

Application of Centrifugal Pump Rotor Dynamic Balancing Technique

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In order to avoid the vibration of centrifugal pump, rotors are required to present a reasonable mass distribution, which is also called rotor balance. In this paper, the principles of centrifugal pump were described and the operating technique for rotor dynamic balancing was discussed. Taking cantilever centrifugal pump for example, the rotor dynamic balancing technique was studied. Causes of centrifugal pump vibration were analyzed, and the effect of vibration was eliminated through reasonable correction. Due to the structure and working principle, a centrifugal pump would unavoidably present rotor imbalance, triggering body vibration. Rotor balancing technique is of importance to centrifugal pump because it is obvious that its rotor imbalance is caused by its performance characteristics.

1. Introduction

Vibration of centrifugal pump—a kind of typical rotary conveying machine—is always troubling people. A centrifugal pump has a high requirement for impeller symmetry, since its working principle is to make liquid produce a centrifugal force through the high-speed rotation of impeller. The most common one of its faults is vibration triggered by the imbalance of rotor mass. Due to the structure and working principle, a centrifugal pump would unavoidably present rotor imbalance, triggering body vibration. Since the cause of this vibration is basically unavoidable, rotor dynamic balancing is the only means to keep the pump working normally; rotor balancing technique is of importance to centrifugal pump, because its rotor imbalance is obviously caused by its performance characteristics, i.e., unavoidable.

2. Literature review

The birth of dynamic balancing machines originated from the emergence of rotating machinery in the late 19th century. With the extensive use of steam engines, generators, electric motors, and centrifugal pumps, compressors, etc., dynamic balancing machines have begun to receive widespread attention and rapid development.

After the second industrial revolution, with the continuous increase in the rotational speed of rotating machinery, the symmetry of the design alone has not been able to guarantee the balanced performance of the machine. Therefore, the most primitive balancing machine emerged, and it is believed that Li et al. studied the world's first balancing machine with patented technology (Li et al., 2016). Lara-Castro et al. studied a balancing machine that was not designed for industrial applications (Lara-Castro et al., 2017). Luo and Miller conducted research on this, and their research played a big role in the development of the balancing machine (Luo and Miller, 2017). Srivastava et al. first started the study of manufacturing dynamic balancing machines (Srivastava et al., 2017). Later Wang and Zhu improved the machine on his basis. The machine used to support the test piece is a spring mounted on the base. The centrifugal force generated by the high-speed rotation of the workpiece causes the bearing to vibrate, and the vibration waveform was recorded with a seismometer vibration measuring device. Then according to the result of the vibration record, the position and the size of the de-duplication needed to eliminate the imbalance were determined (Wang and Zhu, 2017). The structure of the pull-type balancer was very simple, but it is the originator of the measurement of unbalance of

modern high-speed rotating machinery. On their basis, there have been many different types of balancing machines, such as Akimov, Tribelle, and Soderberg balancers.

Du et al. studied a balancing machine with a balanced speed higher than the first-order critical speed of the rotor, which resulted in a corresponding increase in the measurement accuracy and the balance accuracy of the entire system (Du et al., 2017). Zylbertal et al. invented a measuring mechanism by combining a synchronous generator and an optical amplification device. This mechanism can display specific graphics on the screen, through which the unbalanced phase and size can be directly read out (Zylbertal et al., 2017). Shortly thereafter, Rodrigues et al. further developed the method and developed a new type of modern electrical measuring mechanism based on a wattmeter measuring device with an alternator. After this, it was improved again, combining a movable coil type vibration sensor and a wattmeter-based electrical measurement mechanism to establish a double-sided simultaneous measurement method. This measurement method was simple and easy to operate, the accuracy was relatively high, and the performance was relatively good. It can be said at this time that the balance machine was truly applied to industrial production (Rodrigues et al., 2017).

