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A real-time measuring technology for studying distortion of hydraulic turbine blade castings during heat treatment process

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Abstract: During heat treatment process, the distortion behavior inevitably appears in hydraulic turbine blade castings. In this research, a technology was developed for real-time measurement of the distortion in hydraulic turbine blade castings at the still air cooling and forced air cooling stages during heat treatment process. The method was used to measure the distortion behavior at the cooling stages in both normalizing and tempering processes. At the normalization, the distortion at the blade corner near outlet side undergoes four stages with alternating bending along positive and negative directions. At the tempering stage, the distortion could be divided into two steps. The temperature difference between the two surfaces of blade casting was employed to analyze the distortion mechanism. The measured results could be applied to guide the production, and the machining allowance could be reduced by controlling the distortion behavior.

Key words: real-time measuring; distortion; hydraulic turbine blade casting; heat treatment

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Heavy steel castings are the key units in some important equipment. In casting production, it is of great potential to reduce cost through savings in raw materials, energy, etc, which has become more and more attractive to many companies. For this reason, the optimization design of the casting shape has been paid much more attentions due to its great importance for reducing the machining allowance of castings.

During heat treatment process, the deformation behavior often occurs in castings for the thermal stress, transformation stress, etc^[1,2]. The thermal and transformation stresses in castings are affected by the cooling rate, casting geometrical shape and other factors^[3]. The deformation behavior is one of the influencing factors to the design of machining allowance of castings. For that, some numerical simulations on the deformation behavior of castings in production have been carried out, to predict some important information about the

deformation^[4]. The FDM/FEM analysis system for thermal-stress field developed by Kang, et al was successfully applied to predict the deformation and thermal-stress field of a blade casting during heat treatment process^[5]. The thermal stress in a blade during casting process was simulated by Li, et al^[6], and some technical approaches were proposed for improvement in accuracy of the blade castings. The authors^[7] have developed a method for integrated simulation of the deformation behavior of castings during casting and heat treatment processes with a unified finite element model. This method is firstly to analyze the deformation of castings during casting process with the model containing mold and casting, then to update the geometry of casting after casting process, and then to analyze the deformation of castings during heat treatment process, from which the final geometry shape of casting before machining could be predicted. This method was applied to simulate the distortion behavior of a hydraulic turbine blade casting in production. However, for heavy castings, there are very few reports on measuring the casting deformation behavior in production, and sometimes the deformation of the heavy hydraulic turbine blade castings can not be predicted precisely just with the simulation results for complex production conditions.

The results from real-time measurement of the casting deformation process could directly guide the production. Kessler, et al^[8] carried out some experimental study on the

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distortion phenomena in manufacturing chains by using the method of Design of Experiments and a statistical analysis of the results. The Design of Experiments method was also used to analyze the process parameters that affect the distortion of disks in heating, quenching, etc. by Clausen, et al ^[9]. However, the castings covered in above studies are smaller compared to the heavy steel castings which generally weigh more than 5 t, and the above mentioned methods are scarcely employed in the analysis of the distortion behavior of heavy castings.

It can be seen from the previous studies that prediction of the casting distortion behavior in production is important, especially for the complex castings. In this paper, the authors developed a real-time measuring technology for the distortion of heavy steel castings, and with this method, measured the distortion in a hydraulic turbine blade casting at the cooling stages of normalizing and tempering processes.

1 Measuring technology

During heat treatment process, the distortion of blade castings is a kind of different local movements. The illustration of blade distortion is given in Fig. 1. For this reason, the distortion behavior could be measured through measuring the dynamic displacement ^[10]. The method for measuring the distortion of castings during heat treatment is in the process of patent application.

