FIELD ANALYSIS AND BALANCING TOOLS

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Abstract: Considering the economic pressures today for minimizing production downtime and improving operating efficiency, there is increased emphasis for on-site problem detection, analysis, and resolution being accomplished as fast as possible. This set of requirements places a great deal of pressure on maintenance personnel for having all the right tools in one place, at one time, and having them readily available in a single, compact, and easy-to-use package.

Over the last several decades, we have experienced an evolution of portable instruments that can read the data (detection), to sophisticated host-based software that can determine root-cause (analysis), to yet more equipment that can offer the problem solution (correction). The level of sophistication in hand-held electronic devices today, coupled with our experiences and successes in predictive maintenance, allow for all three functions (detection, analysis, and correction) to be integrated into a single, compact, easy-to-use package.

This paper first examines the needs for the basic set of tools for machine condition monitoring applications, including a look at the key elements of detection, analysis, and correction. It then examines the requirements for tools in each area, and proposes a solution on how they can be combined in one hand-held instrument and portable toolkit for maintenance personnel.

I. INTRODUCTION

Over the past few years, we have experienced an evolutionary (if not revolutionary) set of changes in vibration measurement practices for performing predictive maintenance functions and maintaining assets. Technology has been good to us and offered significant advances for the tool set necessary to accomplish the goals and objectives of our jobs.

A key point to remember is that the best analyzing equipment and the most powerful diagnostics software will not solve a single vibration problem. It is a skilled person in the art of applying data that is required. Someone with a toolbox and the right set of tools must be on site to fix the problem. Since machinery unbalance is the most common cause of excessive vibration, it is essential that balancing tools occupy a reasonable portion of the toolbox.

Balancing technology logically falls into the category of field service and repair. However, the associated tasks are highly technical and require a good set of tools and analytical skills. For example, balancing typically involves a good set of mathematical skills in understanding vectors, algebra, and trigonometry. However, with the technology available today, balancing instruments automatically perform these calculations. The user only needs to know how to take good quality measurements and to go through the proper sequence of operator interface functions and menus on the instrument.

Addressing a difficult vibration problem has two major paths – one for diagnosis, and one for correction. On the diagnosis path, there are three main elements: (1) data collection, (2) data analysis, and (3) determining a possible root cause for the problem. Moving to the correction path, there are again three elements: (1) examining alternatives, (2) selecting the best alternative, and (3) problem resolution.

DETECTION is a key element to any successful program. The quality of the output of a process will never be any better than the quality of the input. Thus, it is essential to have the right measuring device to detect a potential problem. For detecting vibration, this means that we need an accurate sensor (meaning more than a wood-handle screwdriver and a tuned ear) and an instrument capable of interpreting the electronic signal and converting it to some meaningful, calibrated units. As an example, let's say that we need an accelerometer with an output of 100 millivolts per g of vibration, an accurate mounting method, a reliable cable and connection, and an accurate measuring instrument. Once this is established, and we secure the right components, we have a means for quantifying and qualifying the amount of vibration that is occurring at any physical location that we select for measuring.

ANALYSIS is the next step in the process. Once we have data, we must decide what it means. It is not enough to say, "Wow! This thing sure is shaking!" We need to say what is vibrating, how much, and under what conditions. In fact, we might want to look at how one part of a machine is behaving relative to another part. This is where it is important to have a reading of the phase parameter in addition to the vibration level. This shows us relative movement of one machine component as compared to another. It is said to either be in phase or out of phase by some measured angle. ("180 degrees out of phase" means that components are moving opposite of each other.)

In order to quantify motion, it is necessary to have another sensor to detect position of the rotating part relative to the vibration magnitude. This is generally accomplished with a tachometer (laser) device and a measurement of speed and relative position of a reference mark on the part.