In the mid-40s of the last century, the vibration technology research group of the German Society of Engineers developed VDI2056 "*Standard for the determination of mechanical vibrations*" and laid the foundation for the vibration standard. During World War II, Americans began to study some of the factors that affect the vibration measurement, such as at what speed to test the rotor, etc. Then in the early 1950s, the United States introduced a national standard for balancing. This standard mainly referred to the long-term accumulated empirical data of manufacturers and users of various types of machinery at that time, and also referred to relevant standards specified by VDI, mainly DIN 45665 "*Vibrational Intensity Standard of Electrical Machinery*" and DIN 4666 "*Vibration Intensity Standard of Measuring Instrument*" and so on. In the 1960s, some manufacturers began to balance the rotor, so VDI launched VDI 2060 to evaluate the balance of rigid rotating bodies.

Afterwards, with the development and exchange of technologies in various countries of the world, the German Institute of Engineers submitted the relevant information of these two standards as recommendations to the International Organization for Standardization (ISO). The organization subsequently developed the ISO 2372 "*Basic Standards for the Evaluation of Motors and Vibrations at Working Speed*" and ISO 1940 "*Equilibrium level of rotating rigid body*." The two international standards mainly referred to the standard VDI 2056.

In order to unify the relevant terminology in technology internationally, ISO has formulated ISO 1925 "*Vocabulary of Balanced Technology*", which clearly defined the related professional terminology involved in the field of balance. Later, ISO also successively formulated some standards that were in great need at the time, such as ISO 2953 "*Explanation and Evaluation Standards of Balancer*", ISO 5406 "*Evaluation Standards of Flexible Rotor*" and ISO 5343 "*Balancing Standards of Flexible Rotor*" and so on. Among them, according to the characteristics of the rotor, ISO 5343 divided the rotor into low-speed and high-speed rotors to determine the balance level and correction method of the rotor in different application fields, and clearly defined the differences between the rigid rotor and the flexible rotor.

In the early 20th century, the working speed of most centrifugal pump rotor systems was below the first-order critical speed. The centrifugal force generated by the unbalanced amount caused the deflection of the rotor to be deformed little, and this type of rotor was a so-called rigid rotor. The dynamic balance correction of rigid rotor can be operated at any speed with two selected correction planes. Since the rotor was rigid, the unbalanced distribution of the rotor mass would not change due to changes in speed, so a well-balanced rotor would remain balanced at any other speed.

In summary, the structure and working principle of the centrifugal pump have been mainly studied, and the causes and mechanisms of its vibration have been analysed; on the other hand, the principle of centrifugal pump rotor balancing technology was studied in detail, and some basic definitions of the rotor balancing technology and the concepts in the specific balancing operations such as balancing accuracy levels were given, and the operating techniques to achieve rotor balancing were discussed; therefore, based on the above research status, this research mainly took the centrifugal pump rotor as an example. It was divided into two types: cantilever type centrifugal pump and corresponding double-support type centrifugal pump. For each type of supporting rotor, the rotor dynamic balancing technology was experimentally studied according to its different structure. Through specific experimental research, the classification of different types of rotor balancing schemes was classified, which provided a certain reference for further improving the dynamic balance correction process.

3. Study of Centrifugal Pump

Instructions for centrifugal pump: Before a centrifugal pump is started, its shell should be filled with liquid. Otherwise, the pump will "run idly" with heating, vibration, and no flow, or the pump will be even damaged,

causing an equipment safety incident; an idler pulley may be installed at the periphery of impeller, for the purpose of a higher energy conversion efficiency of liquid inside pump. The idler pulley is a fixed ring with vanes at the periphery of impeller. Its vanes, bending opposite to the bending direction of impeller vanes and in an angle exactly adapted to the direction of liquid flowing out of impeller, guide liquid to change the direction smoothly inside the pump shell channel, minimizing the energy loss and improving the efficiency of kinetic energy conversion into static pressure energy.