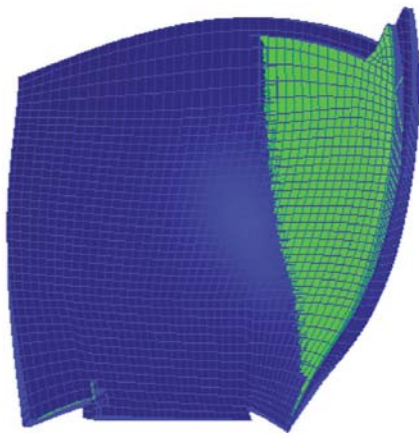


Fig. 1: Illustration of the blade distortion ^[7]

The sizes of some heavy blade castings are greater than 2,000 mm, and the distortion at blade corner can also be greater than 100 mm. So an equipment of resolution within 1 mm could be employed to measure the distortion of blade castings during heat treatment process. Figure 2 shows the measuring system of distortion behavior of castings, which consists of monitoring PC, laser measuring equipment, high speed serial network and casting.

The laser measuring equipment is the key in the system, which is employed to measure the distance between the equipment and points on casting (named as L_{EP}). During the distortion process, the L_{EP} will change when the laser measuring equipment is placed in a certain position. So the variation of L_{EP} could show the distortion:

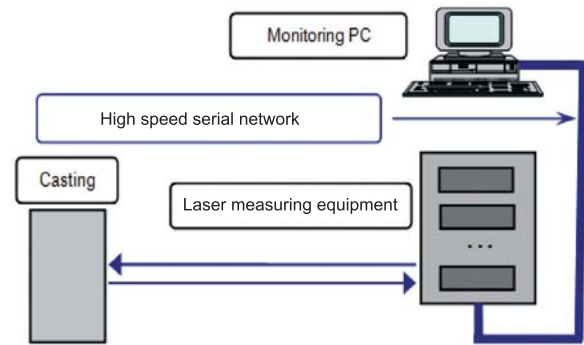


Fig. 2: The measuring system

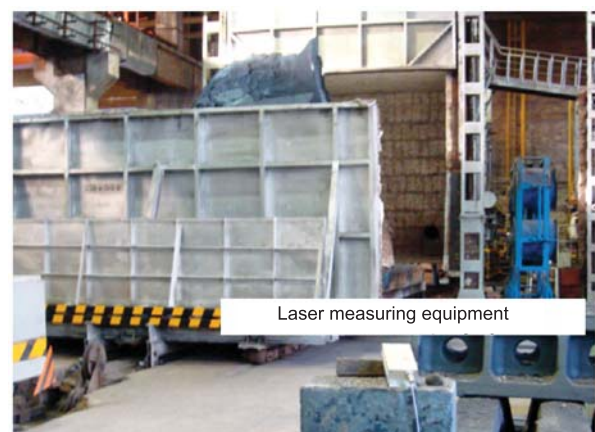
$$\Delta L_{EP} = L_{EPi} - L_{EP0}$$

where L_{EPi} and L_{EP0} are the L_{EP} at t_i and t_0 , respectively.

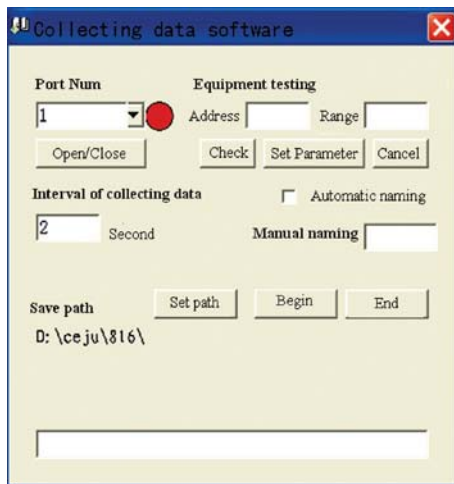
The function of the monitoring PC is to record the data and the time through high speed serial network. The laser employed in the system can penetrate the air well, but it is unable to penetrate the aerosol media environment. So the system could be well used in the forced air cooling or still air cooling condition, but it would be expected to have difficulties in measuring at the mist cooling conditions.

