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 having portable instrumentation that could read the data (detection), to sophisticated host-based software that could determine root-cause (analysis), to yet more equipment that could 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 palm-sized instrument and portable toolkit for maintenance personnel.

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 present to fix the problem. Since machinery unbalance is the most common cause of excessive vibration, it is absolutely 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 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 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 (probably more than a 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, "Yep, 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 a parameter called phase 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 photo tachometer (i.e., 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(s), 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, 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 phase 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.

Balancing as a Correction Tool

Now, let's concentrate on balancing as our primary means for correction. Basically, 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? There are 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 customers.

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

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

These problems are generally addressed 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. This is called 'field balancing", or balancing in place. Today, it is possible to address 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 hauled out to the site and set up anew. 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 almost always pay off and produce a better running condition.

When being called to perform a balancing operation in the field (which seems to be the root cause of a vibration problem about 40% of the time), 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 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 weight distribution.

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 usually had a big toolbox, containing a comprehensive set of tools, and the knowledge and 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 single package. There has also been a driving force to combine this functionally into a small, hand-held (preferably palm-sized) instrument.

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

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 this list is by no means comprehensive, this represents a typical 'wish list':

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

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

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. 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 the overall vibration level and show the contributions by frequency.

Now, knowing the rotating speed and looking at the frequency spectrum, we can very quickly ascertain whether or not we have a 1X RPM problem – 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 “lifelines” like computer assistance, phoning a friend, or asking members of the audience that might be present! (Stealing lines from the popular “Who Wants To Be a Millionaire?” show.)

One package for addressing field problems won’t necessarily make us instant millionaires, but it certainly should improve our efficiency and credibility for vibration analysis and problem solving for condition-based maintenance.

Implementation

Now that we have established that size and weight are two important parameters for our 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 three general settings: (1) Analysis, (2) Balancing, and (3) Instrument Setup. Analysis 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 parameters, so as to a meaningful ‘standard’ 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 plot (FFT) calculation should automatically follow. 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 – again, with a simple-to-use, user-prompting implementation.

The balancing function should be so simple to guide the user right through the proper sequence of steps: the initial run, the introduction of a trial weight, the second 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 a bit of added functionality, like 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, cables, chargers, a small scale (for trial weights), and a portable printer.

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.

Local screen storage and printing is a must for fieldwork. There needs to be a provision for saving images as bitmaps on card or printing them directly. Stored bitmaps allow the user to cut and paste images into customized formats for reports.

Field Example

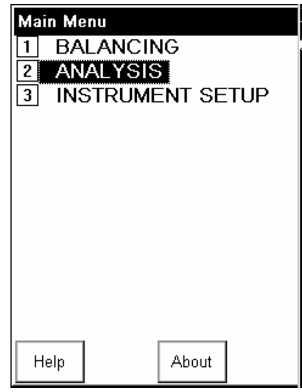

Figure 1. Main Menu

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 1200 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.

We choose the analysis mode, and another menu screen appears, as shown in Figure 2.

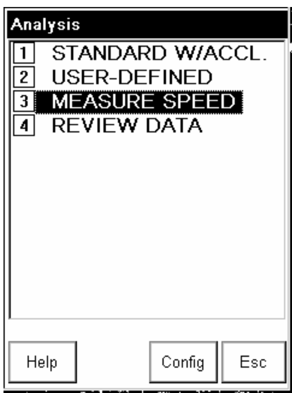

Figure 2. Analysis Menu

We select "measure speed" and aim the photo tachometer (or 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.

Indeed, this does confirm the machine speed at 1200 RPM.

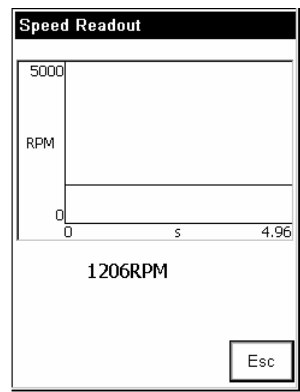

Figure 3. Speed Readout

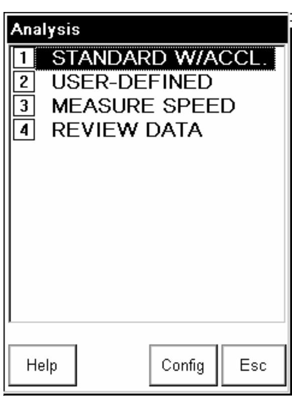

Figure 4. Standard Measurement

Now is the time to get a quick vibration measurement, with FFT (frequencies). We choose the standard measurement with accelerometer, Item 1 in the Analysis Menu, shown in Figure 4.

