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Case Study
Single-Plane Rotor Balancing on a Disk Rotor
With Motionics iPad 2CH Vibration Analysis & Rotor Balancing Kit

1. Introduction

Rotor imbalance is the uneven mass distribution on a rotor, leading to the misalignment of the center of mass of the rotor with the center of rotation of the rotor. Imbalance creates a centrifugal force on the rotor and causes rotor vibration and noise. In the long run, imbalance will impair bearing health, reduce machine life and increase maintenance costs.

Rotor balancing is the process of adjusting mass distribution on the rotor and reducing imbalance force. It is usually achieved by analyzing rotor vibration signals and adding correction weights at proper positions on the rotor, as well as removing excessive materials from the rotor.

Rotor balancing can be expensive and time consuming. It requires some sort of data acquisition system to collect vibration signals from the rotor and personnel to spend time going through the tedious calculation process. Hence, there is an increasing need for a low-cost yet effective system for rotor balancing.

Motionics iPad vibration analysis and rotor balancing kit integrates a DAQ box on the back of an iPad case. The iRotorBalancer App running on iPad continuously collects vibration signals from the accelerometer and optical signals from the laser tachometer connected to the DAQ box, then calculates vibration amplitude and phase for balancing. Operators can follow the step-by-step guide in iRotorBalancer and conduct single-plane and two-plane balancing easily, even without any knowledge of or previous experience in rotor balancing.

In this case study, an experiment is conducted to use Motionics iPad vibration analysis and rotor balancing kit to balance a small single-plane rotor.

2. Experiment Setup

The experiment setup includes a motor running at 2800 rpm and a disk rotor with a 113 mm diameter and 10 mm thickness, as shown in Figure 1. There are 24 holes evenly distributed on the disk and a 2.13 g screw is added to one of the holes to introduce imbalance. Since the rotor thickness is much smaller than its diameter, it is considered a single-plane rotor.

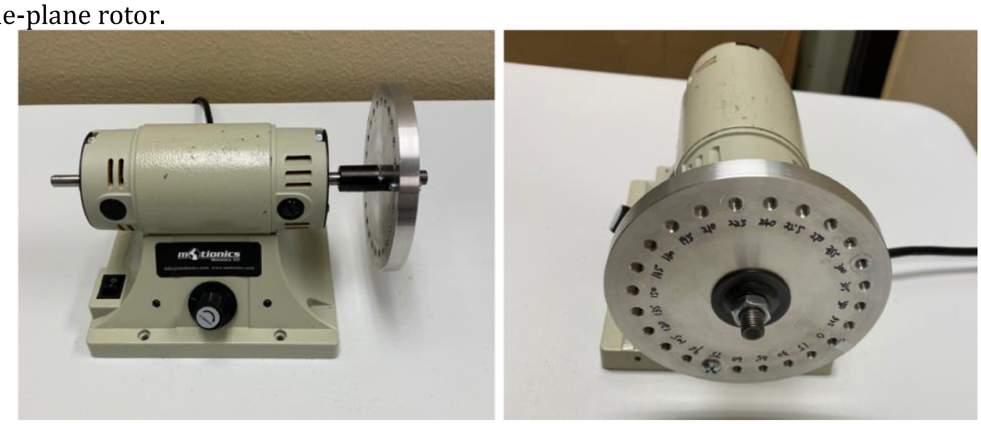

Figure 1 Testing Rotor

The piezoelectric accelerometer included in Motionics iPad vibration analysis and rotor balancing kit is mounted on the top of the motor to collect vibration signals. Screenshots of the vibration waveform and FFT spectrum are taken from Motionics VibraTestPro and shown in Figure 2 and Figure 3.