With a grasp on two key components of vibration, the magnitude and relative phase, we can begin analyzing. However, nothing more can be done until we know what frequencies are contributing to the vibration. It could be anywhere from 1X RPM to exact multiples or any factor thereof, depending on the physical characteristics of the machine. Knowing the rotational speed and physical makeup of the machine components, telltale frequencies pinpoint problems with rolling element bearings, gearboxes, etc. A closer look at frequencies also helps us to decide root-cause, as to whether the problem stems from unbalance, looseness, alignment, bearings, etc.

CORRECTION is next. With a potential problem being detected, and enough analysis work to pinpoint a possible cause, we need to offer a solution and go to the next step of the process. Corrective methods typically include:

- Alignment
- Tightening of loose parts
- Cleaning
- Replacing failed components, such as bearings
- Methods for treating vibration, such as stiffening, damping, and isolation
- Active cancellation.

Prior to initiating any type of field correction, common sense maintenance should be performed. Some examples are:

- Cleaning
- Thorough inspection
- Checking hardware components for looseness.

Approximately 40% of vibration problems associated with machinery maintenance stem from components being unbalanced. Unbalance is characterized by measuring a high amount of vibration at a 1X running speed component.

II. BALANCING AS A CORRECTION TOOL

Now, let's concentrate on balancing as our primary means for correction. We can look at balancing as a procedure of measuring vibration and adding or removing weight to adjust mass distribution. The major goal is to reduce vibration. Why do we go to all this expense and trouble? Balancing offers a number of benefits:

- Minimize noise
- Increase bearing life
- Decrease operating stresses
- Consume less energy
- Improve product quality
- Decrease operator fatigue
- Eliminate fatigue of support structures
- Satisfy safety concerns.

The source of an unbalance problem usually stems from less than perfect manufacturing, typically categorized by:

- Design errors
- Material variation
- Form, fit, and assembly problems.

These problems are generally handled in the latter stages of the manufacturing process, and are addressed by "production balancing".

Regardless of the efforts to produce an ideal machine, vibration and unbalance problems do arise in the field. These maladies are usually caused by deposits or erosion on moving parts, losing previously installed balancing weights, damage, maintenance actions, shifting of parts, or the gradual relief of residual stresses in the shaft or body of the machine. The method to address these problems is called 'field balancing", or balancing in place. Today, it is possible to solve most balancing problems in the field without having to totally disassemble the machine and sending the rotor out for "shop balancing". Field balancing is significantly more challenging than production or shop balancing because it requires that the tool kit and tools be taken to the site and set up. Furthermore, each machine has a different set of characteristics and bears little resemblance to any previous machines that have been balanced. Field balancing is a bit challenging, but the efforts typically pay off and produce a smoother running condition.

When being called to perform a balancing operation in the field, it is important to eliminate any other possible causes, such as resonances, eccentric pulleys, looseness, alignment, and causes stemming from other drive components. In order to avoid going down the wrong path for correction, it is first necessary to verify unbalance with some preliminary analysis. The success of field balancing is never a 100% certainty. The probability of success is more like 80%, even when unbalance is known to be the culprit. Sometimes, there are other sources of 1X RPM vibration that cannot be corrected by changing weight distribution.

III. THE IDEAL SET OF TOOLS

It hasn't been too long ago that each of the 3 fundamentals for problem resolution, DETECTION, ANALYSIS, and CORRECTION, required unique sets of physical tools. A small portable hand-held instrument or meter was typically selected for DETECTION. A linked processor capable of interpreting the measurements then performed ANALYSIS. Yet another device was used for CORRECTION. Thus, the successful maintenance technician typically had a big toolbox (containing a comprehensive set of tools) and the training and the skill set required to use them correctly.

With recent advances in technology, coupled with the needs to consolidate assets and to minimize outlays for capital equipment, there has been a concerted effort by instruments suppliers to incorporate detection, analysis, and correction methods into a small, hand-held package.

This paper is intended to examine the basic features and key attributes of one such product that is currently available in the marketplace.

