UDC 681.2:531.7, 681.2:534.1

VIBRATION PHASE MEASUREMENT ERRORS CAUSED BY PHASE SENSOR INSTALLATION MISALIGNMENT

Pavlo B. Oliinyk, Ph.D.
poleinik@ukr.net, ORCID: 0000-0002-9481-0551
National Technical University of Ukraine
"Igor Sikorsky Kyiv Polytechnic Institute" (Ukraine, Kyiv)

Abstract *– Vibration phase measurement errors, caused by phase sensor are considered and estimated. Practical recommendations that allow one to decrease influence of misalignment are presented.*

Keywords *– vibration phase measurement, phase measurement error, balancing.*

Statement of the problem. Imbalance is the most probable root cause of high vibration levels on heavy machinery, especially steam turbines and generators [1, 2]. In order to reduce imbalance, balancing of the machine is performed; to achieve acceptable vibration levels, one has to measure both vibration magnitude and phase at the rotor rotation frequency. Thus, one has to ensure high measurement precision of both those values, which, in turn, cannot be achieved only by using a high-end instrumentation.

Analysis of recent research. In heavy machinery balancing, influence coefficients method [3, 4] is used most often. In order to use that method, one has to know precise values of both trial (or correction) mass and its installation angle and vibration phase and magnitude. Values of mass and of its installation angle can be precisely measured on a stopped machine; vibration phase and magnitude in each measurement point, however, must be measured using two synchronized channels – one is used as a reference, and another as a signal channel. As a reference channel, either eddy current or optical sensor is used. In both cases, when wedge key or optically contrast mark is in the sensor's field of view, pulse is formed at the channel output; that pulse is used as a reference point to calculate phase of the vibration maximum (so-called "heavy point"). Such an approach is prone to errors when the optical phase sensor is used, as its position relative to machine's shaft is always set with some misalignment.

In paper [5], a novel balancing method is presented, which does not require phase measurements. However, in order to implement that method, one has to do two trial runs instead of one per each trial mass, and each trial run significantly decreases lifetime of the heavy rotating machine; therefore, method is impractical for steam turbines and similar machinery.

In [6], method of fast vibration phase estimation using FFT is proposed; its main drawback is complex phase calculation via trigonometric functions, including sine, cosine and arctangent. Moreover, method, proposed in [6], assumes only ideal sensor positioning, and does not take possible misalignment into account.

Authors of work [7] investigated the effect of imbalance on a rotor shaft using both vibration characteristics and a smart experimental setup based on an algorithm embedded on a FPGA. That setup includes vibration sensors and optic phase sensor, but possible phase estimation errors in [7] are not considered.

Thus, errors of vibration phase measurement caused by phase sensor installation are not discussed or studied in the known references.

Formulation of goals. The goal of the study is to estimate errors, caused by phase sensor misalignment, and to give practical recommendation that allow one to reduce those errors significantly.

Main part. Consider a machine with the horizontal shaft of radius R, on which contrast optic mark is placed. In the ideal case, optic phase sensor should be installed along OA line at the distance l from the shaft surface (Fig. 1); in practice, however, sensor is installed with either angular misalignment α (Fig. 1) or linear misalignment h (Fig.2), or both.

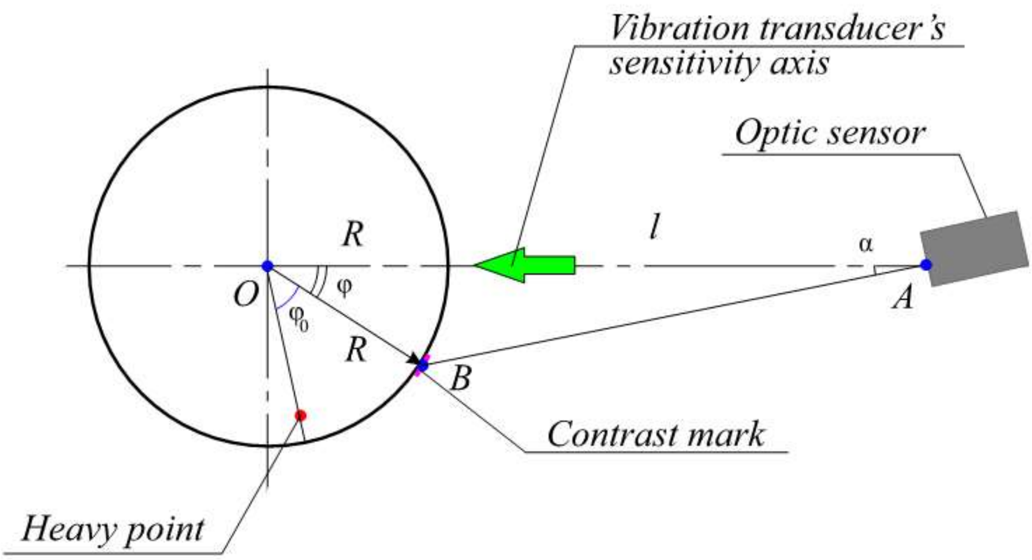

Figure 1. Typical vibration phase measurement setup with angular misalignment of the optical sensor