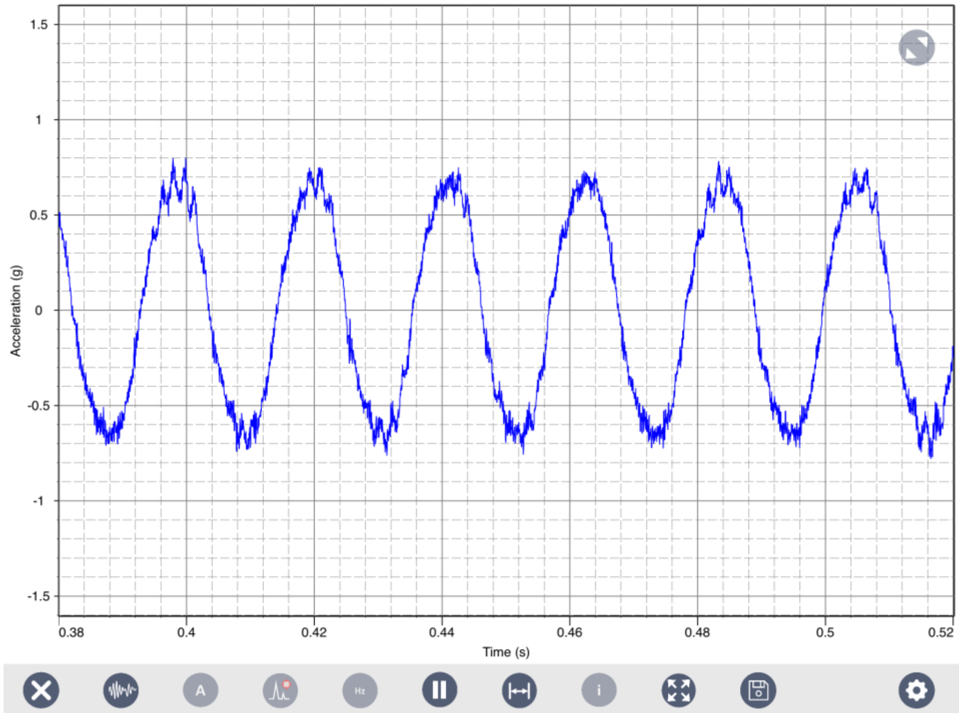

Figure 2 Waveform Before Balancing

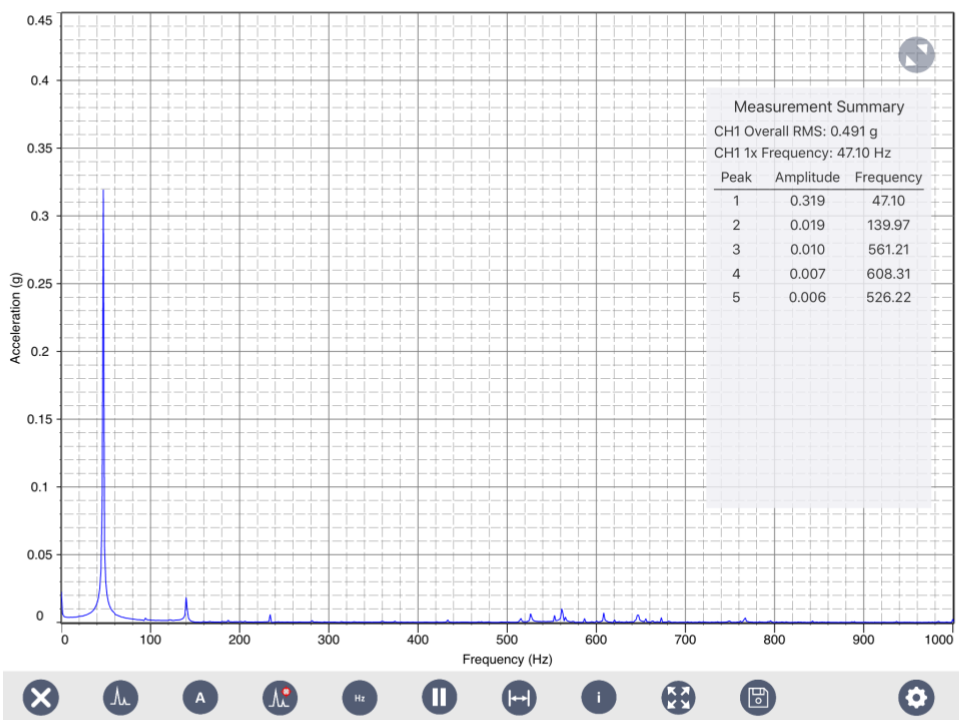

Figure 3 Spectrum Before Balancing

The vibration waveform in Figure 2 presents a sinusoid pattern with a frequency of 46.9 Hz, which matches the rotor's rotating speed. On the FFT spectrum in Figure 2, there is an obvious high peak (0.319 g) at 47.1 Hz.

