A Practical Estimation of Heavy Spot Location for One-Plane Rotor

Luowen Tao
Ph.D. SENDIG Technology Co. Beijing, China

Abstract- *Unbalance causes a major portion of undesirable rotating machinery vibration. Accelerometer and the influence coefficient method are most commonly employed in rotor field balance. However, the need for trial mass and multiple runs makes it expensive. We present a new method for estimating the heavy spot of an unbalanced single-plane rotor without stopping the machine in this paper. This method is based on a phase-calibrated balance instrument and a specially placed accelerometer and laser tachometer. While corrective weights are not computed, knowing where the heavy spot is located can still save time and money on-site. Experiments show that this technology is applicable to a wide range of industrial single-plane rotors. It can also be used as an introduction to trial mass estimate for the influence coefficient approach.*

Keywords—*System Identification, Parameter Estimation, Field Rotor Balancing, Heavy Spot Location*

I. INTRODUCTION

Unbalance causes a major portion of mechanical vibration. After a rotation machine has been installed and run for some time, re-balancing is often required to reduce the machine vibration. The basic purpose of any balancing procedure is to measure the imbalance weights and their angular locations so that correcting weights can be attached to the rotating part to provide a counterbalancing load.

The influence coefficient method is most widely used in field balance of rotors. It requires that synchronous vibration amplitude and phase be measured and one or more trial weights be attached to the rotating part. This involves shutting down the machine to attach and detach trial weights and final correction weights. This can be costly in terms of lost production time, increased machine startup stresses, and extended labor costs, especially for large machines, particularly those on critical duty.

To avoid these costs, people have been continuously trying to find a solution to shorten the influence coefficient based balancing process.

The conventional way is based on the relationship of “HEAVY SPOT” and “HIGH SPOT”, the angles of all lag and sensor and integration [1], [4].

Cindy McCoy [2] proposed a method to replace the trial weight runs by controlled loading of the machine structure and impacting the machine with an instrumented force hammer. An analyzer is used to measure and compare the input load (force) and the output response (vibration) simultaneously using cross channel analysis functions.

Sang-Hoon Seong, No-Gill Park [3] proposed a method capable of one-shot running based on the equations of motion, an algorithm to find the magnitude and phase of the unbalance.

II. VIBRATION PHASE AND ONE-SHOT METHOD FOR VERY LOW SPEED ROTOR

Unbalanced masses in the rotating parts create a centrifugal force that tends to make the rotor toward the bearings on the side the unbalance is located. If a dial indicator is mounted at the bearing with the indicator stems in contact with the shaft, it will create a “HIGH SPOT”. At rather low speeds, this high spot will be in phase with the unbalanced mass (HEAVY SPOT). As speed increases, the HIGH SPOT begins to lag the HEAVY SPOT.

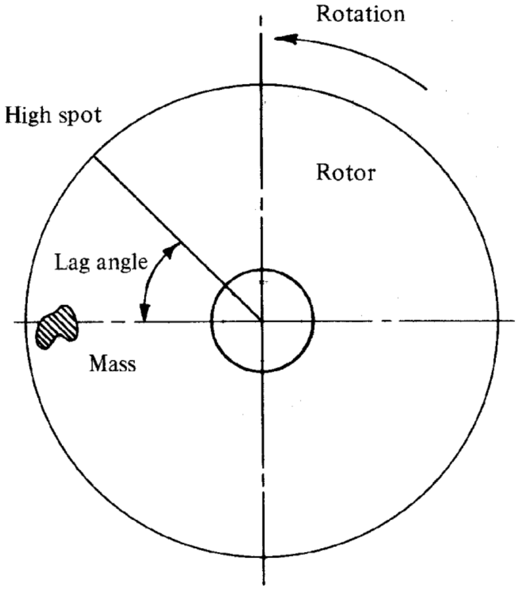

Fig.1 HIGH SPOT and HEAVY SPOT

This is a one-shot balancing method still used today for some very low speed rotors to locate the heavy spot so to mount balance mass at the opposite side as LIGHT SPOT. It requires the use of a speed-controllable stroboscope, dial indicator and marking on the shaft. Unfortunately, the dial indicator is not suitable for displacement measurement at higher rotational speed rotors. Although eddy current proximity probe can be used, it is not easily been installed on a field machine so not really suitable for portable balancing.

As the rotation speed increases and approaches its first critical speed the rotor will resonate. Then the high spot will lag the heavy spot by 90°. The rate of change of the lag angle as the critical speed is traversed has an inverse relationship with the amount of system damping. Sample amplitude and phase plot (Bode plot) are shown in Fig.2.

