uptime

nov 2006

the magazine for PdM & CBM professionals

Proving the Value of Maintenance

Infrared: Resolution Revealed • Motors: Basic (re)Training • Alignment: The Fixed/Moveable Myth • Vibration: The Time Waveform Revisited

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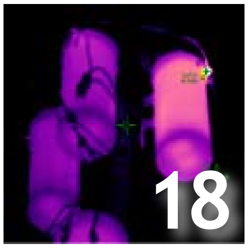

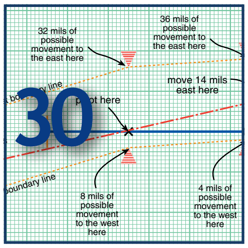

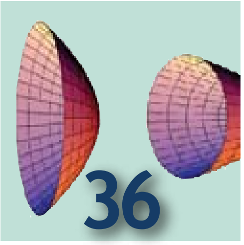

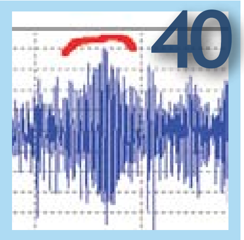

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upfront

Delivering Value

Value. It's something we all want. From our toaster ovens to our tools. From our shoes to our cell phones. We want to know that the money we are spending, for whatever goods or services we require, is going to be worth the investment. In fact, we should expect nothing less.

Just as we want to spend our money wisely, companies do too. They want to know that the money they spend will be worth the investment. On this we can all agree - proactive maintenance is an investment in future company performance.

At some point in the distant past, maintenance was co-opted. Many top level executives and accountants started viewing maintenance as a necessary evil, not an investment in the future. Unfortunately, that mind-set remains pervasive in many companies to this day.

The time has certainly come to change that way of thinking. In many enlightened organizations it has changed, and many of those are now top performers in their industry. However, for those companies not yet there, it is tough to overcome the years and culture of the "maintenance as merely an expense" thinking.

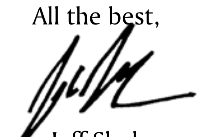
It remains the maintenance industry's responsibility to convert the non-believers. There is no better way to do this than to prove, beyond the shadow of a doubt, that excellent maintenance is indeed a good value, and money well spent. The feature article this month, which describes a concept known as Value Driven Maintenance®, provides a look into one way of doing this. The authors have endeavored to quantify, with a set of mathematical formulas, the actual value of maintenance.

Discussing maintenance in terms of delivering value and return on investment is the key to gaining support for proactive maintenance practices. Framing the discussion in these terms aligns maintenance with the concepts most meaningful to those deciding how to spend corporate money. Decision makers want to spend money, but only in areas they are convinced will provide a good return on investment.

Everybody wants a good value. We all know that proactive maintenance is a good value. Let's go out and prove it!

Thank you for reading. Please feel free to contact me with any questions, comments or suggestions that you think will help Uptime be more valuable to you.