2 Measuring the distortion of a hydraulic turbine blade casting during heat treatment process

According to the measuring technology described above, the distortion behavior of a heavy hydro turbine blade casting during heat treatment was measured. The laser measuring equipment is shown in Fig. 3(a), which could precisely measure the distance within 50 meters. The software for collecting data is shown in Fig. 3(b), where the data collection interval is designed at one second or greater, with actual interval of five second employed in this case. The data acquisition software could collect four sets of data at the same time. In Fig. 1, the maximum displacement appears at the corner of blade near outlet side, while the displacement is relatively small near the blade inlet side. Therefore, in production, the distortion at these two points in the blade casting was measured, as shown in Fig. 3(c).



(a) Measuring equipment



(b) Software for collecting data



(c) Measured position in blade

Fig. 3: Measuring the distortion of blade

In production, the maximum boundary dimensions of the blade casting are: 4,720 mm × 3,340 mm × 200 mm, and the thickness of blade casting from the inlet to the outlet side is 200 mm – 40 mm. For the poured blade casting using ZG0Cr13Ni4Mo alloy, its gross weight is 17 t (excluding riser). During normalizing process, it was firstly heated to about 1,020°C, and then was cooled with forced air at a speed of about 10 m/s. During tempering process, the blade casting was heated to about 610°C, followed by still air cooling. The maximum room temperature was about 27°C when the measurement was carried out. To minimize the measuring

error from high temperatures exposed on the laser measuring equipment, the unit was placed at side near the door of the furnace with a suitable distance.

Figure 4 shows the distortion behavior in the normalizing process. It can be seen in Fig. 4(a) that the distortion at P1 ranged up to 110 mm, and that two peaks and a valley appeared in the distortion process. The first peak appeared after 50 minutes of cooling, followed by the valley after 220–240 minutes. The second peak appeared after 500–520 minutes of cooling. Compared to the distortion at P1, the distortion at P2 is small and its final distortion could be neglected.

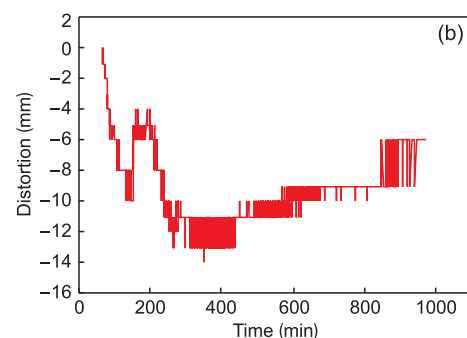
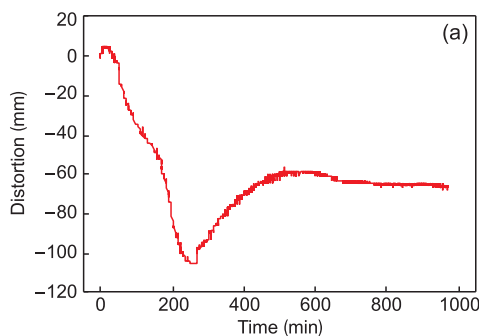


Fig. 4: Distortion at P1 (a) and P2 (b) positions in blade casting during normalizing process

Figure 5 shows the distortion of the blade castings in tempering process. Clearly, the distortion developed at blade was along one direction, and the final distortion at P1 reached 45 mm.

Given machining allowance of casting depends on the control of final distortion. Usually, a large machining allowance is set because the distortion behavior is hardly controlled to ensure final shape and minimum machining value in production. However, it greatly affects the production cost and the casting quality in production. Relatively large machining allowance will result in extension of machining

period and cost. Nowadays, the machining allowance of casting in China is set much larger than that of advanced level for poor casting deformation control during casting and heat treatment [11]. For castings like the hydro turbine blade, reducing the machining allowance will significantly decrease the gross weight of the casting, bringing in a lot of benefits. At the same time, the properties near the casting surface are generally better than that of the internal for its higher cooling rate. So, it might also improve the surface performance of final product as the machining thickness is decreased.

