49	651.25	650.03	-0.24	-1.22
	down	651.48	651.70	650.45	+0.22	-1.25
B	up	848.07	847.62	847.28	-0.45	-0.34
	middle	848.16	847.61	845.77	-0.55	-1.84
	down	848.03	847.81	847.26	-0.22	-0.55
C	up	750.15	750.12	749.22	-0.03	-0.90
	middle	750.17	750.35	748.54	+0.18	-1.81
	down	750.25	750.42	749.97	+0.17	-0.45

The size of common normal line was larger or smaller, but deformation was not large before and after carburizing by Table.3 and Table.4. It is almost smaller before and after quenching, and reduction at the two ends of common normal line was much larger than that at the middle of common normal line.

The difference of cooling velocity at three positions above could be discovered by comparison and analysis of cooling velocity at each position, structure and hardness of gear shaft during cooling process. And the difference of cooling velocity at each position, that of surface, transition area, and the heart position and asynchronism of structure transition are main reasons for deformations of gears. The asynchronism of structure transition is the main reason leading to deformations of gears.

2.3. Simulation of quenching deformation of solid and hollow gear shaft

Firstly simulation was done intended for deformation situation of hollow and solid gear shaft, and schematic diagram of hollow and solid gear shaft were showed in Fig.2 and Fig. 3 as follows.

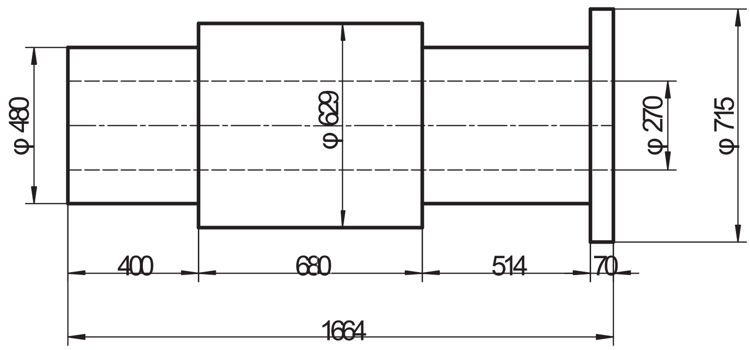


Fig. 2 Schematic diagram of hollow gear shaft

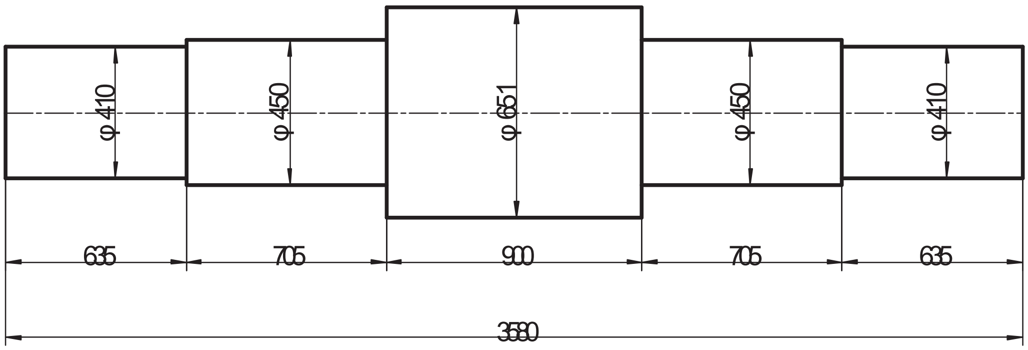


Fig. 3 Schematic diagram of solid gear shaft

The quenching simulation procedure of solid and hollow gear shaft was showed in Fig.4 as follows:

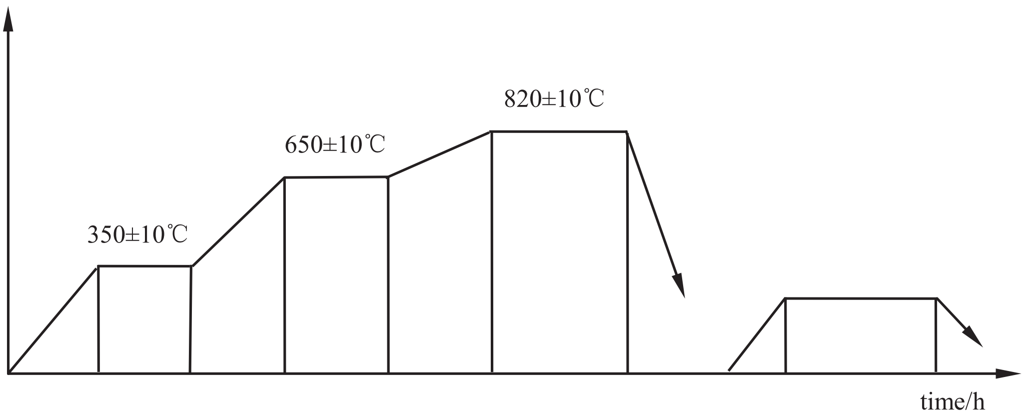
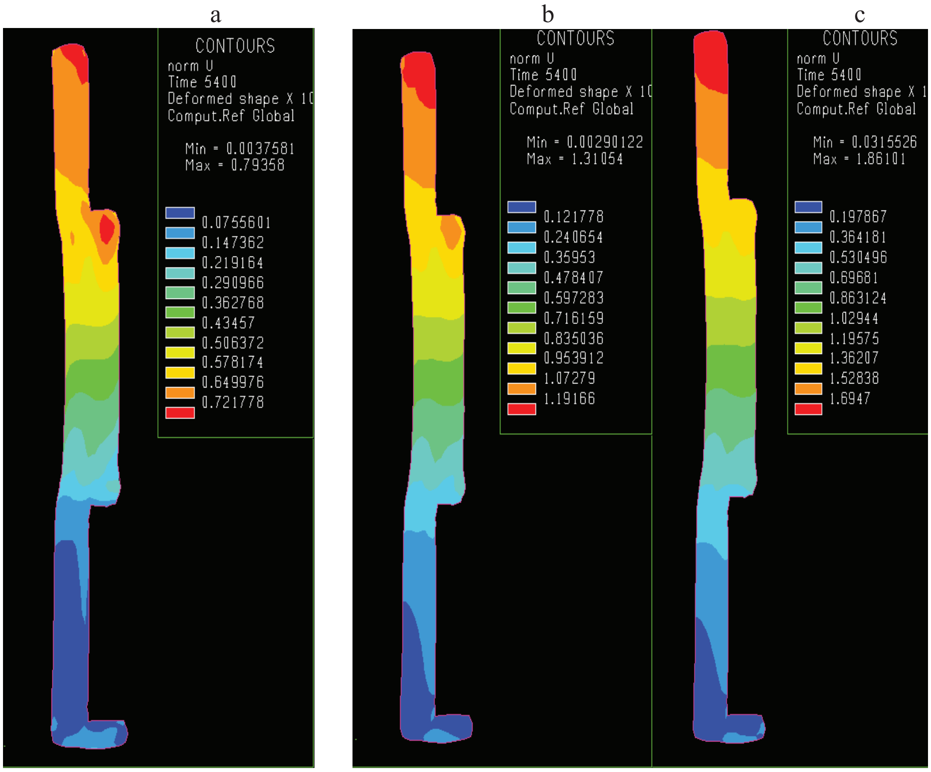


Fig.4 Quenching procedure

The simulation of quenching deformation of hollow and solid gear shaft at different medium temperatures was showed in Fig.5, Fig.6 and Table.5.