IV. FUNDAMENTAL REQUIREMENTS

Now that it is stated that we need a single package to detect, analyze, and correct problems in complex machinery that stem for an early onset of increased vibration levels, we need to define our requirements. Although the following list is by no means comprehensive, it represents a typical 'wish list' from a maintenance technician' viewpoint:

- Small, lightweight, and hand-held package.
- Proven platform for performance.
- Accurate and reliable.
- Functionally independent, with no dependence on host software.
- Easy to use and intuitive operator interface.
- Complete package, with all accessories and peripherals included.
- On-board data storage and recall.
- Built-in analysis capabilities for vibration amplitude, frequencies, and phase.
- Two-plane balancing capability.

These qualities span all three fundamental elements of plant asset management: detection, analysis, and correction.

V. SINGLE PACKAGE APPLICATION

If a problem is suspected with plant machinery, it is first necessary to do an overall vibration measurement with a known good instrument, thereby qualifying and quantifying the observation relative to industry guidelines (ISO). At the same time, it is wise to measure and verify the running speed. It would be desirable to perform these measurements without requirements for in-depth training and lots of set up time. Thus, we could quickly confirm that the machine is running at its target speed and the vibration reading is at a specific level.

Next, we should perform a frequency spectrum measurement to show what frequencies are contributing to the overall vibration level. With a built-in FFT capability, we can quickly progress beyond reading the overall vibration level and show the contributions by frequency.

Knowing the rotating speed and looking at the frequency spectrum, we can very quickly ascertain whether or not we have a problem stemming from 1X RPM – and most likely a problem associated with unbalance.

If unbalance is deemed as the problem, it is desirable to quickly move to a correction of the problem by having a field-balancing tool. Ideally, we could perform all these functions out of one tool case with some independence, and no need to use external resources.

Having a single package with a quick solution should improve our efficiency and credibility for vibration analysis and problem solving for condition-based maintenance.

VI. IMPLEMENTATION

Now that we have established that size and weight are two important parameters for our ideal field tool, and we can only assume that price carries an equal weighting, we need to look at requirements. First of all, we need to follow the ‘K.I.S.S’. principal, and keep it simple. At initial power-on, the instrument menu needs to self-evident and prompting the user. One implementation would be to have a simple structure showing fey items like Measure, Balancing, and a few Instrument Setup options. Measure should be listed first, as it is a prompt to take an initial reading. The sub-menu should also be simple, with a preset group of industry-standard parameters, so a meaningful reading is obtainable with a single press of a button. There should also be a provision for the more sophisticated user to have access to easily adjust other measurement parameters. In addition to seeing the overall vibration level, a frequency display (FFT) should be included. There should also be a measurement of running speed available at a single press of a button. This, with initial data collected and displayed, it is easy to verify the presence of a 1X running speed component as a major contributor to the overall vibration level.

Once adequate data is available and studied, it is time to address the possible root cause of the vibration. As mentioned before, with 40% of the vibration problems stemming from an unbalance condition, where a major contributor is at 1X running speed, it makes sense to incorporate balancing as a dedicated correction tool – with a simple-to-use, user-prompting implementation.

The balancing function should prompt the user right through the proper sequence of steps: the initial run, the introduction of a trial weight, the calibration run, and finally, the recommendation on the size and location of the weight to be used for correction. The balancing implementation should also have the provision for added functionality such as one or two planes, continuous or fixed rotor positions, adding or removing weight, and additional trim runs.

In addition to the basic instrument and its peripherals, there is a group of key accessories for balancing that needs to be nicely packaged in a kit. This group includes transducers, tachometer, cables, and charger.

All information should be presented in clear and concise graphical screens, with prompts for action and navigation. Summary readouts should also be available at intermediate steps and at the conclusion of the process.

The storing and recall of vibration and balancing run data is a must for fieldwork.

VII. FIELD EXAMPLE

Let us now take a look at a practical example for vibration analysis and balancing in the field. We will walk through the typical steps and techniques, and touch on all three fundamental elements (detection, analysis, and correction) for machine condition monitoring and asset management.

As we approach the subject machine we are told that it is running at about 1050 RPM, and that it was discovered to be running roughly just a few days before.

We power on our data collector/analyzer instrument, and see the initial menu screen as shown in Figure 1.