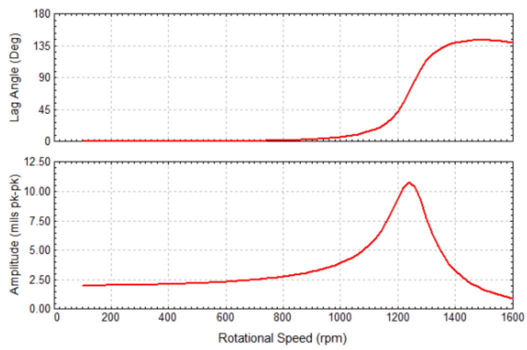

Fig.2 Amplitude and phase plot

Due to the very strong vibration and instability at resonance, the critical speed area is always been avoided during the design and operation stages. These 2 stable phase areas away from the critical speed and that the relationship between HEAVY SPOT and HIGH SPOT make it possible to quickly locate the unbalance and its compensation positions.

III. INSTRUMENT MEASURED PHASE

The above discussion on HEAVY SPOT and HIGH SPOT is more theoretical. For practical balancing work, we need some instruments to measure vibration amplitude and phase. A typical field balancing instrument includes a laser tachometer, 1 or 2 accelerometers, an electronic circuit, and a display with a signal block diagram like:

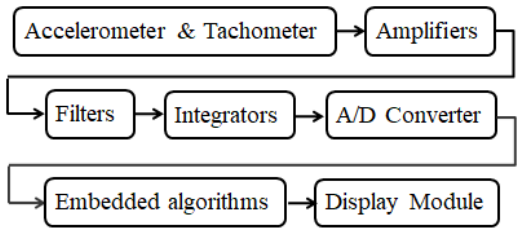

Fig.3 Signal flow of balancing instrument

We need to be aware that almost all of the blocks have polarity or phase differences that affect the final displayed phase. For example:

- The accelerometer's polarity as in Fig.4 depends on the installation direction of the crystal element:

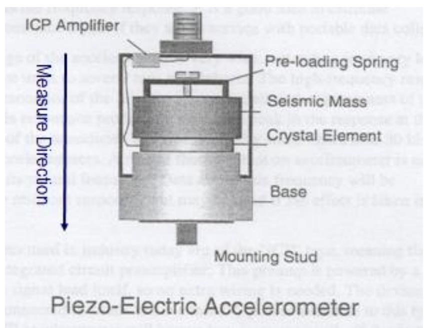

Fig.4 Typical accelerometer structure

-Amplifier, integrator and filter's polarity or phase differences depend on how to use operational amplifiers. The use of an inverting operational amplifier will output a 180° difference phase than input as in Fig.5.

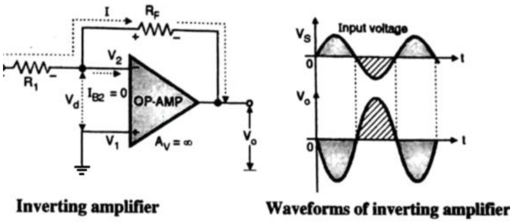

Fig.5 Operational amplifier polarity

-Even A/D converter and algorithm can have polarity

. Measurement parameter selection is also important for phase measurement. It is well documented that 90° phase differences exist between acceleration, velocity and displacement.

Relative displacement between bearing and shaft is easier to understand but it needs a proximity probe which is not so easy for field installation. Acceleration and a double integrated displacement from the accelerometer are more sensitive to noise. Therefore, velocity may be the best parameter to use for balancing due to its stability and mostly used to evaluate machine health status in most standards.

IV. ESTIMATION OF HEAVY SPOT WITHOUT STOPPING THE MACHINE

A new method to estimate the heavy spot location is proposed here based on the following conditions:

1) Single plane rotor
2) Critical speed is always been avoided during the design and operation stages.
3) Below the first critical speed, HIGH SPOT is in phase with the HEAVY SPOT.
4) Above the first critical speed, HIGH SPOT has a nearly 180° phase difference, which may be less that depending on the amount of system damping, than HEAVY SPOT.