All the best,



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uptime
volume 2, issue 13

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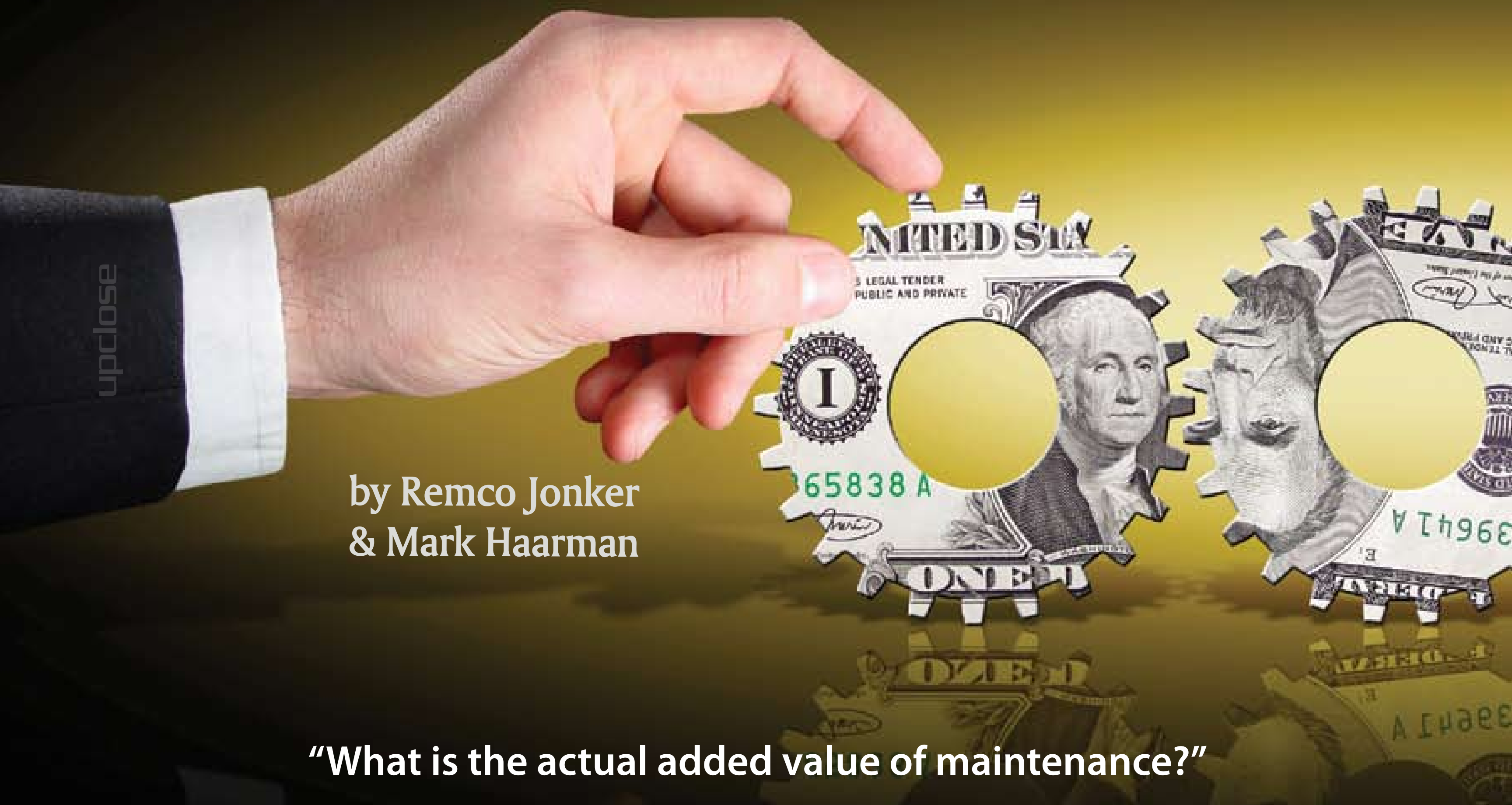
POSTMASTER: Send address changes to: Uptime Magazine PO Box 07070, Ft. Myers, FL 33919.

Value Driven



by Remco Jonker
& Mark Haarman

"What is the actual added value of maintenance?"

That is a frequently heard question in boardrooms the world over. Even though maintenance is often critically important, few maintenance managers are able to answer the question convincingly. Especially when they are asked to express the benefits in terms of economic value added or shareholder value - the language being spoken in boardrooms.

For this reason Mainnovation developed the Value Driven Maintenance® (VDM) methodology, which is implemented in leading maintenance organizations like DSM, Smurfit Kappa, Sara Lee, GlaxoSmithKline, Akzo Nobel and Volvo Cars.

VDM builds a bridge between traditional maintenance philosophies and managing by shareholder value. Not only does VDM simplify the boardroom discussion, it also shows that far from being a cost center, maintenance is actually a major economic value within the overall business performance.

What is Value?

Before you can manage by shareholder value, you have to understand what exactly value is. Reference to financial literature reveals that value is defined as the sum of all future free cash flows, discounted to today.

This sounds impressive, but what does it really mean? Let's start by looking at the first part of the definition. A cash flow is the difference between income and expenditure. This is not the same as the difference between revenues and costs, because that's an item

Maintenance

that can be greatly influenced by accounting practices. Some companies use highly creative lease, depreciation and reservation techniques to keep their book profits artificially high (or low). Newspapers have been crammed with articles on this subject in the recent past. As we have seen from many of these stories, questionable accounting techniques do not always contribute to shareholder value - and are rarely good for the long-term health of a company.