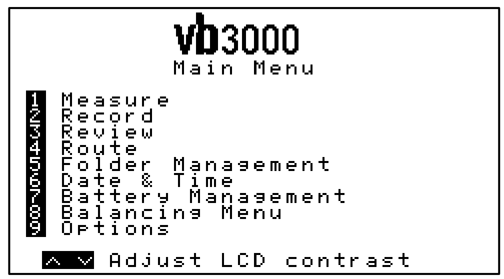

Figure 1. Main Menu

We choose the Measure mode, and a second menu (Measurement Menu) screen appears, as shown in Figure 2.

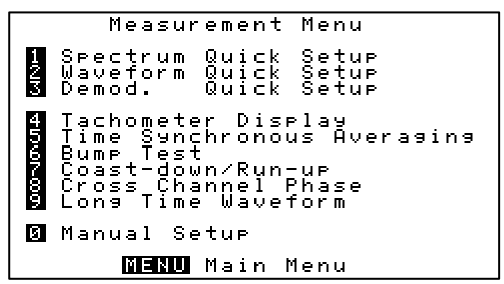

Figure 2. Measurement Menu

We select Tachometer Display and aim the tachometer device (laser) at the reflective tape on the machine shaft to verify the running speed, and we arrive at a “live-time” display, as shown in Figure 3.

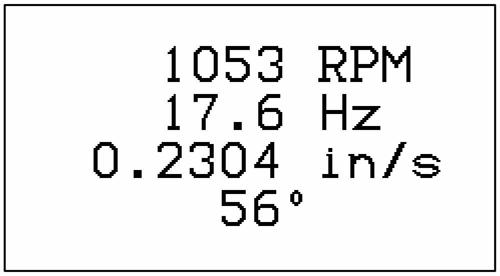

Figure 3. Tachometer Display

Indeed, this does confirm the machine speed at approximately 1050 RPM. Also, it is noted that the velocity overall reading is at 0.2304 IPS peak.

Now is the time to get a quick vibration measurement, with FFT (frequencies). We choose the Spectrum Quick Setup measurement with accelerometer, Item 1 in the Measurement Menu, shown in Figure 2. The resulting FFT display is shown in Figure 4.

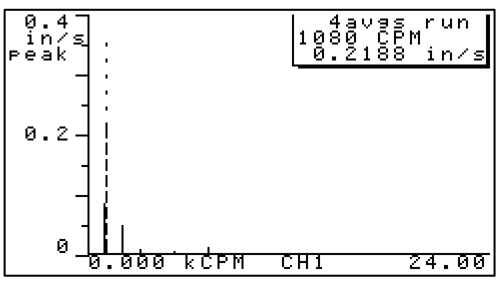

Figure 4. Standard Spectrum Measurement

Note that we have an overall vibration level at 0.230 IPS (inches per second) peak, with the majority of the contribution (0.218 IPS) at 1X RPM (1080 RPM).

From the published industry charts, we are certainly in the "Rough" category, with thresholds as shown in Table 1.

Based on the significant 1X contribution, we go from the detection and analysis stages to correction (Balancing), and we make this choice from the Balancing Menu shown in Figure 5.

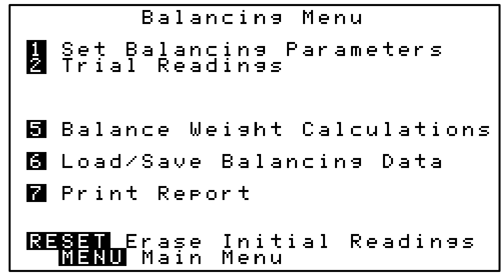

Figure 5. Balancing Menu

We now need to set up balancing parameters and choose menu item 1, resulting in the screen shown in Figure 6.