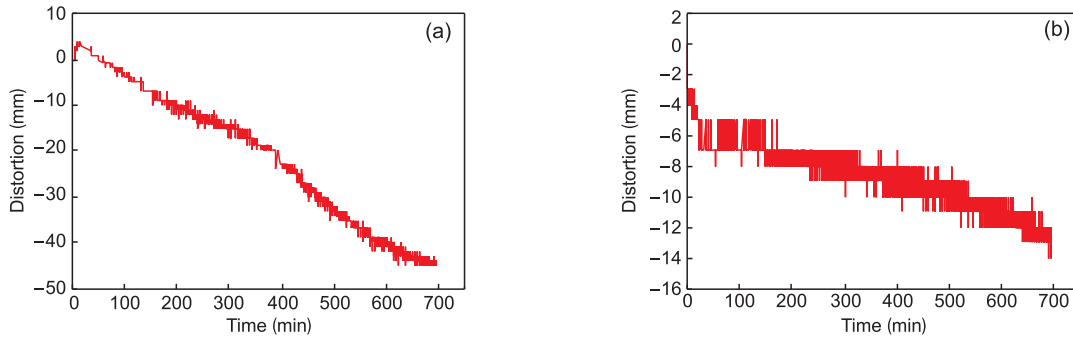


Fig.5: Distortion at P1 (a) and P2 (b) positions in blade casting during tempering process

3 Discussion of the distortion at P1 in blade casting during normalizing process

When the blade castings were lifted off the furnace, they were cooled by fans, as shown in Fig. 3 (a). For unveiling distortion mechanism of the blade casting during normalizing process, a coupled fluid-thermal finite element analysis on the forced cooling process of blade castings was carried out on the platform of workbench. The fluid was considered as ideal air, and the blade was steel material.

Figure 6 shows the distribution of temperature difference between two surfaces of the blade after cooling for (a) 50 minutes, (b) 200 minutes and (c) 500 minutes. The material of the measured blade casting is a martensitic stainless steel with a starting temperature of 276°C for martensite transformation. When the blade casting was set in the furnace, its temperature field was uniform, and the temperature difference between the two surfaces of the blade casting was zero. After cooling of 50 minutes, the temperature difference near the blade corners

increased. At this stage, the distortion was influenced by the thermal effect because the temperature in blade casting was greater than the starting temperature for martensite transformation. Consequently, when the temperature difference increased, the distortion along positive direction gradually increased. When the temperature in blade casting was lower than the martensitic transformation temperature, the distortion of the blade casting would be affected by both thermal effect and phase transformation. The martensite transformation is expansive, and therefore, in this period, the blade castings would distort along negative direction with the increasing phase transformation. Further cooling would drop the back side temperature of the blade casting below the starting temperature for martensitic transformation, triggering the phase transformation in that part of the casting. Meanwhile, the phase transformation had finished in part of the zone in front side of the blade casting, making the blade distort along positive direction. With the decreasing temperature difference between two surfaces of the blade casting, the distortion behavior at the corner of the blade castings would decrease.