As the uneven mass component rotates, the imbalance force also rotates with the rotor and reaches its maximum once per revolution at the accelerometer mounting spot. The sinusoid pattern in the time waveform and the high peak at 1X in the FFT spectrum are good indications of the presence of imbalance, as well as useful metrics to check before and after balancing.

3. Balancing Methods
   Two commonly used methods for single-plane balancing are the single-channel Four-Run method and the two-channel vector method.
   a) Single-Channel Four-Run Method
      Using the Four-Run method, only accelerometer input is required (Figure 4) and 4 measurement runs are taken:
      i) Take original vibration.
      ii) Add a trial weight to 0° on the rotor and take vibration with trial weight.
      iii) Move the same trial weight to 120° and take vibration with trial weight.
      iv) Move the same trial weight to 240° and take vibration with trial weight.

Figure 4 Single-Channel Four-Run Balancing Setup

Vibrations taken from the 4 runs and trial weight used are recorded in Table 1.

Trial Weight	1.63 g
Run 1: Original Vibration	0.4852 ips
Run 2: Vibration w/ Trial Weight at 0°	0.6759 ips
Run 3: Vibration w/ Trial Weight at 120°	0.7595 ips
Run 4: Vibration w/ Trial Weight at 240°	0.2045 ips

Table 1 Single-Channel Four-Run Balancing Parameters

In order to calculate proper correction weight, a graphic method can be used:
i) Draw a base circle using the original vibration V_0 as the radius

ii) At 0° on base circle, draw a circle using the run 2 vibration V_1 as radius
iii) At 120° on base circle, draw a circle using the run 3 vibration V_2 as radius
iv) At 240° on base circle, draw a circle using the run 4 vibration V_3 as radius
v) Roughly mark the center of the intersection, connect with base circle center point, measure V_t length and angle $\emptyset_c$
vi) Correction weight value can be calculated as $\frac{|V_0|*W_t}{|V_t|}$, angle equals to $\emptyset_c$

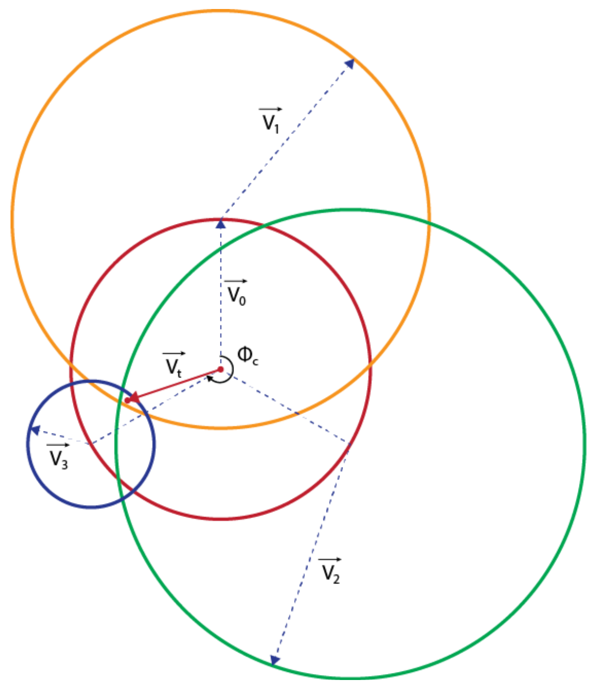

Figure 5 Single-Plane Four-Run Balancing Diagram

The whole process can also be completed in the iRotorBalancer app. On the Four-Run balancing page, four vibration runs are listed in order and four ***Get*** buttons are added for the user to capture vibration in each run. After four vibration readings have been taken, the user only needs to press the ***Correction Weight*** button to get the correction weight.