Once we select the standard measurement, we begin collecting and storing overall and spectral data, as shown by Figures 5 and 6.

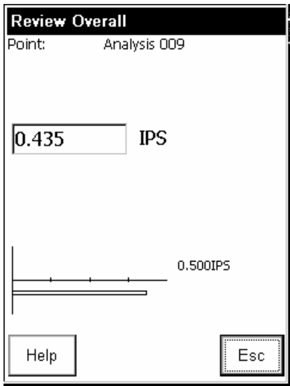

Figure 5. Overall

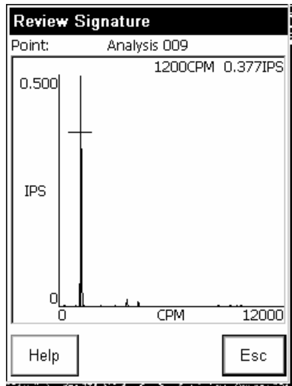

Figure 6. Spectrum

Once data are stored, it can be recalled and displayed through the Review Data menu selection, as shown by selection of Item 4 in the Analysis Menu, Figure 7.

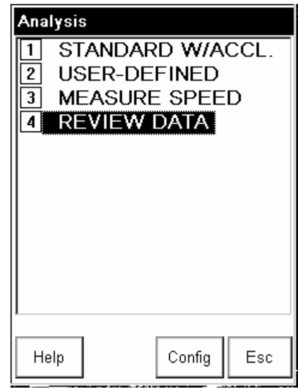

Figure 7. Review Data

A selection is made from the stored data, Analysis 009, as shown in Figure 8, and the overall and spectral values are retrieved and displayed as shown in Figures 9 and 10.

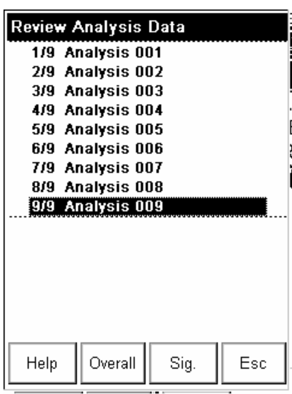

Figure 8. Selection

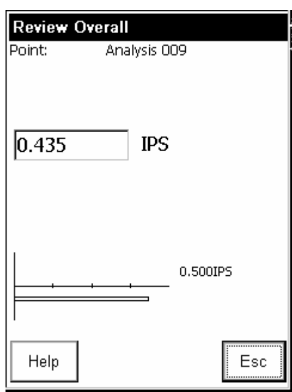

Figure 9. Overall

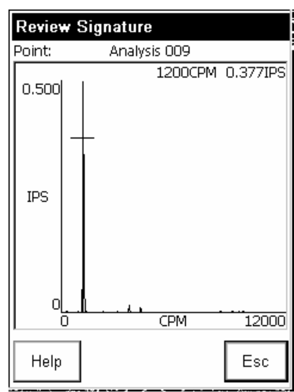

Figure 10. Spectrum

Note that we have an overall vibration level at 0.435 IPS (inches per second) peak, with the majority of the contribution (0.377 IPS) at 1X RPM (1200 RPM).

From the published charts, we are certainly in the "Rough" category, with definitions as shown 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

Based on the significant 1X contribution, we go from the detection and analysis stages to correction (Balancing), and we make this choice from the following menu (Figure 11).

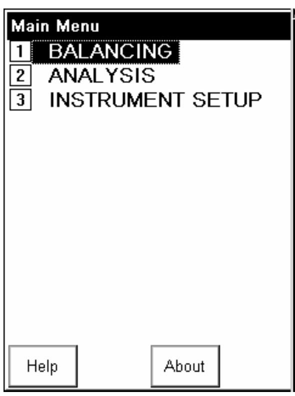

Figure 11. Main Menu

After this choice, we either verify or modify the default settings for two planes, as shown in Figures 12 and 13.

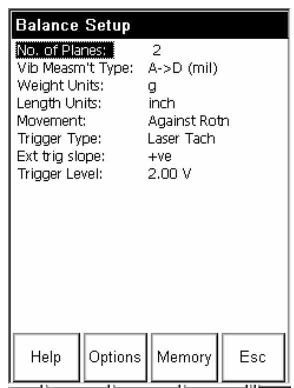

Figure 12. Options 1

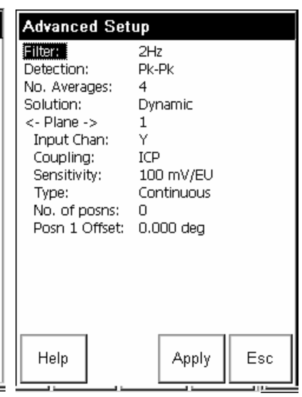

Figure 13. Options 2

Now, we begin the two-channel balancing process.