4. Rotor of Cantilever Centrifugal Pump

A cantilever centrifugal pump does not have a carrier base. Instead, its body is directly fixed to the motor flange plate by means of short bracket. Its impeller shaft is conically inserted into the motor shaft end and tightened by a boom for torque transfer. The motor footing acts as the mount set of pump. The structure of pump rotor is shown in Figure 1.

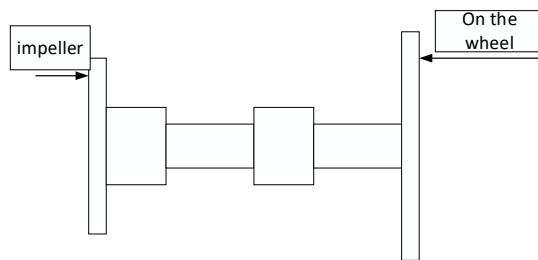


Figure 1: Cantilever centrifugal pump rotor schematic

Since how to select the correction surface determines the rotor correction formula and even the entire balancing plan, the correction surface of cantilever centrifugal pump rotor can be selected in the following ways, allowing for weight adding, weight reduction, and other factors:

- (1) To reduce weight on the correction surface of impeller by polishing mainly. This program is a relatively common correction program, generally used where rotor imbalance is not big and the impeller is thick. Despite not needing to consider the replacement or installation of coupling, its scope of application is small. It is impossible when the weight to be reduced is heavy;
- (2) To add weight on the correction surface of impeller by welding. This program can be used where rotor imbalance is big where weight adding is convenient for impeller. It can also be used where correction is not convenient for coupling. Its advantage is no destruction. It is impossible when the impeller is small.

The most common, also the most standard, dynamic balance is that both of the two correction surfaces support the centrifugal pump rotor in the middle, as shown in Figure 2, 3. What we should notice is the selection of equilibrium surface in the case of multistage. In this case, we normally select two impellers. However, the rotor is heavy sometimes and in this case the weight to be reduced is too heavy to two impellers and would decrease their strength. Therefore, it is required to share this weight with adjacent impellers, so as to ensure the balance precision.

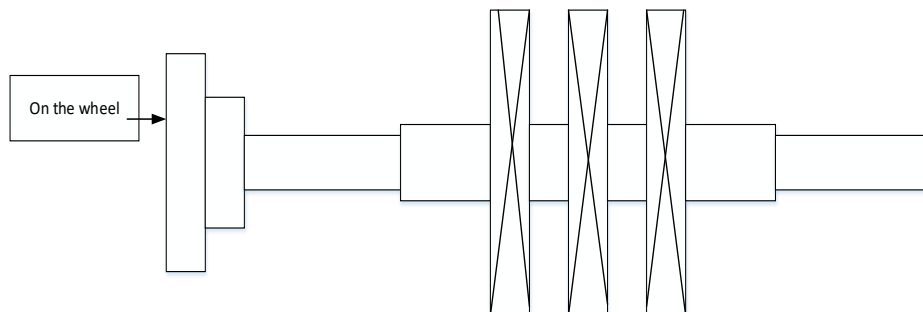


Figure 2: The adjustment surface is located between two supports

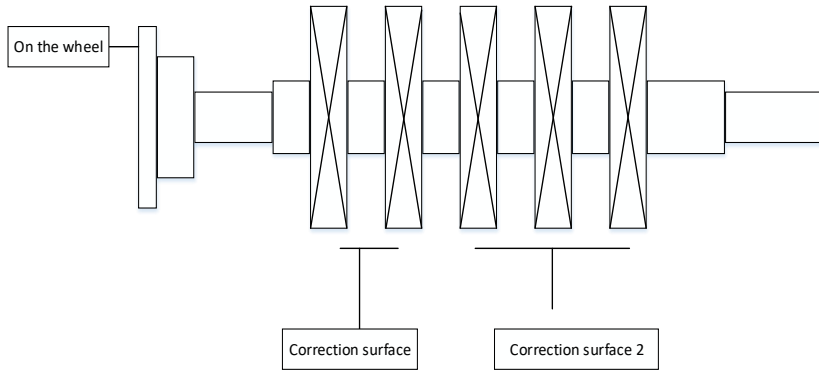


Figure 3: The decomposition of the facet

Another common type of rotor dynamic balance is that two correction surfaces respectively support the double-support rotors at both sides and are located at the two sides of support position, as shown in Figure 4. The concrete dynamic balancing method is similar to the kind of rotor above. Attentions:

(1) Support. In principle, support positions should be selected with reference to the bearing position in actual operation of rotor. To this kind of rotor, however, the support position should be close to correction surface, as appropriate, so as to avoid the gyroscopic effect during correction.

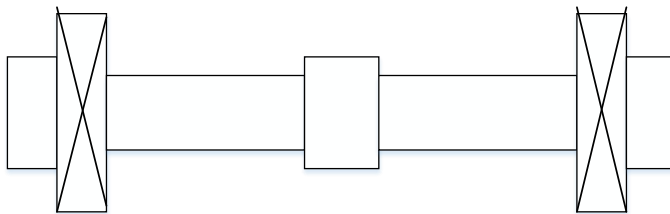


Figure 4: The adjustment surface are located the support position both sides

(2) Selection of equilibrium surface. Such rotor generally has two impellers, so two impellers are enough for equilibrium surface.

(3) Weight adding or reduction method. Due to the special structure, such rotor does not have many levels. In some cases where the weight to be reduced is too heavy, the rotor requires weight adding, through welding, so as to prevent rotor structure from being damaged; However, in more cases, weight reduction is first considered through polishing.

5. Experimental Study of Centrifugal Pump Rotor Dynamic Balancing

Experimental device: Horizontal dynamic balancing machine (Schenck Process GmbH) is the main experimental device used in this paper, as shown in Figure 5.

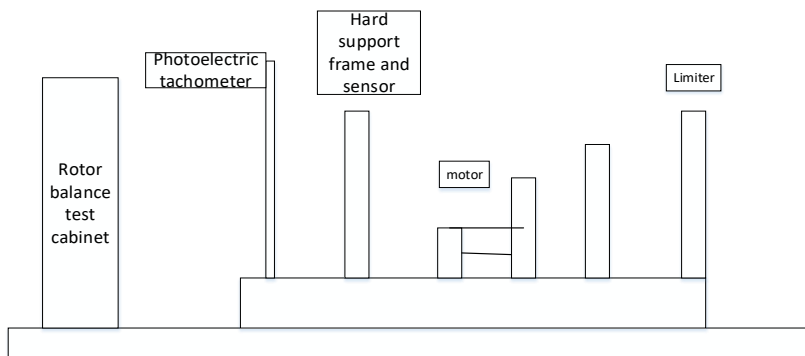


Figure 5: Experimental device

Experimental design: Weigh the rotor, and obtain its working speed. Calculate the residual allowable amount of unbalance after the balance precision grade of the rotor is determined. Measure the external dimensions of rotor, including maximum diameter, overall length, shaft diameter at the drive position, and shaft diameter at the bearing position. Then, adjust the bracket and drive motor positions of dynamic balancing machine, for good coordination. Select a correction surface, and prepare a dynamic balancing correction program correspondingly. Measure the rotor imbalance data. Do a weight adding test to balance the rotor. Take away the added weight after data are recorded. Select another correction surface, and recycle the last two steps until all the correction programs are selected.

6. Experiment Process

Theoretical study: For the experimental rotor, weight: 35 kg; overall length: 730 mm; working speed: 2,950 r/min; impeller diameter: 270 mm; impeller thickness: 6 mm; coupling diameter: 160 mm; coupling thickness: 6 mm; shaft diameter at the drive position: 115 mm; shaft diameter at the bearing position: 50 mm. At both sides of the selected impeller are correction surfaces. The amount of unbalance determination data are listed in Table 2.