Table.5 The relationship between quenching oil temperature and the largest deformation

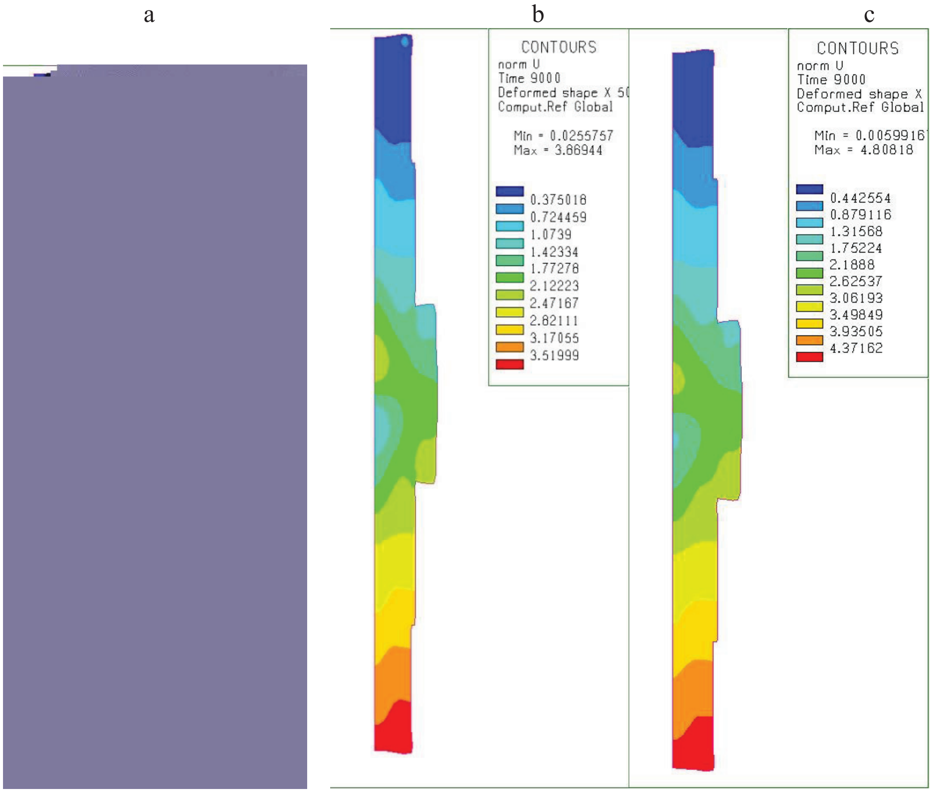
Temperature of medium	The largest deformation of hollow shaft （mm）	The larges deformation of solid shaft（mm）
Oil temperature 40℃	0.79	2.9
Oil temperature 60℃	1.31	3.9
Oil temperature 80℃	1.86	4.8



(a) hollow cooled in 40℃ oil (b) hollow cooled in 60℃ oil (c) hollow cooled in 80℃ oil

Fig. 5 Simulation of quenching deformation of hollow gear shaft

at different temperatures of medium（100X）



（a） solid cooled in 40℃ oil (b) solid cooled in 60℃ oil (c) solid cooled in 80℃ oil

Fig.6 Simulation of quenching deformation of hollow gear shaft

at different temperatures of medium（100X）

The largest quenching deformation of hollow and solid gear shaft was both larger with the larger medium temperature at 40℃, 60℃, 80℃ by the simulation results in Fig.5, Fig.6 and Table.5. The deformation of hollow gear shaft was obviously smaller than that of solid gear Shaft.

2.4. data statistical and analysis of deformation of hollow gear Shaft

The detection and analysis were done intended for the sizes of addendum circle and common normal line of three hollow gear shafts during practical production. And the sizes of addendum circle and common normal line before and after quenching were showed in Table.6 and Table.7.

Table.6 Size change of addendum circle of hollow gear shaft before and after quenching (mm)

Situation		Before quenching		After quenching		distortion	
the measuring position number of forged piece		0°	90°	0°	90°	0°	90°
D	Up	629.30	629.27	629.65	629.47	+0.35	+0.20

	middle	629.28	629.10	629.55	629.13	+0.27	+0.03
	down	629.35	629.32	629.57	629.53	+0.20	+0.20
E	Up	629.21	629.23	629.45	629.47	+0.23	+0.24
	middle	629.07	629.14	629.20	629.34	+0.13	+0.20
	down	629.21	629.25	629.45	629.43	+0.24	+0.18
F	Up	628.88	628.93	629.26	629.19	+0.38	+0.26
	middle	628.80	628.79	628.81	628.79	+0.01	0
	down	628.83	629.01	629.17	629.07	+0.34	+0.06