Note From Figure 14 that we are provided with a graphical representation of amplitude and phase readings for both planes.

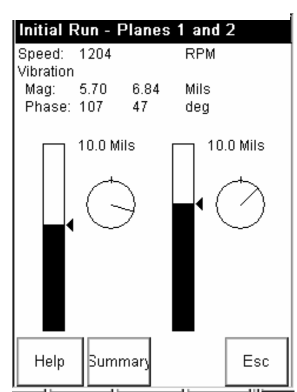

Figure 14. Balancing

Now we are prompted to attach a trial weight in plane 1 and to make another measurement. As shown in Figure 15, we add 1.5 grams at 0 degrees to plane 1 of the rotor, and bring the rotor back to balance speed. The new readings are shown in Figure 16.

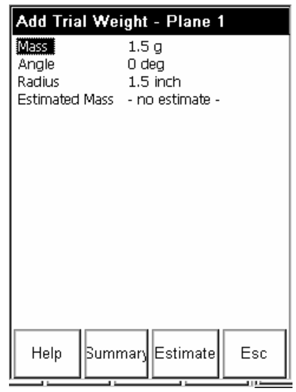

Figure 15. Trial Wt. 1

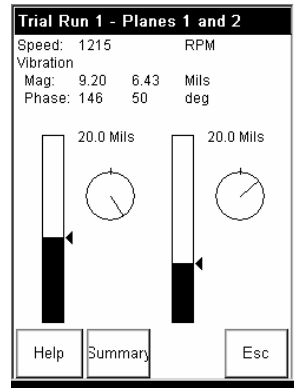

Figure 16. New Reading 1

Next, we are prompted to remove this weight and to perform the same operation for plane 2. As shown in Figure 17, we add 1.5 grams at 0 degrees in plane 2 of the rotor, and bring the rotor back to balance speed. The new readings are shown in Figure 18.

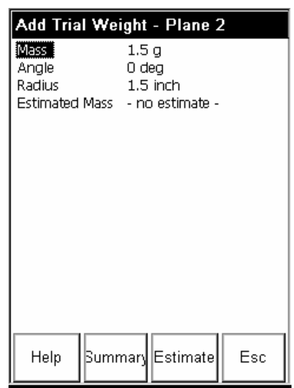

Figure 17. Trial Wt. 2

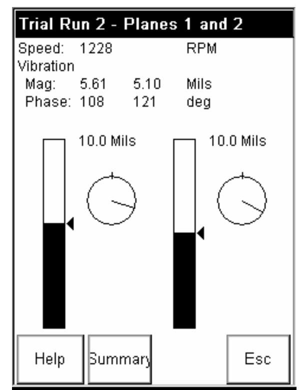

Figure 18. New Reading 2

Once that these operations are completed, the instrument will compute the size and angle position of correction weights for the two planes, as shown by the displays in Figures.19 and 20.

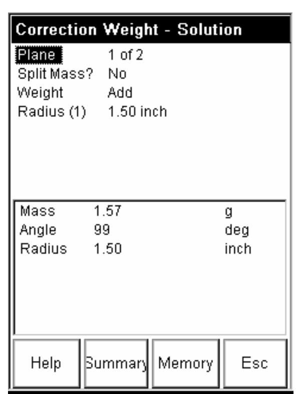

Figure 19. Plane 1 Correction

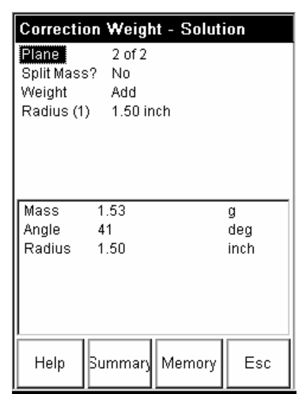

Figure 20. Plane 2 Correction

Correction weights are measured and placed at the appropriate angles in each plane, and a set of vibration measurements is made again, as shown in Figure 21.

At this point in the process, we have the choice of trimming the balance condition even further or saying that we are done. If we declare that we are finished, we can look at the vibration summary tables for the two planes, as shown in Figures 22 and 23.