The second part of the definition stems from the knowledge that the value of a cash flow is related to time. One dollar is worth more today than one dollar next year. This is because you can deposit a dollar at the bank today and use it to generate income over a period of one year. Therefore, you have to adjust future cash flows.

Value of Maintenance

A maintenance manager is likely to say: "This theoretical approach is all very well and good, but what good is it to me in practice? The value of maintenance comes from delivering maximum availability at minimum cost!" While this is true in theory, it's little help in the day to day operation. This is because you have to prioritize: do you want to reduce costs or increase uptime? Is a 1% increase of uptime just as valuable as a 1% reduction of costs? And how do you determine the value of safety?

VDM provides answers by identifying the value potential of four value drivers in maintenance and enabling you to manage by those drivers.

Figure 1 shows what maintenance is all about. Today's maintenance managers are constantly balancing between higher machine availability (asset utilization) and lower maintenance costs (cost control). In doing so, they must take into account the growing body of laws and regulations covering safety, health and environment. To make everything work, they need to use the right technicians, spare parts, knowledge and contractors (resource allocation).

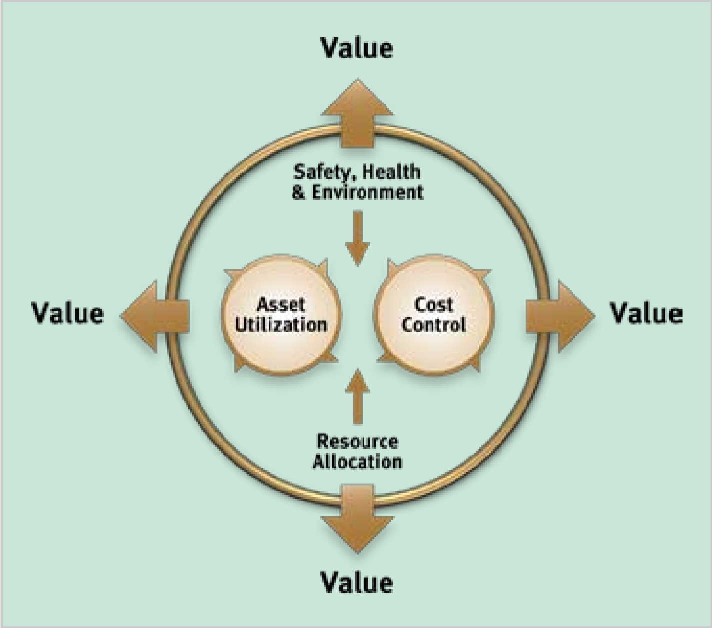


Figure 1: Maintenance Value Drivers

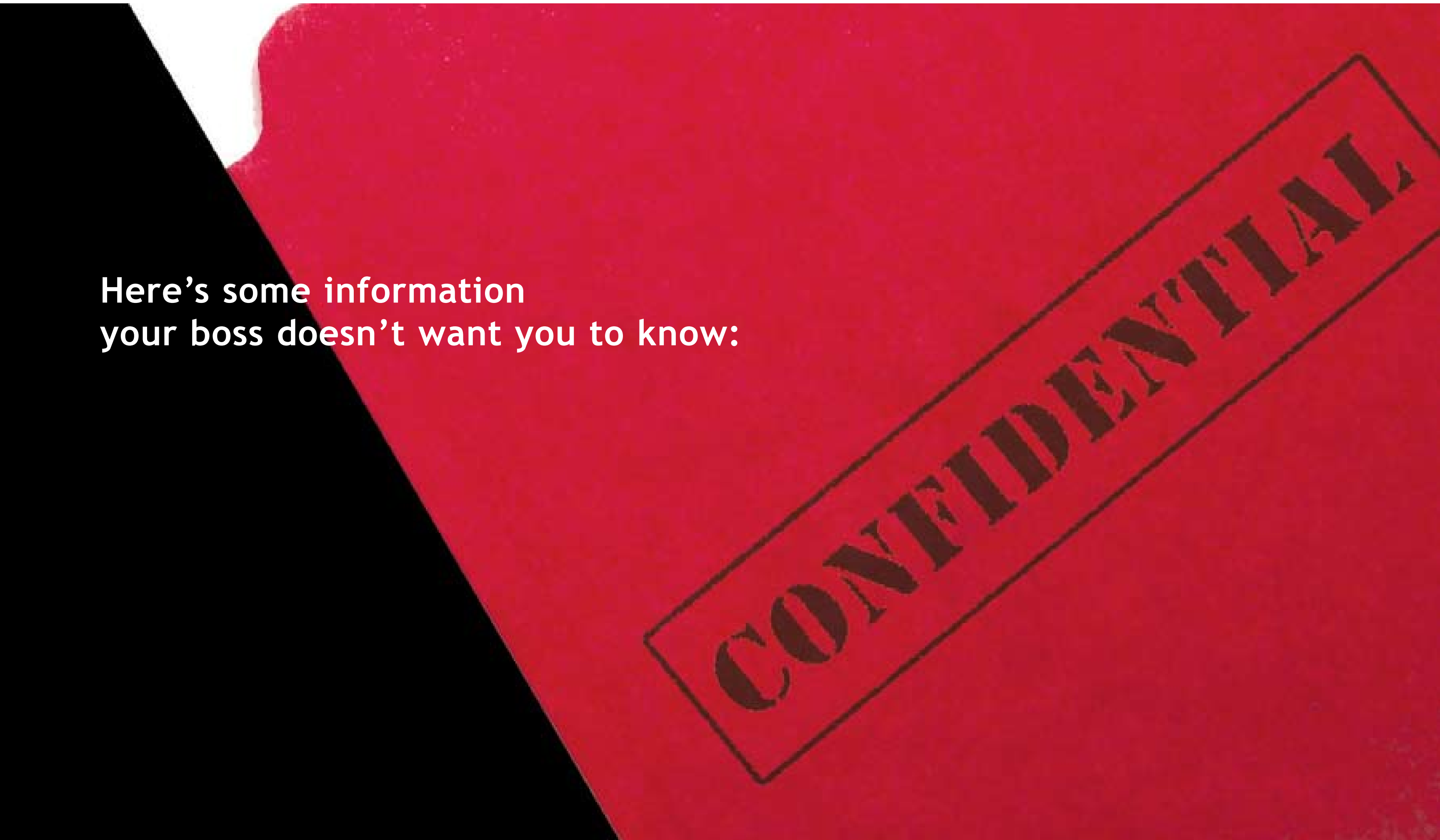
For all four value drivers, maintenance can and does help to increase a company's economic value. In a market where there is more demand than supply, greater machine availability results in more products, more income and thus higher value. On the other hand, lower maintenance costs produce higher value by avoiding expenditure. The same applies to resource allocation. One example is a technical storeroom. Smarter inventory management of spare parts can enormously increase value for a company.

