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A laser shaft alignment system with dual PSDs*

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Abstract: Shaft alignment is an important technique during installation and maintenance of a rotating machine. A high-precision laser alignment system has been designed with dual PSDs (Position Sensing Detector) to change traditional manual way of shaft alignment and to make the measurement easier and more accurate. The system is comprised of two small measuring units (laser transmitter and detector) and a PDA (Personal Digital Assistant) with measurement software. The laser alignment system with dual PSDs was improved on a single PSD system, and yields higher measurement accuracy than the previous design, and has been successful for designing and implements actual shaft alignment. In the system, the range of offset measurement is ±4 mm, and the resolution is 1.5 μm, with accuracy being less than 2 μm.

Key words: Rotating machine, Shaft alignment, Laser alignment, Position sensing detector (PSD), Laser micro-displacement measurement
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INTRODUCTION

Precise alignment occurs when the centerlines of rotation of two shafts are essentially collinear with each other. The degree to which two machines are misaligned can be determined by examining the amount of offset and angularity that exists between them. Offset is the distance between the two rotational centerlines, and angularity is the angle between the centerlines created by the misalignment of the two centerlines. The traditional precise shaft alignment method is dial indicator alignment (Piotrowski, 1995), and the two most popular methods are the rim and face method and the reverse indicator method.

With the traditional technique, the measurement results must be graphed out manually and the calculations must yield the corrections required. With the laser alignment system all these are done automatically. Real time alignment values are displayed as the machine moves. The laser alignment system cuts the measurement time at each coupling by 50% compared to the previous method of taking 16-point rim and face dial readings (Perry, 1998). The improved accuracy of the laser also minimized the number of subsequent bearing alignment corrections required. The laser alignment system has been adopted for more and more precise shaft alignments, such as rotor system (Brommundt and Krämer, 2005), vibration (Lee, 2004), cooling tower fans (Luedeking, 2003), gas turbine (Luedeking, 2005), Link Coupling (Pan *et al*., 1998), turbine driven feed water pump (Parry, 2001), etc.

The single PSD laser alignment system designed by us has been applied in actual shaft alignment (Jiao *et al*., 2006). Dual PSDs method is based on the single PSD laser alignment system, and has evidently improved the system measurement accuracy through some modification in the light road, circuits, and software.

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MAIN METHODS AND TECHNIQUES

Laser alignment system

The measurement principle of laser alignment is based on the dial indicator method. Alignment by dial indicator is an accurate method provided these potential problems that can adversely affect readings are dealt with correctly (Studenberg, 2002; VibrAlign Inc., 2002): (1) indicator bar sag, (2) indicator hysteresis, (3) low resolution, (4) reading errors, (5) role in mechanical linkages, (6) components the indicator touches magnetized by an exciter, (7) shaft axial play.

Instead of steel bars with dials, it uses laser beam. Unlike steel bars, the laser beams do not have the disadvantage of sagging. In addition, PSD provides a high resolution and PSD signal processing circuit calculates the readout of laser system, so it eliminates human errors. All of that contribute to high degree of accuracy. The schematic overview of the laser alignment system is given in Fig.1.

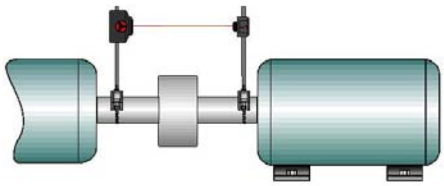

Fig.1 Schematic overview of the laser alignment system

Design with dual PSDs

In the optics design, compared with the single PSD laser alignment system, the dual PSDs laser alignment system adds a prism between the laser transmitter and the detector. As Fig.2 shows, the 45° prism separates the incidence laser light to two beams, and the beams finally project to the PSD surface.

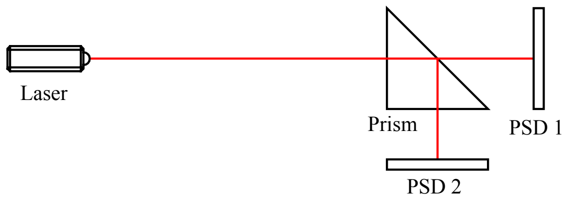

Fig.2 Structure of the laser alignment system with dual PSDs

From the feature of PSD (Perry, 2001), we know the position of the incidence light spot on each PSD is described by the formula below:

$$\text{Position } X=\frac{L_x}{2}\cdot\frac{X_1-X_2}{X_1+X_2},$$

$$\text{Position } Y=\frac{L_y}{2}\cdot\frac{Y_1-Y_2}{Y_1+Y_2},$$

where L_x and L_y are PSD length in the X and Y directions, respectively. Moreover, X_1, X_2, Y_1 and Y_2 are the photoelectric currents generated by the incident light respectively.

In the dual PSDs method, the light spots on each PSD are enantiomorphous about Y-axis. Therefore, we can calculate the spot position through the two PSDs. The relationship of them is:

$$PosX=\frac{PosX_1-PosX_2}{2},$$

$$PosY=\frac{PosY_1+PosY_2}{2},$$

where $PosX$ and $PosY$ are the final position values of the light spot, and ($PosX_1$, $PosY_1$), ($PosX_2$, $PosY_2$) are the positions of the light spot on PSD 1 and PSD 2, respectively.