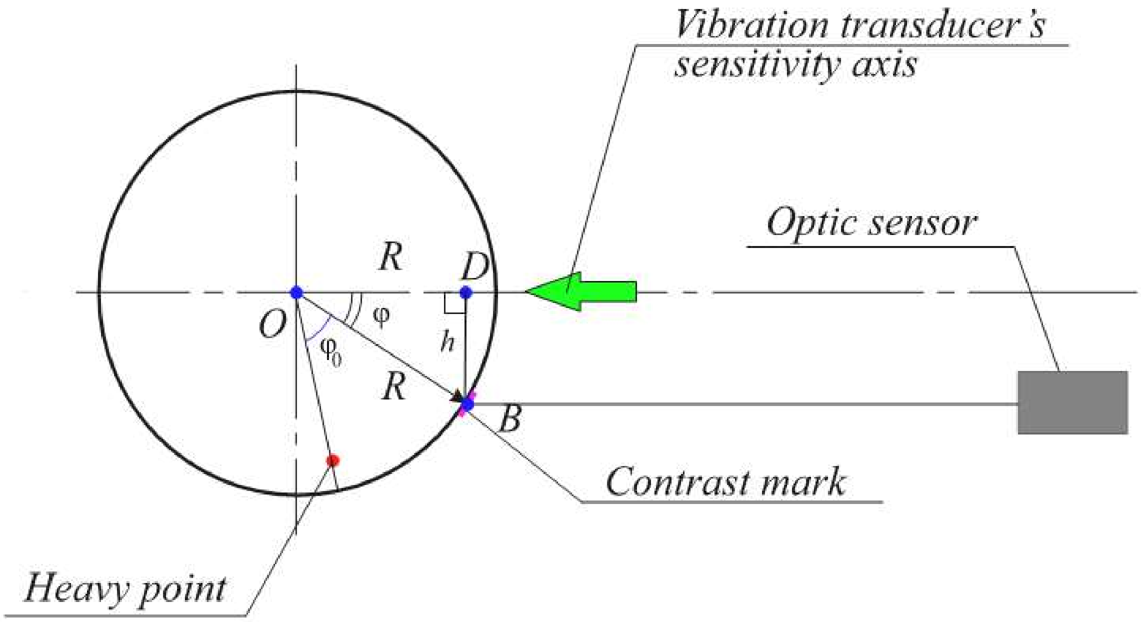

Figure 2. Typical vibration phase measurement setup with linear misalignment of the optical sensor

If optic phase sensor is installed with an angular misalignment α, as shown in Fig. 1, or with a linear one h as shown in Fig.2, measurement system will measure vibration phase as shown if Fig. 3. Grayed pulse is the pulse that corresponds to the real vibration phase $\varphi_0 + \varphi$; dashed pulse corresponds to the phase φ_0, measured by the system with misalignment. So, phase measurement error is equal to φ.