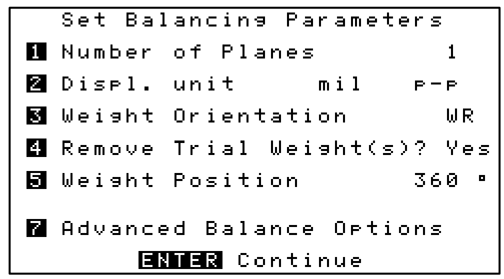

Figure 6. Balancing Parameters

For the sake of simplicity in this example, we will perform a single-plane balance, and choose displacement in mils pk-pk as our measurement parameter. We proceed with the balancing mode and an initial reading, as selected by menu item 1 in the Trial Readings screen, as shown in Figure 7.

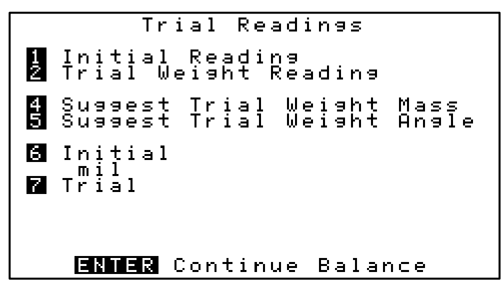

Figure 7. Trial Readings

The initial reading is displayed as shown in Figure 8.

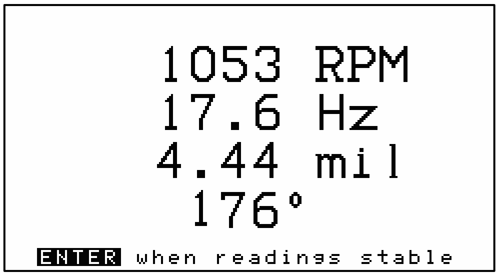

Figure 8. Initial Reading

We proceed now by placing a trial weight for calibration. We choose a weight value and angle placement, as shown in Figure 9, where a 1 gram weight is placed at an arbitrary reference point marked 0 degrees.

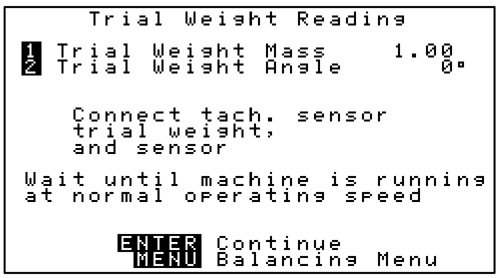

Figure 9. Trial Weight Setup

Next, we perform another run with trial weight in place. The measurement is displayed as shown in Figure 10.

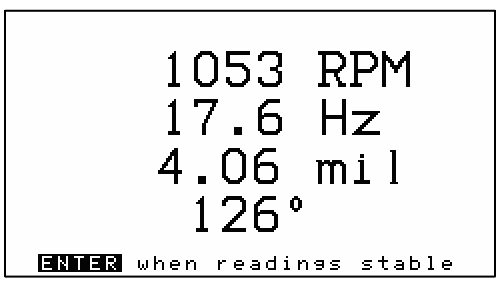

Figure 10. Trial Weight Reading

As we have passed the so-called “30-30” test for a 30 degree angle change or a 30% shift in amplitude, we then proceed with balancing by selecting menu item 3,.as shown in Figure 11.

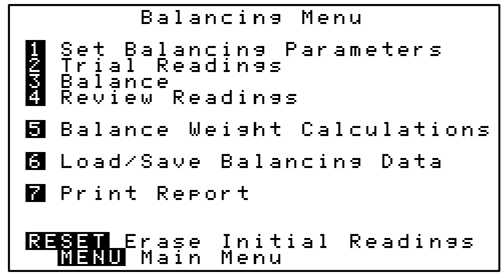

Figure 11. Balancing Menu

The trial weight is removed (per our setup in Figure 6) and the correction weight and location are called out, as shown in Figure 12.