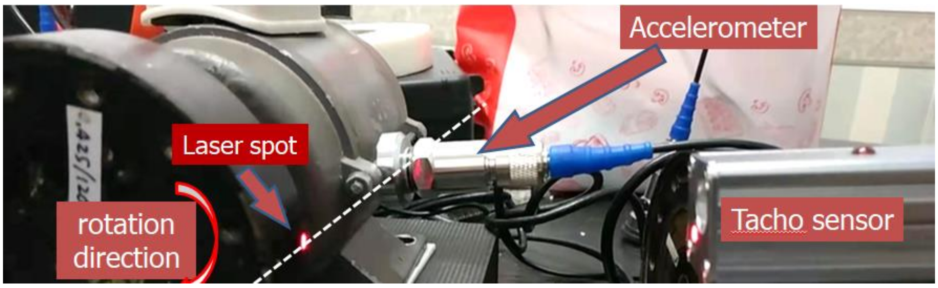

Fig.6 Laser spot and accelerometer setup

5) The velocity parameter is more stable and mostly used to evaluate machine health status.
6) 90° phase difference exists between velocity and displacement measurement.
7) The actual vibration phase may go through a complicated way to be displayed. Still, it is fixed for a specific accelerometer and tachometer and their setup relationship with the rotor.

Based on these conditions, an estimation method is proposed to locate the heavy spot of an unbalanced rotor without stopping the machine and without adding trial mass. This makes the balancing process easier and quick, so to save the field balancing cost and time.

Firstly, we prepare a good velocity-phase-calibrated balancing instrument or a velocity phase meter. Secondly, set up sensors like the Fig.6.

Thirdly, try to estimate the critical speed as in the later experiment and in [6]. Then:

1. Fix the accelerometer aligned to the shaft core
2. Make the laser spot of the tachometer and the accelerometer in a line parallel to the axis
3. Paste on a narrow reflective paper on the rotor shaft if there is not. Notice the rotation direction of the rotor.
4. Measure velocity amplitude and phase at rotation speed when the machine is running.
5. Take the measured phase as the HEAVY SPOT of the rotor if the rotation speed enough lowers than the first critical speed as in Fig.7.
6. Take the measured phase as the LIGHT SPOT of the rotor if rotation speeds enough higher than the first critical speed.

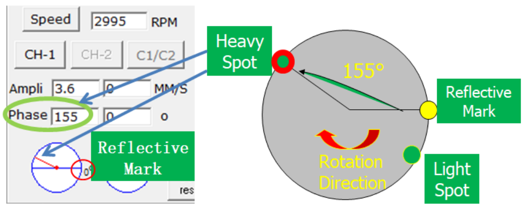

Fig.7 Measured phase as the HEAVY SPOT

7. Please notice the above procedure is valid only for a suitably installed accelerometer at bearings as in

Fig.8.

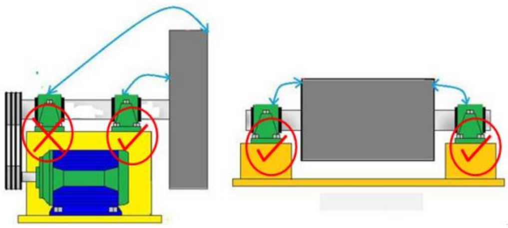

Fig.8 Install the accelerometer at right bearing

V. EXPERIMENTS ON A BLOWER

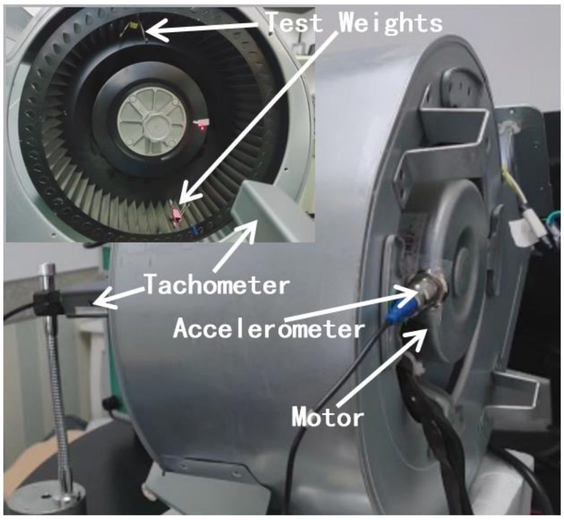

Fig.9 Blower with Weights & Sensors

A coast-down test was conducted firstly to find its first critical speed at 587 RPM

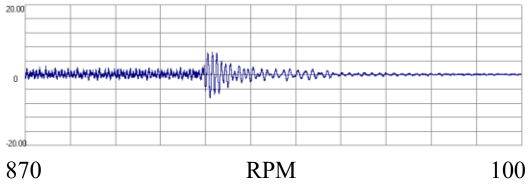

Fig.10 Coast down test from 870 to 100 RPM

We measured the phase of the velocity parameter at 4 different rotation speeds compared with the heavy spot more accurately estimated by the influence coefficient method:

RPM	Phase °	Real heavy spot °
853	147	312
670	109	312
518	340	311
441	316	311

When rotation speed is far away from the critical speed of 587 RPM, phase at 441 RPM is a good estimation of heavy spot with only a deviation of 5^o, and phase at 853 RPM is a good estimation of light spot with a deviation of 15^o.