Similarly, the safety, health and environment (SHE) factor affects value. SHE accidents tend to necessitate substantial expenditure, which results in large negative cash flows. Damage caused to personnel, environment and image, for example, will increase expenditure. An even greater danger is loss of the license to operate because of an inability to comply with SHE legislation. No license to operate means no production and no income.

Value Potential

Maintenance managers must show where there is potential for value within their maintenance organization. VDM provides calculation models and tools for this purpose (see nex page). One of those tools is the VDM Control Centre; an online platform that allows maintenance managers to measure and benchmark their maintenance performance against anonymous companies in the same industry. The VDM Control Centre also provides a transparent picture of the contribution a maintenance organization is making to creating value for a company.

Note that the result of the calculation of value will differ markedly depending upon the industry involved. In the bulk chemical



Value Driven Maintenance - The Inner Workings

The definition that value is equal to the sum of all future cash flows, discounted to today, is translatable into the following formula:

$$\mathbf{PV = \sum \{CF_t / (1+r)^t\}}$$

Where: **PV** = value (present value)
CFt = future free cash flow in year t (cash flow)
r = discount rate

To calculate the value of maintenance, this formula can be applied in the following way:

$$\mathbf{PV_{maintenance} = \sum \{FSHE_{,t} \times (CFAU_{,t} + CFCC_{,t} + CFRA_{,t} + CFSHE_{,t}) / (1+r)^t\}}$$

Where:
PVmaintenance = value of maintenance
FSHE,t = SHE factor in year t (% of compliance with SHE regulations)
CFAU,t = future free cash flow in year t from asset utilization
CFCC,t = future free cash flow in year t from cost control
CFRA,t = future free cash flow in year t from resource allocation
CFSHE,t = future free cash flow in year t from SHE
r = discount rate