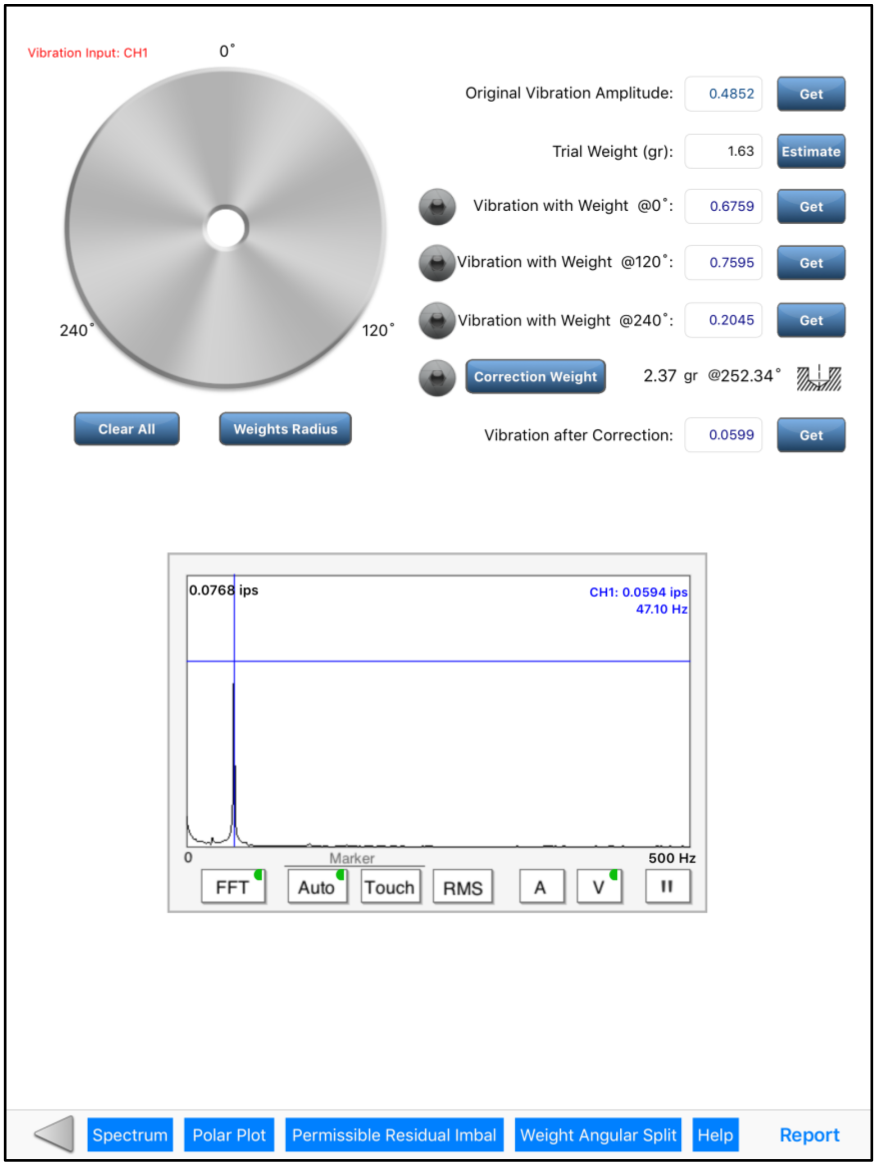

Figure 6 Single-Plane Four-Run Balancing using iRotorBalancer App

b) Two-Channel Vector Method
Using the two-channel vector method, both accelerometer input and laser tachometer input are required (Figure 7) and two measurement runs are taken:
i) Take original vibration.
ii) Add a trial weight to the rotor and take vibration with trial weight.

Figure 7 Single-Plane Two-Channel Balancing Setup

Vibrations taken from the 2 runs and trial weight used are recorded in Table 2

Original Vibration Amplitude	0.6066 ips
Original Vibration Phase	32.62°
Trial Weight	1.63 g
Trial Weight Angle	210°
Vibration w/ Trial Weight Amplitude	0.4037 ips
Vibration w/ Trial Weight Phase	79.43°

Table 2 Single-Plane Two-Channel Balancing Parameters

In order to calculate proper correction, a graphic method can be used:

i) Draw original vibration V_0
ii) Draw vibration with trial weight V_1
iii) Connect V_0 and V_1 to get vibration by trial weight alone V_t and measure length
iv) Shift V_t to origin and extend V_0 in the opposite direction to get V_c
v) Measure angle $\emptyset_c$ between V_t and V_c
vi) Correction weight value can be calculated as $\frac{|V_0|*W_t}{|V_t|}$ (W_t is trial weight value)
vii) Correction weight angle equals to $\emptyset_c + \emptyset_t$ ($\emptyset_t$ is trial weight angle)