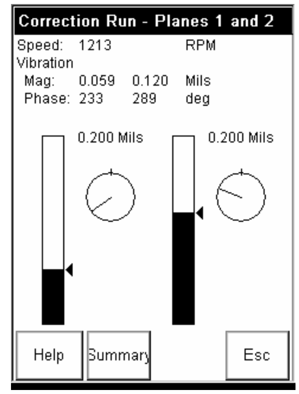

Figure 21. Correction Run

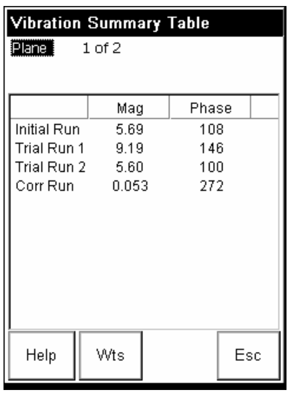

Figure 22. Vibration Summary 1

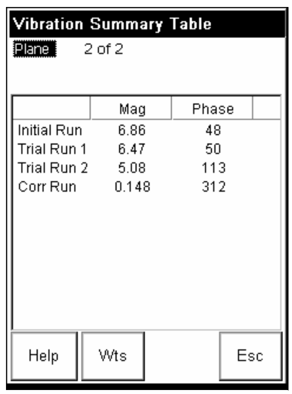

Figure 23. Vibration Summary 2

Alternatively, we can also view the weights summary, as shown in Figures 24 and 25.

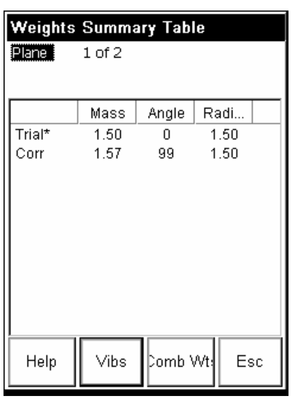

Figure 24. Weights Summary 1

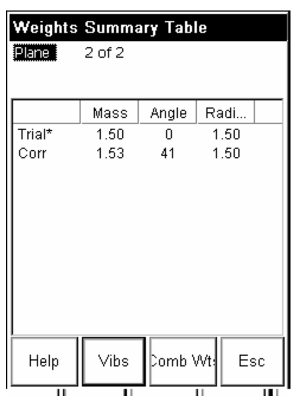

Figure 25. Weights Summary 2

In just a few steps, we were able to take a machine running at a very rough level of 6 mils to approximately 40 times less, or 0.15 mils.

In fact, it is very useful to take overall and spectral information once again to verify our success. See Figures 26 and 27.

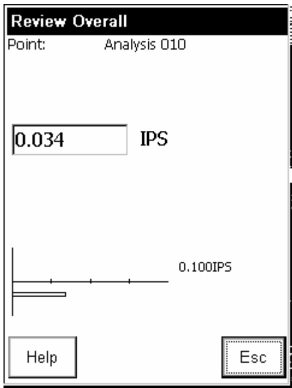

Figure 26. Overall After Balancing

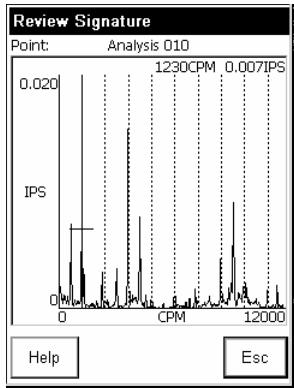

Figure 27. Spectrum After Balancing

In this brief example, we stopped after one correction. Note that the 1X component contribution has gone from 0.377 IPS all the way down to 0.007 IPS – a reduction of 50 times. At 0.034 IPS overall, the machine is now running in the Fair category and warrants a look at other factors (other than balancing) that may be contributing to vibration.

Note that we have taken spectrum data on two different scales, and the one in Figure 27 is at a full-scale value of only 0.020 IPS. (The spectrum in Figure 10 is displayed with a full-scale value of 0.500 IPS.)

For a better comparison, the "Before" and "After" data are normalized (without cursor) to the same scale (0.500 IPS) and shown in Figures 28 and 29.

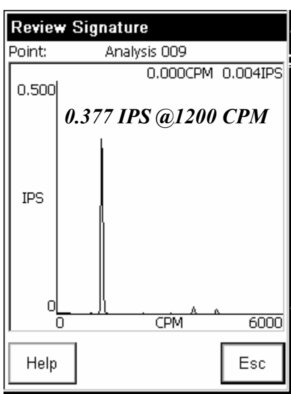

Figure 28. BEFORE

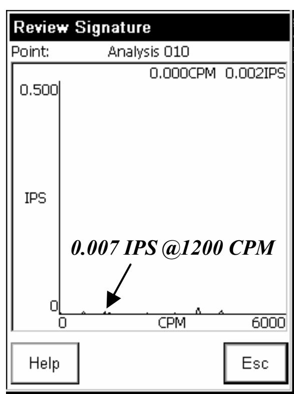

Figure 29. AFTER

Although we finished this particular balancing run with just one correction, the complete process is shown by the flow chart in Figure 30.