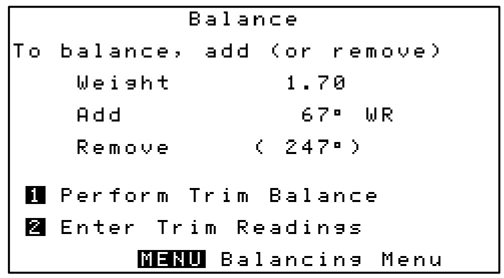

Figure 12. Balance Weight Callout

The appropriate weight is placed on the rotor at the angle indicated (with rotation per our setup in Figure 6) and a trim run is performed. The resulting measurement is shown in Figure 13.

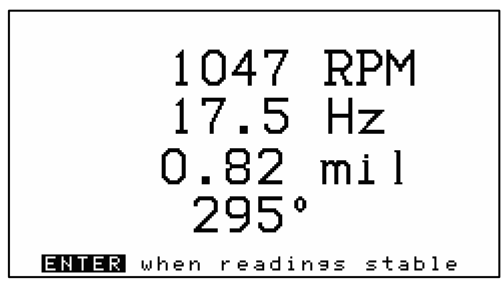

Figure 13. Correction Run

Even though balancing has improved the vibration from 4.40 mils to 0.8 mils, we can proceed with the balancing run and ‘trim’ even further. An additional trim weight callout is shown in Figure 14.

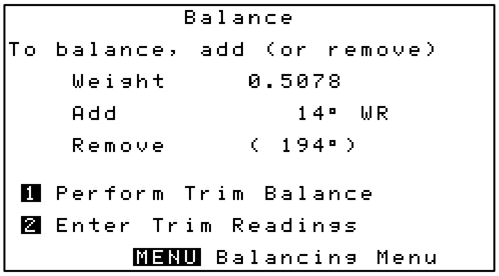

Figure 13. Correction Run

We elect to make this trim with the weight call-out and proceed with another measurement. This new reading is shown in Figure 14.

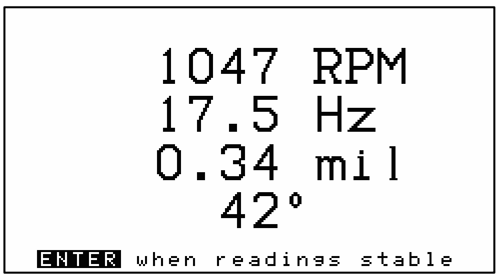

Figure 14. Trim Run

As this point, we could continue, but vibration levels have been improved by more than 10 to 1, and the machine is only vibrating at 0.34 mils pk-pk. Hence, we declare it a "completed job".

We can now take a quick look at our balancing history on this job, as shown in Figure 15.

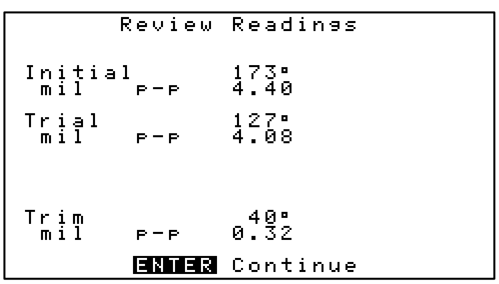

Figure 15. Balancing Review

Now is a good time to read the overall vibration again, as we did in the very beginning of this example. We arrive at the display as shown in Figure 16.

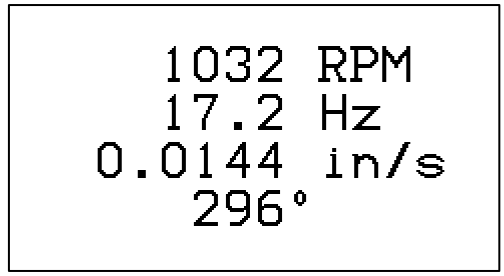

Figure 16. Overall Vibration

Note that our overall peak velocity has improved from 0.2304 IPS to 0.014 IPS.

We can confirm that the 1X element has been significantly improved by viewing the FFT data again, as shown in Figure 17.