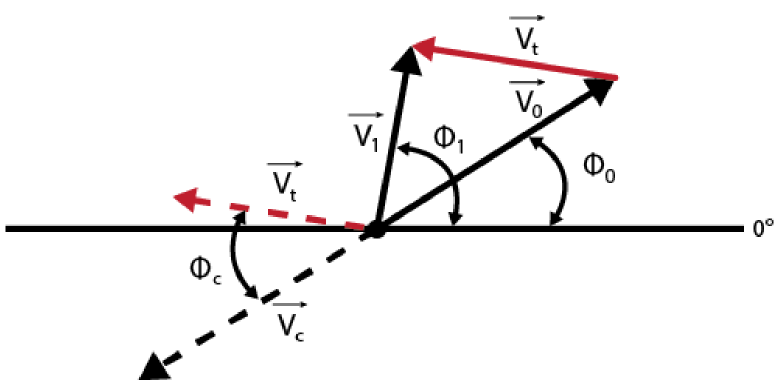

Figure 8 Single-Plane Two-Channel Balancing Diagram

The whole process can also be completed in the iRotorBalancer app. On the 2-CH single-plane balancing page, tap the first ***Get*** button to capture the original vibration amplitude and phase. Add a trial weight to the rotor, then enter the trial weight value and angle. Run the rotor again and tap the second ***Get*** button to capture vibration amplitude and phase with the trial weight. Finally, tap the ***Correction Weight*** button to calculate the correction weight value and angle. If fine-tuning is required after adding the correction weight, one more vibration reading can be taken to calculate trim weight.