To see how this fomula works, look at the following example:

Say a paper factory produces 1,000,000 kilograms of high-quality paper each year, with 50% asset utilization. The price of each kilogram of paper is € 10, with a profit margin of 15%. The factory's annual maintenance costs come to € 500,000 and it keeps € 300,000 of spare parts in stock. The annual management costs for the inventory of spare parts (personnel, space, insurance, etc) equals 15% of the value of the stocks. The maintenance concept is of a highly corrective nature, with a SHE factor of 95%.

Based on a thorough reliability study, the reliability engineer has recommended giving the maintenance concept a strongly preventive nature. Each week an extra one-day inspection will be carried out by two technicians (mechanical and electrical). This will increase annual maintenance costs by 52 x 2 x € 500 = € 52,000.

Given the preventive nature of maintenance, the reliability engineer expects to increase asset utilization to 55% and to reduce the inventory of spare parts to € 250,000. The new maintenance concept will not influence the SHE factor.

This makes the value of this improvement proposal:

FSHE,t	= 95%	**CFAU,t**	= 5% x 1,000,000 x 15% x 10 = € 75,000
CFCC,t	= € - 52,000	**CFRA,t**	= 15% x 50,000 = € 7,500
CFSHE,t	= 0	**r**	= 16% (internally determined discount factor)

PVmaintenance, t = 0->10 = Σ { 0.95 x (75,000 – 52,000 + 7,500) / (1 + 0.16)t }
= € 140,043

PVmaintenance is greater than zero, so there is an increase in value and the recommendation should be adopted.

Figure 2: Maintenance Core Competences

industry, for example, there is currently less demand than supply and worldwide prices are under considerable pressure. The value potential here lies mainly in controlling costs and the smarter deployment of people and resources. In the pharmaceutical industry, the situation is the other way around. Demand for medicines continues to grow but the technical availability of the production process is relatively low. This matter is obviously receiving attention. The SHE factor here is becoming more and more important with the growing role of the regulating authority FDA (Food & Drug Administration).

Value and Time

The next example shows that value depends not only on the industry concerned, but also on time. In the aviation industry, traditionally the focus was on increasing fleet availability and meeting the regulations of the Aviation Authorities. As a result of the attacks on September 11th, 2001, there has been a (perhaps temporary) reduction of the demand for air travel. This reduces the importance of fleet availability. At present, many airlines are concentrating on controlling costs. This requires an enormous turnaround, one in which the VDM methodology can guide the way.

Value and Competencies

Once the value potential has been identified, the maintenance function must be organized accordingly. Which competencies are, and are not, important? There will be little point in giving priority to reducing the stock of spare parts if the value potential lies in more uptime. Unfortunately, all too often, we see that these decisions are not made by the maintenance department. VDM, however, does so and it creates a link between value drivers and core competencies (see Figure 2).

Take the example of bulk chemicals. The market situation means that most value is currently achievable by controlling costs. So the right-hand value circle must be configured from maintenance budgeting to cost analysis. The opposite applies to the pharmaceutical industry. There, the left-hand value circle must be organized from equipment performance planning to loss analysis. Interestingly, both value circles include the competencies of reliability engineering, planning & preparation and maintenance execution. These competencies are the link between the four value drivers and thus form the heart of VDM.

Value and Best Practices

Now that we know the important competencies, the next step is to organize and control them in the right way. For this purpose VDM puts forward best practices from leading maintenance organizations. Total Productive Maintenance (TPM) thus enjoys a reputation mainly as the best practice for registering, analyzing and improving production losses (asset utilization) in discrete production. In contrast, Asset Based Costing (ABC) is a proven best practice for properly controlling maintenance costs.