By this way, we can decrease the error of the system, and provide a method we describe subsequently to calibrate the laser light at the beginning of alignment.

PSD signal processing

PSD is a photoelectric device that converts an incident light spot into four photoelectric currents, which can be calculated to continuous position data. Most of the calculation methods are based on the circuit by ACU (Analog Computational Units) (Hamamatsu Photonics, 2001; Jin and Li, 1998). In that way, the light spot position data were converted to a voltage signal, which can be acquired by ADC (Analog-to-Digital Converter). Nevertheless, those components in circuit such as amplifier or ACU will bring some additional noises to the system which are difficult to reduce.

We adopt a method that calculates the light spot position by an SCM (Single Chip Micyoco), MSC1210, which is a mixed signal device incorporating a high-resolution delta-sigma ADC, an

8-channel multiplexer, and an 8-bit microcontroller (Texas Instruments, 2002). Therefore, one MSC1210 completely deals with eight channels signals of the two PSDs. Only a little component is needed in the signal processing circuit. It improves the stability of the detector unit by greatly decreasing the electro-circuit noise.

SYSTEM DESIGN

The laser alignment system with dual PSDs is comprised of two small measuring units (laser transmitter and detector) and a PDA with measurement software. A schematic of the laser alignment system is given in Fig.3.

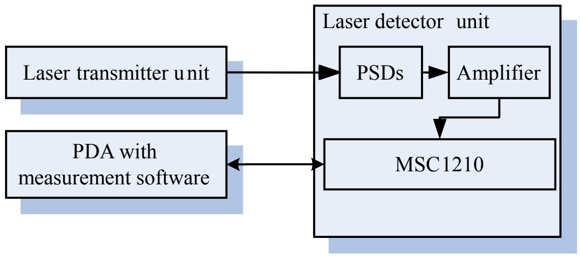

Fig.3 The laser alignment system with dual PSDs

Laser transmitter unit

The laser transmitter unit is made up of diode laser and the mechanism with built-in micrometer screws for adjustment of the laser beam in horizontal and vertical level. From the PSD response spectrum, the peak sensitive wavelength of this PSD is 960 nm, but it is necessary that the light must be visible when the operator adjusts the angle of incidence at the pre-alignment of shaft calibration. So the 635 nm diode laser was selected in the visible wavelength region. Because of the PSD's feature which is sensitive to the light spot barycenter, the light wavelength or intensity does not hamper the precision of the light spot position.

Laser detector unit

PSDs and the PSD signal processing circuit comprise the laser detector unit. In the dual PSDs signal processing, the method adopted is similar to the single signal processing (Luedeking, 2005), i.e., use software arithmetic to calculate the value of the laser spots position on PSD to replace the pure circuit method which usually involves many components between detector and CPU, such as ACU, ADC, etc. These components will bring to the system some additional noises that are difficult to reduce. An SCM, MSC1210, has been selected as the key chip of the detectors. The MSC1210 includes a 24-bit resolution ADC consisting of an input multiplexer (MUX), an optional buffer, a Programmable Gain Amplifier (PGA), and a digital filter (Studenberg, 2002). The architecture is described in Fig.4.

The PSD sensor and CPU are connected directly. It was proved in a later test that this method can efficiently remove those noises and improve the system accuracy and stability.

The photoelectric currents generated by PSD flow through the amplifier circuit and are converted into voltage signals. Then MSC1210 converts those voltage signals into digital value, and transports them to the PDA through RSC232. The software on the PDA calculates the position of the light spot when the data is received.

Measurement software on the PDA

During shaft calibration, the laser transmitter and detector units are mounted on the stationary and the movable machine, respectively. After the measurement software is started, the program may ask for every necessary distance datum, and then, must measure and input the distances between the measuring units and feed the software, after the software waits for the data of the laser detector unit. The whole measurement is carried out step-by-step on the display. The shafts with measuring units are turned to position 9 o'clock, and then 12 o'clock, and finally 3 o'clock, after which offset, angular values and shim adjustment values are clearly displayed on the PDA screen. Both horizontal and vertical values are shown "live", so that it is easy to adjust the machine.