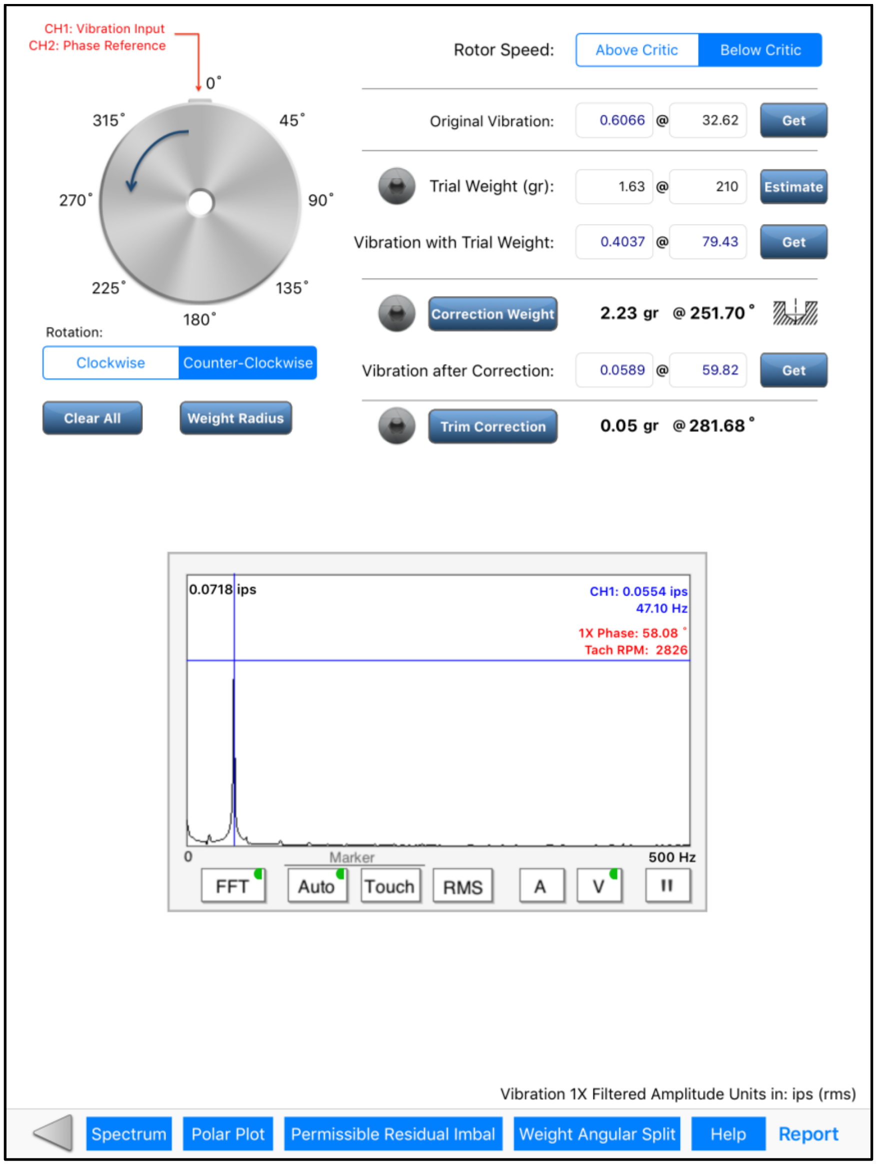

Figure 9 Single-Plane Two-Channel Balancing in iRotorBalancer App

4. Results
   a) Single-Channel Four-Run Method
      A 2.37 g correction weight at 252.3° is calculated using the single-channel Four-Run method. After adding the correction weight, vibration reading is reduced to 0.0599 ips.

Figure 10 and Figure 11 show the waveform and FFT spectrum after adding the correction weight.