Using these best practices, a technical department can quickly become a professional maintenance organization that adds value to the overall business performance. In VDM terminology, this is called the Most Valuable Maintenance Organization (MVMO). To ensure that the new way of working is embedded in the day-to-day business, the processes and best practices are described in the VDM process map. This is a complete and interactive description of the processes involved and roles and responsibilities resulting from it. Naturally the people should be trained accordingly. The different steps in the process

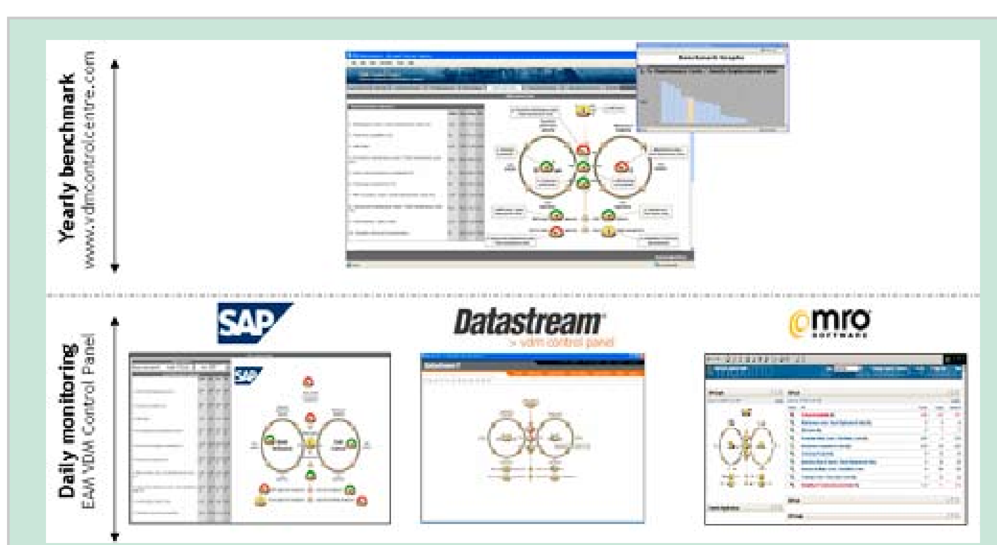


Figure 3 - VDM COntrols Panels in leading EAM Vendor Software

get proactive

Make the shift...

Your organization wants to stop putting out fires. You want your guys to take charge before things become costly. Making the shift from reactive to proactive is not straight forward but it needs to start somewhere. So why not start with the basics...Asset Basic Care?

Asset Basic Care records the condition (sight, smell, touch, sound) of your assets using an electronic checklist on a handheld computer. It's an excellent way to start recording what's going on with your machinery and changing the mind-set from reactive to proactive. In a very short time, your equipment database becomes populated with information that can prevent failures before they happen—putting you in control AND saving money.

Built on a multi-tiered pyramid approach to reliability, **MAINT***elligence*™ provides a simple start toward becoming proactive with a solid foundation in Asset Basic Care, (operator inspections and total lubrication management). Then when you are ready to expand your reliability program, **MAINT***elligence*™ will support you each step of the way at a rate that suits your organization.

Talk to a DMSI reliability specialist to ask how we can assist you in meeting your reliability goals.

MAINT*elligence* **> helping you become proactive!**

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VDM Business Simulation

Just a game or powerful tool to support change?

Value Driven Maintenance® (VDM) is a new maintenance concept that provides a quantitative control model that explains how maintenance can contribute to economic added value through the adoption of World Class principles and practices. Today it is recognized worldwide as an innovative and trendsetting maintenance philosophy. Maintenance organizations from different parts of the world have now adopted the VDM concept with very impressive results.

Learning by Doing

One of the biggest challenges of implentation is getting the people on board to drive the strategy at an operational level. The VDM Business Simulation encourages people of all levels in the organization to adapt to the upcoming changes and to use the VDM philosophy. They experience the power of the concept by applying it - learning by doing.

The simulation not only shows the value of a certain strategy but also how it impacts the 'day-to-day' way of working. The simulation has been applied at many different companies with great success.

Fun to Play

The VDM Business Simulation takes place in a competitive environment: teams are faced with true life maintenance problem situations, limited information and conflicting demands. During the simulation all kind of events are introduced. Each team defines its maintenance strategy with variables - number of mechanics, number of critical spares, number of planners, number of optimized preventative maintenance schedules, number of updated drawings and number of performance contracts. A team can also choose to implement best practices (RCM, TPM, Equipment Based Budgeting, Gatekeeping etc.). Implementing these practices, however, requires investments that will not always create value. Due to the limited budget available for investments the teams learn to make choices and trade-offs.