Laser beam calibration at pre-alignment

To obtain the best possible conditions for shaft alignment, it is necessary to check whether the incidence angle of the laser beam projected to the PSD surface is perpendicular. From Fig.2, we know only if

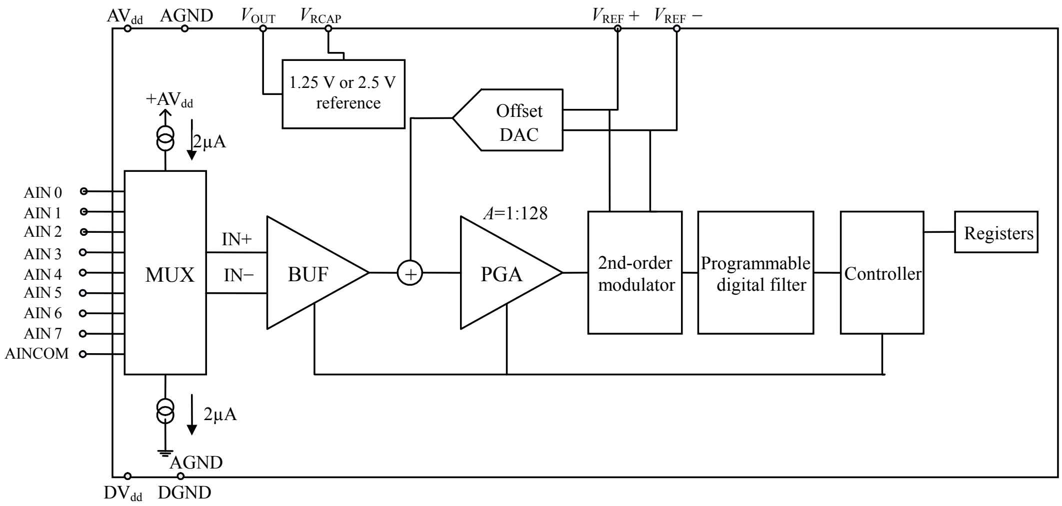

Fig.4 Block diagram of the MSC1210

the laser light spot on each PSD is at the PSD center, the laser light can be said to be perpendicularly incident to the detector unit. Therefore, in the self-calibration software, we defined an acceptable range to adjust the laser transmitter unit.

As Fig.5 describes, if the spot position is out of the inner circle (radius=25.4 μm), we screw the four dimension adjustment in the laser transmitter until the spot falls into the circle.

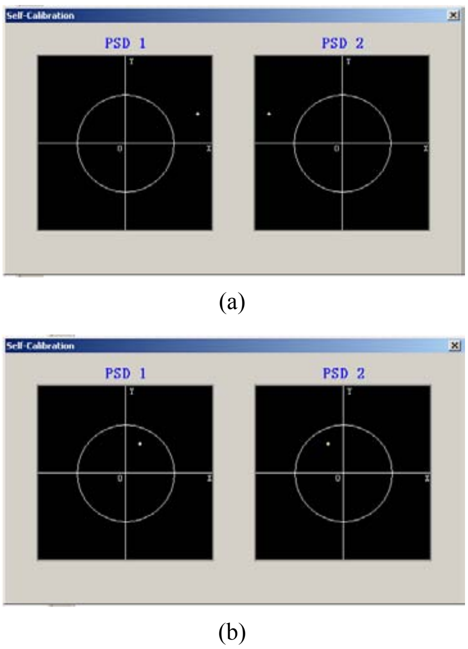

Fig.5 Laser beam calibration at pre-alignment. (a) Before adjustment; (b) After adjustment

SYSTEM TEST

The test is same as that in the previous method (Luedeking, 2005) that mounts the laser transmitter on a plane with built-in micrometer screwing for indicating the laser transmitter movement in horizontal and vertical level, and fixing the plane and the laser detector on a steady workbench. Additionally, we put the single PSD system into the test as Fig.6 shows. First step of the test is to adjust the laser beam to be centered perpendicular to the PSD chip surface. Subsequently, we adjust the micrometer 1 μm in horizontal and vertical level each time. Simultaneously, we record the position value of the light spot.

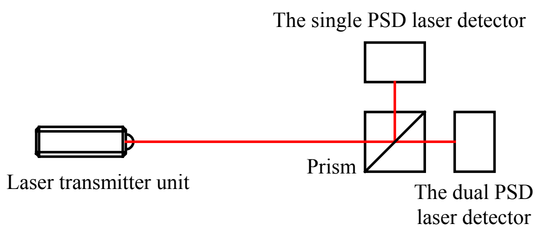

Fig.6 Installation of the test

After the test, we list the measured values and compare them with the previous values measured by the single PSD system in Table 1.

From Table 1, we can see the laser alignment system with the dual PSDs yields higher accuracy than the single PSD system. In the measurement range (±4000 μm), the variance of the dual PSDs system is 1.89 μm, and the single one is 5.33 μm. Therefore, the dual PSDs system can be applied to shaft calibration in high-speed (near 7200 rpm) rotating system (VibrAlign Inc., 2002).

Table 1 Measured values compared with previous measurement

Scale value (μm)	Measured value (μm)	
	Dual PSDs system	Single PSD system
0	−4516	−4623
1000	−3998	−4008
2000	−3001	−3009
3000	−1997	−2005
4000	−999	−1002
5000	2	−6
6000	1003	996
7000	2002	1995
8000	3001	3003
9000	4002	3994
10000	4438	4872

CONCLUSION

Much like the philosophical change from shafts alignment with dial indicators to shafts alignment with laser-based systems, these types of measurements will take some time to be generally accepted and routinely practiced. The laser alignment system described above will lead to lower misalignment levels, increased mean time between failures, decreased maintenance expenditures, and increased production.

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