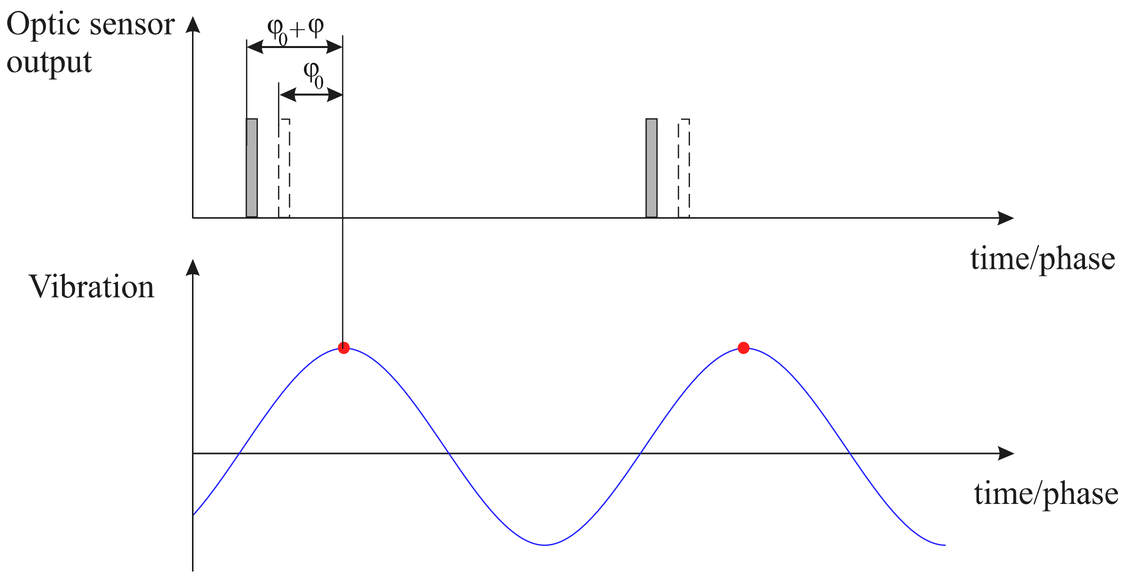

Figure 3. Phase measurement error, caused by phase sensor installation errors

If only angular misalignment is present (Fig. 1), then using sine theorem for triangle *OAB*, one can easily write down, that

$$\frac{R}{\sin(\propto)} = \frac{R+l}{\sin(\pi-\varphi-\alpha)} \quad (1)$$

After simple algebraic transforms, and taking into account that both α and φ are acute, one can deduce that

$$\varphi = arcsin\left(\frac{R+l}{R}\sin(\alpha)\right) + \alpha \quad (2)$$

If only linear misalignment is present (Fig. 2), then from the right-angled triangle OBD one can deduce, that

$$\varphi = asin\left(\frac{h}{R}\right) \quad (3)$$

Assuming that *R=150 mm*, and different values of distance *l*, error estimation for different angular and linear misalignment values using (2) and (3) were calculated. Results of calculations are presented in Table 1 and Table 2 respectively.

Table 1. Phase measurement error with angular misalignment

Angular misalignment α, degrees	Phase measurement error φ, degrees	
	l=300 mm	*l=600 mm*
1,0	3,0	5,0
2,0	6,0	10,0
5,0	15,2	25,0
10,0	31,4	60,0
15,0	50,1	shaft is out of sensor's field of view

Table 2. Phase measurement error with linear misalignment

Linear misalignment h, mm	Phase measurement error φ, degrees
1,0	0,38
2,0	0,76
5,0	1,91
10,0	3,82
20,0	7,66

As one can see from Table 1, depending on the distance from optic sensor to the shaft, phase measurement error may have a value from 3-5 degrees (comparable to typical vibration phase angle measurement error) to as much as 50-60 degrees, which is unacceptable. At that, the nearer sensor is to the shaft, and the smaller misalignment is, the smaller phase measurement error is and vice versa. Calculation results, presented in Table 2, show that linear misalignment of even 20 mm causes phase measurement error of 7,66 degrees; thus, angular misalignment has a much higher influence on the phase measurement error than linear one has. Therefore, in order to mitigate misalignment influence and reduce phase measurement error, one has to minimize angular misalignment of the optical phase sensor in the first place.

As for eddy current sensors, due to small installation distance from the shaft (l is up to 5-10 mm) and the fixed place of sensor installation, the above conclusions do not apply. Those sensors usually provide minimal phase measurement error.

Conclusions. As one can see, phase sensor installation error may have a significant influence on the precision of vibration phase measurement and, as a result, on balancing quality overall. In order to mitigate that influence and thus to reduce phase measurement error, one has to provide minimal angular misalignment of that line of view from the horizon. Minimal vertical misalignment of the optic phase sensor's line of view from the shaft axis is also desirable. Practical check and improvement of the above recommendations may become a goal of the future research.

References

1. M
2. Lees A.W. Misalignment in rigidly coupled rotors, Journlal of Sound and Vibration. 2007. Vol. 305 (1–2). pp. 261–271. DOI: 10.1016/j.jsv.2007.04.008.
3. Xiaoping, Yu. General influence coefficient algorithm in balancing of rotating machinery. The International Journal of Rotating Machinery. 2004. Vol. 10, Issue 2, pp. 85-90. DOI:10.1155/S1023621X04000090
4. Zhou, S.Y.; Shi, J.J. Active balancing and vibration control of rotating machinery. A survey. The Shock and Vibration Digest. 2001. Vol. 33. pp. 361-371. DOI:10.1177/058310240103300501
5. Bhende, Amit R. A new rotor balancing method using amplitude subtraction
6. Podgórski, Andrzej, Charazka, Pawel. An Algorithm for Estimation of the Amplitude and Phase of a Vibration Signal Used for Determination of Rotating Mass Unbalance. Conference Record. // IEEE Instrumentation and Measurement Technology Conference. (2006) pp. 1425-1429. DOI: 10.1109/IMTC.2006.328601.
7. Guilherme, Kenji Yamamoto, da Costa, Cesar, da Silva Sousa, João Sinohara. A smart experimental setup for vibration measurement and imbalance fault detection in rotating machinery. Case Studies in Mechanical Systems and Signal Processing. 2016. Vol. 4. pp. 8-18. DOI: 10.1016/j.csmssp.2016.07.001.