When rotation speeds near the critical speed of 587 RPM, phase at 670 RPM is an estimation of light spot with a deviation of 23^o, and phase at 518 RPM is an estimation of heavy spot with a deviation of 28^o.

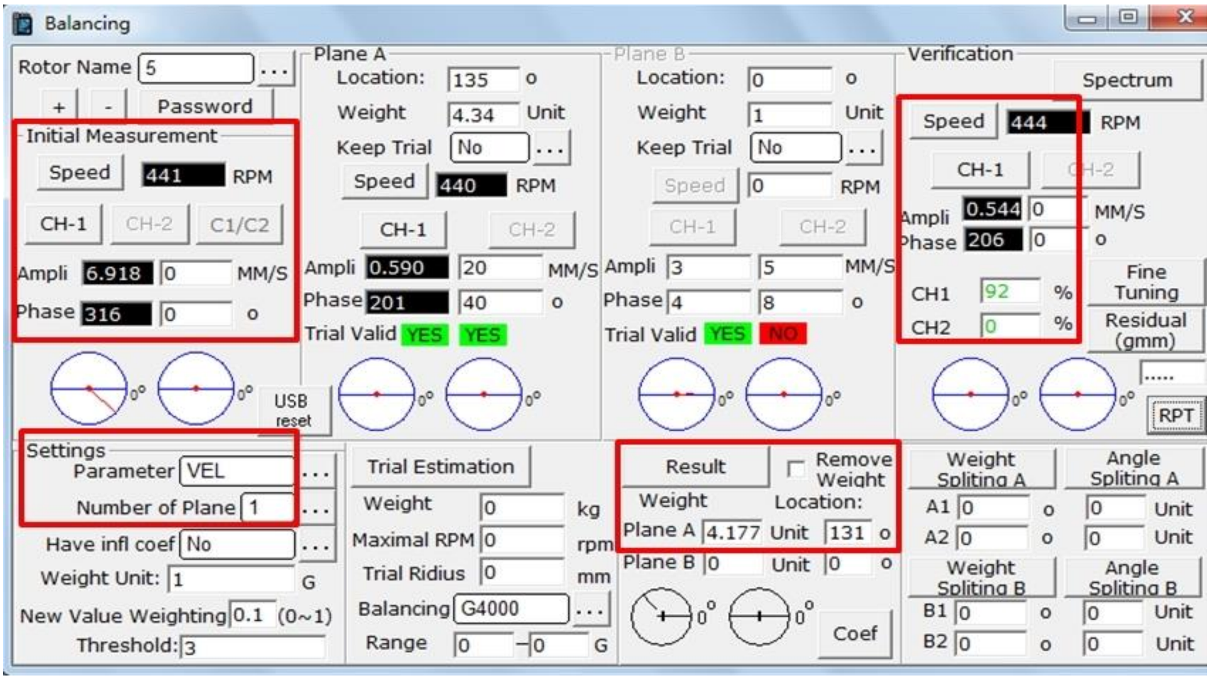

Fig.11 Phase measurement at 441RPM is a good estimation of heavy spot with only a deviation of 5^o

VI. CALCULATE CORRECTION WEIGHT

There are some ways to quickly estimate a trial weight [4]. Then we can stop the machine and fix the trial mass at the light spot.

Restart the machine and measure again the vibration amplitude and phase which is also a new estimation of the rotor heavy spot. If it does not change but the amplitude becomes smaller, then add more weight at the same light spot. Say, Original 10mm/s, now 5, then double the correction mass.

If the new measured phase changed to the opposite direction (180° different), then need to reduce the correction mass proportionally.

For other newly measured phases, may take it also as a shifted heavy spot, so may fine-tune by adding new correction mass (should be smaller).

The 1st correction mass may be taken as a trial mass for the standard influence coefficient based balancing calculator to get a more accurate correction mass.

VII. CONCLUSION

It is feasible to calibrate a balancing instrument with the accelerometer to estimate the heavy or light location of a single plane rotor based on the relationships: 1) between HEAVY STOP and HIGH SPOT at a given rotation speed; and 2) between displacement and velocity.

In addition to good experimental validation on some blowers and fans in our laboratory, the method has also been effectively validated on many blowers and fans in industrial sites.

While corrective weights are not computed, knowing where the heavy spot is located might still save time and money on-site. It can also be used as a useful starting point for estimating trial mass using the influence coefficient approach.

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