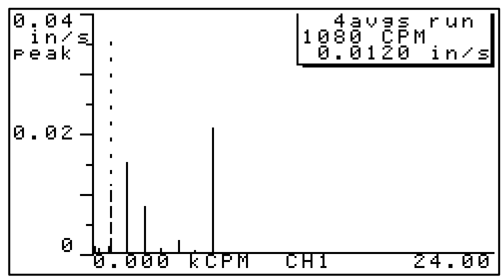

Figure 17. FFT

We have moved from the "Rough" to "Good" category on the Machinery Severity chart shown in Table 1.

In just a few steps, we were able to take a machine running at a very rough level of 4.4 mils to approximately 13 times less, or 0.34 mils.

In this brief example, we stopped after one correction and one trim. Note that the 1X component contribution has gone from 0.218 IPS all the way down to 0.012 IPS – a reduction of 18 times. At 0.0144 IPS overall, the machine is now running in the Good category and warrants a quick look at other factors (other than balancing) that may be contributing to vibration.

“Before” and “After” data can be summarized by the following displays:

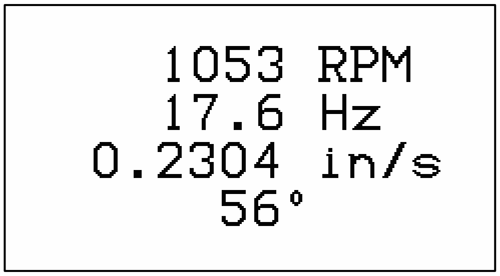

Figure 18. Overall Reading - Before

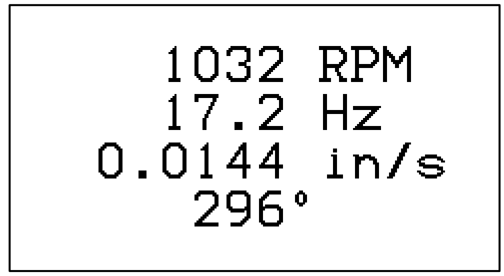

Figure 20. Overall Reading - After

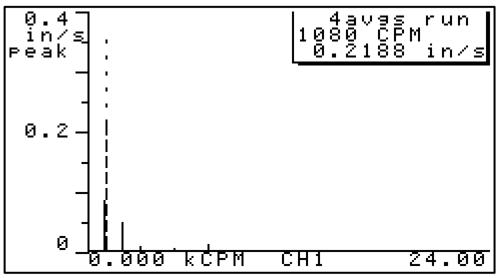

Figure 19. Spectrum (FFT) Display - Before

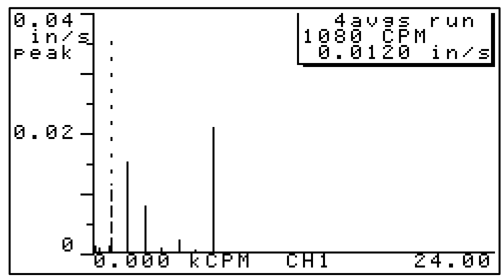

Figure 21. Spectrum (FFT) Display - After

Although we finished this particular balancing run with one correction and one trim, the complete process is shown by the flow chart in Figure 22.

The Machinery Severity table is provided in Table 1 below.

Vibration Velocity (IPS – Peak)	Vibration Velocity (mm/s – Peak)	Severity Level for Machine
.001	0.025	Extremely Smooth
.002	0.051	Very Smooth
.004	0.102	Smooth
.008	0.203	Very Good
.016	0.406	Good
.032	0.813	Fair
.064	1.626	Slightly Rough
.128	3.251	Rough