Table.7 Size change of common normal line of hollow gear shaft before and after quenching (mm)

Situation		Before quenching		After quenching		distortion	
measurement position Number of forged piece		0°	90°	0°	90°	0°	90°
D	Up	275.90	275.94	276.08	276.08	+0.18	+0.14
	middle	275.81	275.70	275.96	275.88	+0.15	+0.18
	down	275.92	275.88	275.98	276.08	+0.06	+0.20
E	Up	276.05	176.10	276.08	276.10	+0.03	0
	middle	275.88	275.85	275.90	275.90	+0.02	+0.05
	down	276.10	276.10	276.10	276.12	0	+0.02
F	Up	275.94	275.90	275.08	276.08	+0.14	+0.18
	middle	275.80	275.84	275.88	275.88	+0.08	+0.04
	down	275.88	275.90	276.28	276.28	+0.40	+0.38

The sizes of addendum circle and common normal line were all larger after quenching. The reduction of sizes at the middle position was small. Compared to the size of addendum circle and common normal line of solid gear shaft, the size at the two ends was a little larger and it was much smaller at the middle position, and thus distortion was obviously better. And the cooling situation of hollow gear shaft was average because internal and external were both cooled during the cooling process. And moreover the cooling velocity of hollow gear shaft was faster than that of solid gear shaft, and thus distortion was smaller and the strength at the heart position was improved.

2.5. Hardness detection of hollow and solid gear shaft

Hardness detection of hollow and solid gear shaft was showed in Table. 8 as follows.

Table. 8 Hardness detection of hollow and solid gear shaft (mm)

Number of products	Hollow structure		Number of products	Solid structure	
	Hardness of gear surface（HRC）	Hardness of shaft neck（HRC）		Hardness of gear surface（HRC）	Hardness of shaft neck（HRC）
D	59	38	111-1337	58	35
E	58	39	111-1336	57	36
F	60	39	111-1026	59	35

It is showed from Table. 8 that hardness of the surface of hollow and solid gear shaft was a little increased after quenching, and that hardness of hollow gear shaft at the shaft neck position was obviously higher than that of solid gear shaft after quenching. And therefore the strength at the heart position was increased so that the service life was improved.

The deformation situation in the direction of gears of hollow gear shaft by gear hobbing machine was showed in Table.9 as follows.

Table.9 The situation of deformation in the direction of gears (mm)

Number of gear shaft	detection in the direction of gear（gear surface on the left）				detection in the direction of gear（gear surface on the right）				Type of machines
	1	2	3	4	1	2	3	4	
D	0.3	0.25	0.25	0.3	0.3	0.25	0.25	0.3	RFW-16S
E	0.35	0.3	0.2	0.35	0.35	0.3	0.2	0.35	RFW-16S
F	0.45	0.4	0.3	0.3	0.4	0.35	0.3	0.3	RFW-16S

There was no size beyond tolerance after the procedures of addendum circle grinding and gear grinding intended for these seven experimental shaft. It is demonstrated that the method is feasible and the theoretical analysis of reasons for the distortion of heat treatment is proved. Therefore，it is necessary to analyze cooling and thermal technologies of the structure of products and thus more reasonable technology and processing methods can be found.

3. Conclusion

The distortion during carburizing and quenching of 17CrNiMo6 gear shaft mainly happen in the carburizing process and the quenching distortion is largely influenced by the structure of gear shaft. And thus the distortion of common normal line of gear shaft was reduced by 0.3 mm on average and the residual of gear grinding reached the international standard after carburizing and quenching by changing the structure of gear shaft and changing solid into hollow shaft on condition that the using properties of gear shaft is not influenced. The optimization of the structure of gear shaft not only reduces the energy waste during the quenching process, but the cost is also lowered and the overall quality of gear shaft is improved.

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