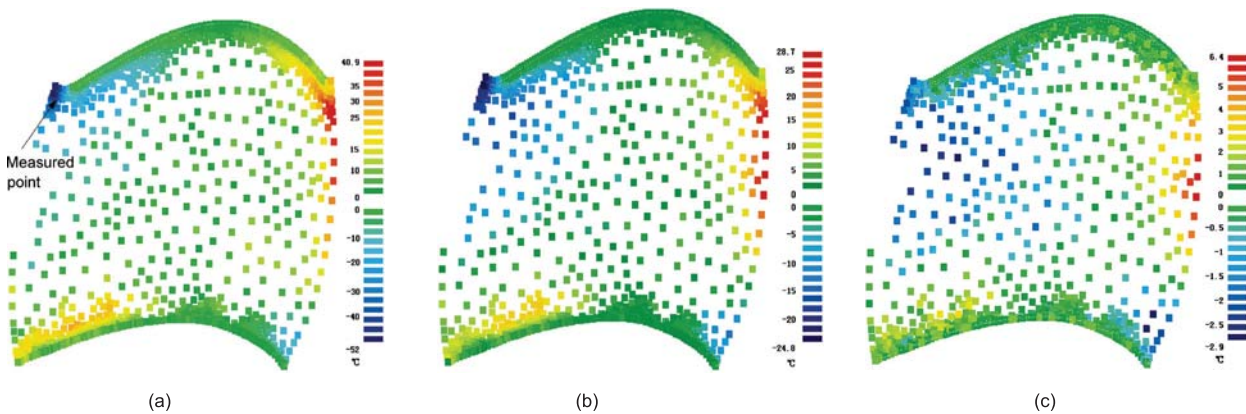


Fig.6: Temperature difference between blade surfaces after cooling of 50 (a), 200 (b) and 500 (c) minutes

4 Conclusions

(1) A real-time measuring system with laser equipment was established to measure the distortion behavior of hydro blade casting during heat treatment processes. The method could be well used in the environment without aerosol, such as forced air cooling, while the real-time measuring technologies for the environment with aerosol should be developed further.

(2) The real-time measuring technology was applied to measure the distortion behavior of blade during heat treatment process. Under the certain production conditions, the distortion at blade corner near outlet side could reach 110 mm in the normalizing process and that at blade center zone was small. The distortion in the blade was about 50 mm in tempering process.

References

- [1] Yonetani S, Notoya H, Shibata K, Takatsuji Y. Residual stress and distortion in AC3A aluminum castings by grinding. *Journal of Japan Institute of Light Metals*, 1989, 39 (1): 25–31.
- [2] Song Jinzhu, Wang Yaoxian. Repairing the distorted large iron casting using hot-creep recovery Theory. *Heat Treatment of Metals*, 2005, 30 (9): 86–87.
- [3] Chen Lugui, Ling, Yong Kang, Xiuhong, Xia Lijun, Li Dianzhong. Numerical simulation of stress and deformation for a duplex stainless steel impeller during casting and heat treatment processes. *Journal of Materials Science and Technology*, 2008, 24 (3): 364–368.
- [4] Zhong Huipng. Study of effect factors on thermal stress of casting steel during cooling process in heat treatment. *Hot Working Technology*, 2008, 37(17): 38–40. (in Chinese)
- [5] Kang Jinwu, Huang Tianyou, Liu Baicheng. Review of production status of heavy steel castings and key technologies for their manufacture in China. *China Foundry*, 2008, 5(1): 1–6.
- [6] Li Fengyu, Wang QingYu. Technical measures to improve casting accuracy of blades. *Power System Engineering*, 2007, 23(2): 71–72.
- [7] Yu HaiLiang, Kang JinWu, Huang ShiXiong, Huang TianYou. Integrated simulation of castings deformation during casting and heat treatment processes. *Advanced Materials Research*, 2011, 148–149: 103–107.
- [8] Kessler O, Prinz C, Sackmann T, et al. Experimental Study of Distortion Phenomena in Manufacturing Chains. *Materialwissenschaft und Werkstofftechnik*, 2006, 37(1): 11–18.
- [9] Clausen B, Frerichs F, Kohlhoff T, et al. Identification of process parameters affecting distortion of disks for gear manufacture Part ii: heating, carburizing, quenching. *Materialwissenschaft und Werkstofftechnik*, 2009, 40 (5–6): 361–367.
- [10] Kang Jinwu, Huang Tianyou and Hu YongYi. A measuring method of the dynamic deformation of heavy castings during cooling in air during heat treatment. Chinese patent, 200910218810.3, 2009. (in Chinese)
- [11] CAS Members & Academic Divisions. Status and development of casting technology in China. *Bulletin of Chinese Academy of Sciences*, 2006, 21(5): 395–398. (in Chinese)

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