Table 1. Machinery Severity

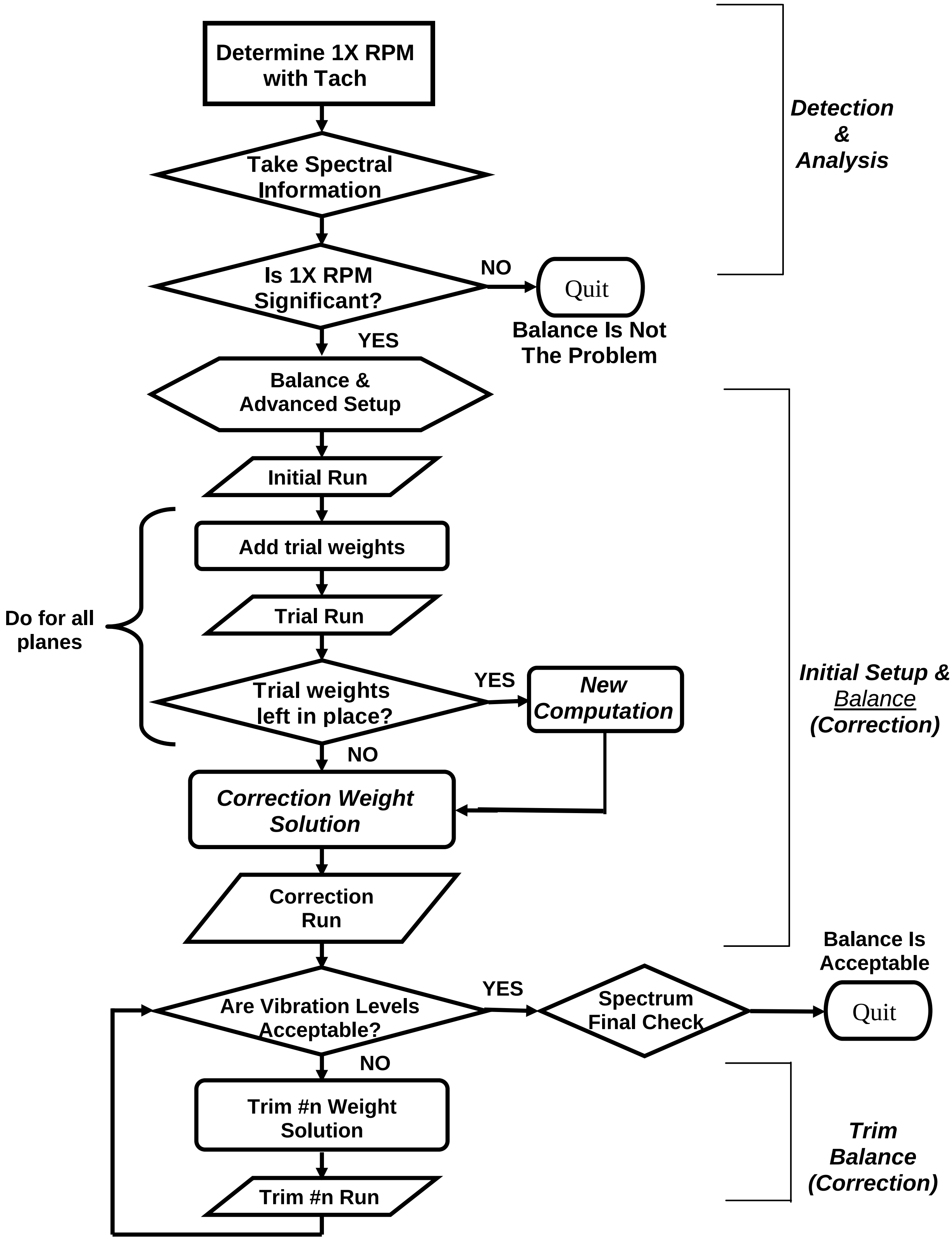

Figure 22. Flow Chart for Detection, Analysis, and Correction - using Balancing

VIII. CONCLUSIONS

As time is money in any field repair work, balancing is no exception. It behooves the user to always be prepared. It makes a lot of sense to have anything and everything that could possibly be of benefit ready and on site in a compact, lightweight, and easy-to-use package. This is the trend for the industry as we have experienced the evolution.

There were several intents in composing this paper, and they are summarized below:

- Reflect on the fundamentals of vibration analysis
- List fundamental requirements in applying the technology
- Identify the required tools for problem resolution
- Examine the elements of field analysis and balancing
- Witness success of a specific implementation.

In covering these elements, it is hoped that the reader will gain some insight in being able to quickly detect, analyze, and correct vibration and unbalance problems in the field.

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