Table 1 The initial unbalance amount

It can be seen that the total weight reduced of this rotor is 53 g, and its imbalance precision grade is G 100. In order to balance this rotor, adhesive and cement were together used in this experiment. First, cut an additional weight of 15 g and two additional weights of 18 g. Second, grind the fitting surface of rotor at the weight adding position. Glue the rotor and additional weights together by using 502 Glue. Do determination again on the machine.

Case study: For the experimental rotor, overall length: 710 mm; weight: 23 kg; working speed: 2,960 r/min; impeller diameter: 310 mm; impeller thickness: 7 mm. Since the impeller is very thin, we decided to select impeller and coupling as the two correction surfaces, hoping to minimize the weight reduced on impeller and not to influence the impeller strength. The program is shown in Figure 6.

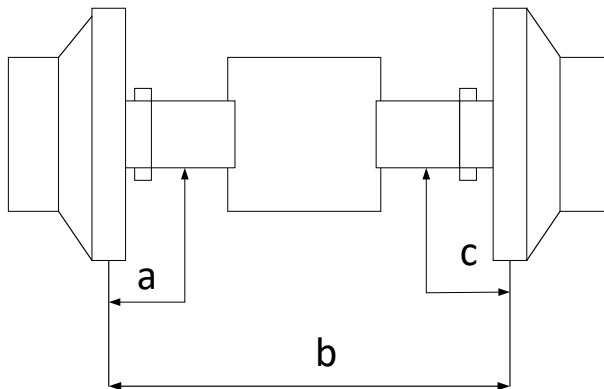


Figure 6: Correction programme

7. Results

Result of theoretical experiment: From Table 1, it can be known that the rotor unbalance amount decreases significantly. Since there are more than one pasting blocks, a certain angle deviation and mass decomposition are normal. Later, cement was added several times, till the end of rotor balancing. The balancing data are listed in Table 2.

Table 1: The unbalance amount

Serial number	Standard way	Rotating speed (r/min)	Left calibration surface		Right calibration plane	
			Weight(g)	Angle (°)	Weight(g)	Angle (°)
1	Aggravated	600	2.7	80	12.3	121

Table 2: Balance correction data

Serial number	Standard way	Rotating speed (r/min)	Left calibration surface		Right calibration plane	
			Weight(g)	Angle (°)	Weight(g)	Angle (°)
1	Aggravated	600	1.01	78	4.15	110
2	Aggravated	600	0.783	79	2.1	112
3	Aggravated	600	0.314	75	0.177	109

As stated above, the balance correction of this rotor was finished. In the end, its balance precision grade reached G1 and it could work well. Data were recorded.

Result of example experiment: After the first weight reducing, the data recorded are found to decrease well, and the angle does not change basically. Repeat the above correction operations, and distribute evenly the residual unbalance amount on impeller surfaces. Subsequent data are given in Table 3.

Table 3: Balance correction data

Serial number	Standard way	Rotating speed (r/min)	Left calibration surface		Right calibration plane	
			Weight(g)	Angle (°)	Weight(g)	Angle (°)
1	Aggravated	1202	5.34	132	7.97	109
2	Aggravated	1203	0.781	123	1.01	130
3	Aggravated	1203	0.485	120	0.182	170
4	Aggravated	1200	0.251	158	0.134	165

8. Conclusion

Affected by the flexible rotor, the angle jumped several times during correction. But it did not actually influence balancing. Through dynamic balance correction, the residual unbalance amount of rotor was less than 1 g at last, and its precision grade was G2.5, completely complying with the safety production requirements. This dynamic balancing is successful.

In fact, there are so many research fields and technical provisions regarding the rotor dynamic balancing technique. This paper is just a classified study of rigid centrifugal pump rotor based on support type, involving little things about other rotary machines or more complicated flexible rotor. Thus, further research is to be done into those aspects.

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