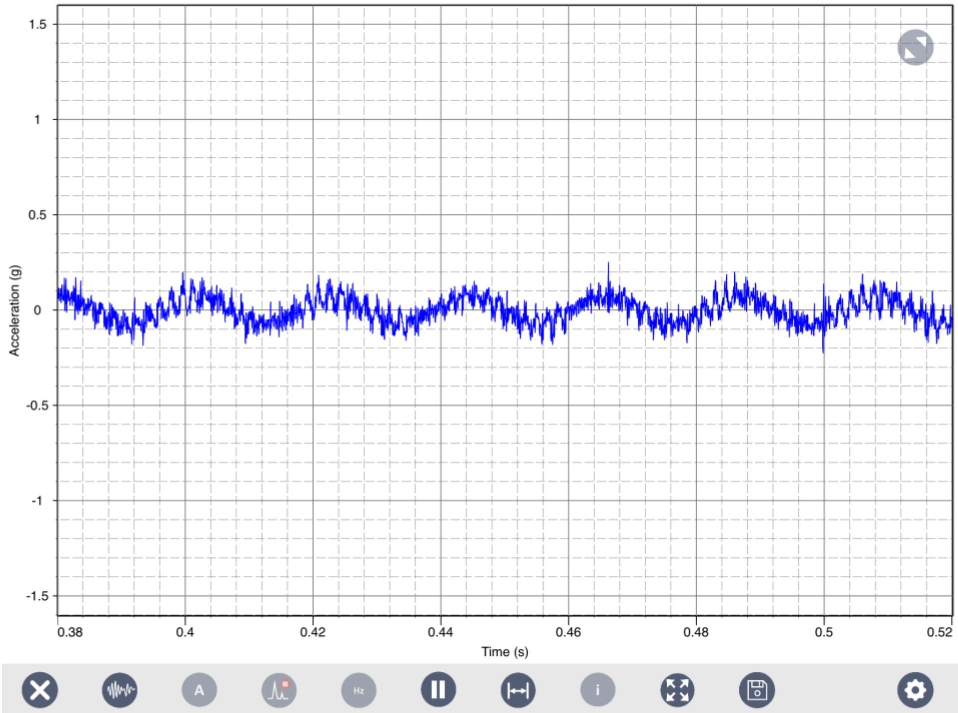

Figure 10 Waveform After Balancing with Single-Plane Four-Run Method

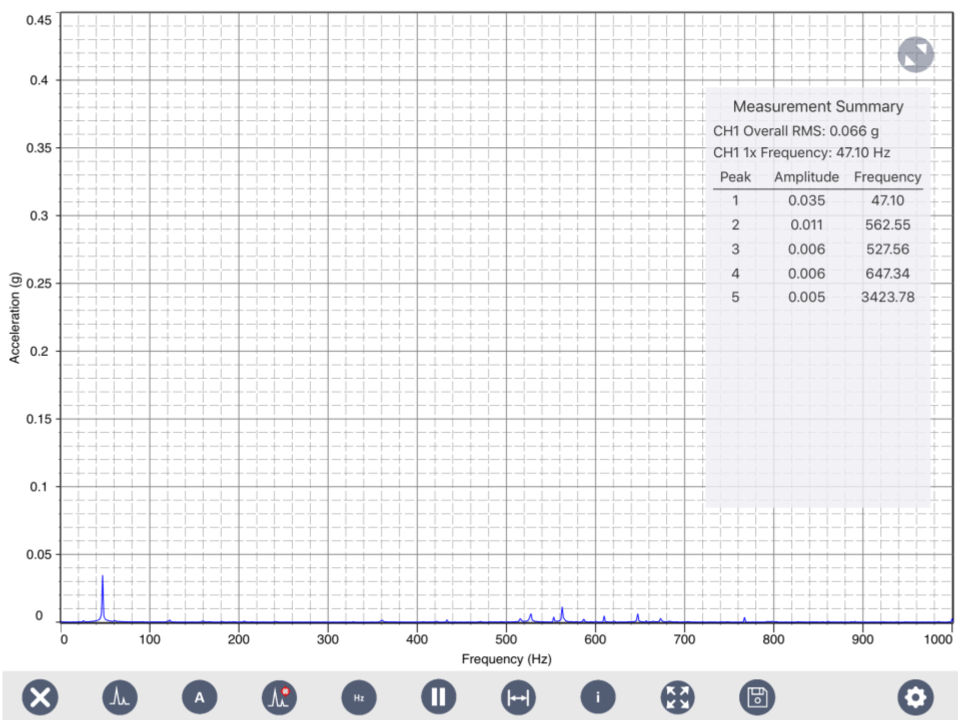

Figure 11 Spectrum After Balancing with Single-Plane Four-Run Method

b) Two-Channel Vector Method
A 2.23 g correction weight at 251.7° is calculated using the two-channel vector method. After adding the correction weight, the vibration reading is reduced to 0.0554 ips. Figure 12 and Figure 13 show the waveform and FFT spectrum after adding the correction weight.