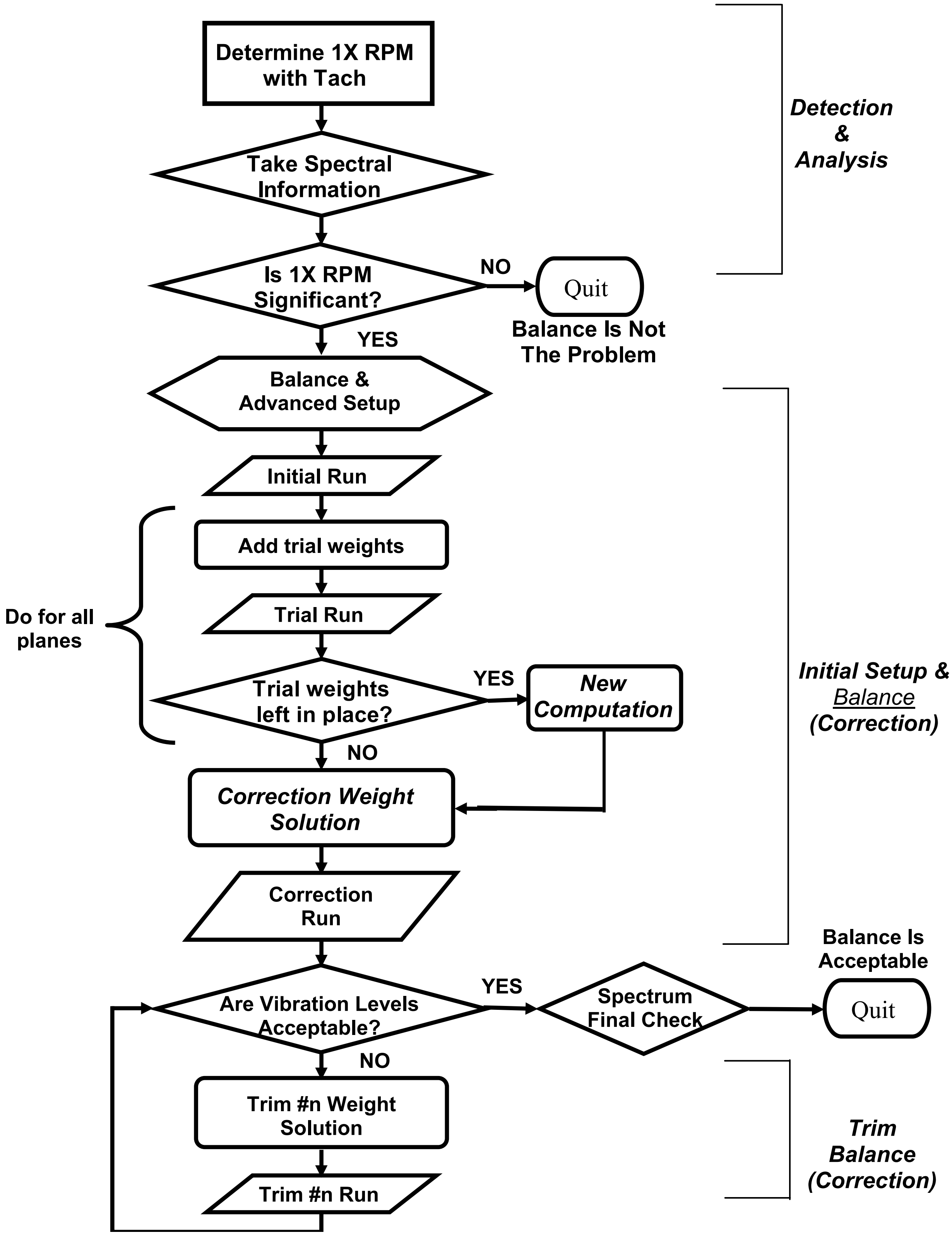

Figure 30. Flow Chart for Detection, Analysis, and Correction - using Balancing

Conclusions

As time is money in any field repair work, balancing is no exception. It behooves the user to always be prepared (like the Boy Scouts of America motto goes). 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 s 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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