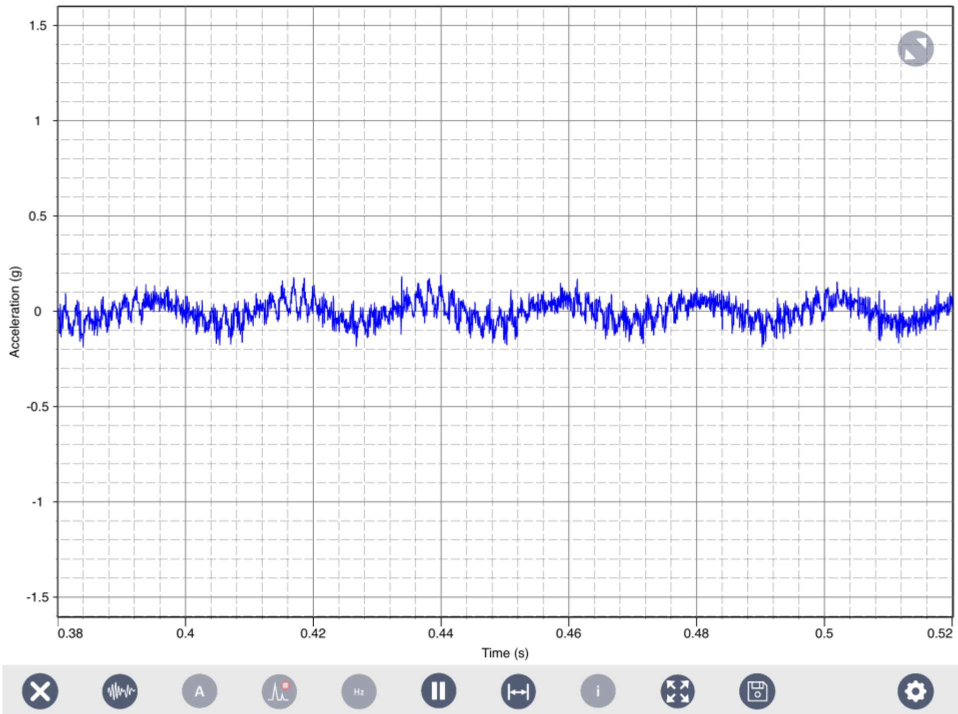

Figure 12 Waveform After Balancing with Single-Plane Two-Channel Method

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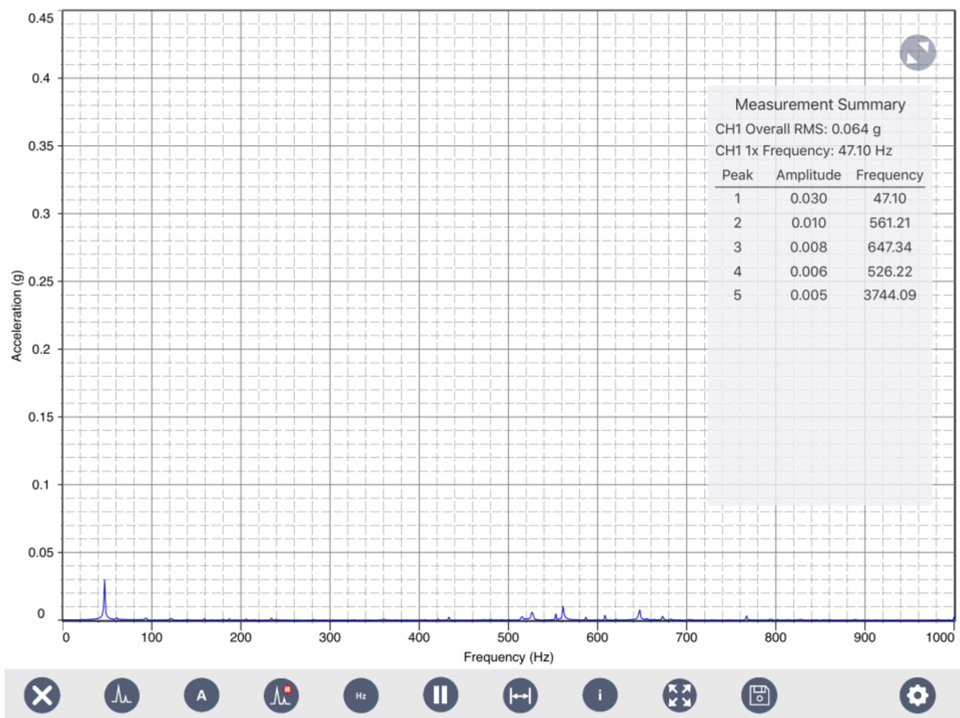

Figure 13 Spectrum After Balancing with Single-Plane Two-Channel Method

When comparing the waveforms after balancing (Figure 10 and Figure 12) with the waveform before balancing (Figure 2), the sinusoid pattern still persists, but the amplitude is greatly reduced (0.15 and 0.15 vs 0.7). Similar results can also be seen in the FFT spectra (Figure 11 and Figure 13 vs Figure 3), where the 1X peak value drops to 0.035 and 0.03, while the original peak value is 0.319. The overall vibration RMS value also drops to 0.066 and 0.064 respectively, compared to the original 0.491. The remaining 1X component could be further reduced by adding trim weight. When comparing the outcomes of the two methods, the vibration readings after balancing are very close to each other.

It's worth mentioning that the higher frequency vibration components (fluctuations superimposed on the sinusoid shape in waveform and small peaks in the 500-800 Hz range in the spectrum) are not changed before and after balancing. These vibration components might be caused by other factors such as bearing issues and cannot be corrected through rotor balancing.

5. Summary
In this case study, an experiment is set up to introduce imbalance to a disk rotor, then use Motionics iPad vibration analysis and rotor balancing kit to balance it. Two balancing methods are used: the single-channel Four-Run method and the two-channel vector method.

The single-channel Four-Run method requires less input channel and might be more suitable for occasions when there is limited space to set up a tachometer. While the two-channel vector method needs less measurement runs. Both methods take no longer than 10 minutes to complete without involving any calculation for the operator. Rotor vibration reduces significantly after both processes, proving that Motionics iPad vibration analysis and rotor balancing kit is an effective and time-saving system for rotor balancing.

Correction weights calculated from the two methods are slightly different. This might be caused by calculation of phase related to the additional channel signal in the two-channel vector method or vibration introduced by the laser tachometer placed on the test table. More experiments will be conducted to find the exact root cause in the future.

6. References

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