The effects of the team's decisions are measured against the 10 VDM KPI's and benchmarked every playing round. The overall result, the maintenance performance of a team, will be translated into the added value for the fictitious company. The team that creates the most economic value after a number of playing rounds wins the prestigious VDM award.

Focus and Setting Priorities

In real life, the maintenance manager faces three stakeholders with conflicting interests. The production manager is interested in higher equipment availability and reliability, while the financial manager scrutinizes every penny in the maintenance budget, especially in economic downtimes. At the same time the maintenance manager is experiencing mounting pressure from laws and regulations introduced by government and the company.

Making quality choices is paramount in an environment with conflicting interests. The VDM Business Simulation is a very powerful tool to support decision making based on the economic added value of maintenance. It is an excellent tool for getting everyone in an organization - operators, maintenance, accountants, managers, executives - to understand the effects their decisions have on the company as a whole.

Experience the Simulation

The VDM Business Simulation is not only a game that can be played by companies that are familiar with VDM, but by anyone who wants to know and learn about how maintenance can be a driver adding value to the overall company result. You can play the game at the International Maintenance Conference, IMC-2007 - on December 8th in Daytona FL. The simulation is being offered as a Post Conference workshop. During the day several teams will play against each other in break out sessions for the prestigious VDM award. For more information, please visit www.maintenanceconference.com

Volvo Cars produces more than 460,000 cars per year. Their production site in Gent, Belgium alone builds 260,000 cars. 5000 people are in service and 300 of them are active in the maintenance organization. About 725 industrial robots are commissioned at the 10-mile long production line. In 2004 management received the challenging task to streamline the maintenance processes. This was mainly instigated by macro economic trends - increasing costs of raw materials, a weak dollar against the euro and little growth in the major markets - that led to considerable pressure of the profit margins.

To standardize maintenance processes the site managers in Belgium and Sweden decided to set up uniform and transparent work processes in line with Value Driven Maintenance. The processes are based on internal best practices across the sites and enriched with external best practices. They are all translated into a standardized common Maximo system. Of course this whole exercise affected the jobs of many people. "As a consequence the cultural change is probably our greatest challenge in order to deliver results at the end of the day", says Marc Begijn, Maintenance Manager at Volvo Cars Gent. "We decided to use the VDM Business Simulation to familiarize the key players in the maintenance organizations with the new or adjusted roles and the new way of working. The main objective is to get the right mind set - so people understand the reasons why change is necessary and how it affects the way they work. The first results are very promising. We are even considering playing the simulation at board level".

map are also linked to the different steps in the EAM-system.

Monitoring via the EAM System

If these processes and practices are supported well by the EAM-system, that is definitely a solid basis for continuous improvement. However that is only the beginning. To enable the organization to focus on value adequately, it is necessary to visualize the management information properly. That is recognized by the leading EAM-vendors. Therefore, VDM Control Panels are developed in Maximo, Datastream 7i and SAP EAM (Figure 3). This is a graphical overview with drill down functionality, showing the performance of the maintenance organization at a glance. It also allows for the detection of deviations, defects and their causes in just a matter of a few mouse clicks. It shows answers to questions like "Why didn't we perform according the Service Level Agreements we made with Production?" or "Why do the actual costs deviate from the originally budgeted costs?" etc.

Valuable?

Is VDM valuable? We and a growing number of multinationals on all continents think it is. Or, as Bengt Svensson (maintenance manager of Volvo Cars Manufacturing) explains: "If you want to improve your maintenance process, you need an operating control system. VDM is such a system, while it shows us where and how to improve."

Managing by value is not just a must; it is the only way to discover the true significance of maintenance. VDM makes maintenance more than a cost center because it contributes in various ways to a company's economic prosperity. In fact, VDM confirms what we in the maintenance and reliability world already thought, but now we have the proof!

Mark Haarman MSc MBA is Managing Partner in Mainnovation, the company he founded in 2000. Today the company is one of the leading maintenance consultancies in Europe and the inventor of Value Driven Maintenance®. In the course of his career, Mr. Haarman has become a maintenance expert with a wide array of expertise, helping customers develop "World Class" maintenance and reliability policies and practices. He is a former chairman of the Dutch Maintenance Association (NVDO) and the author of the book entitled "Value Driven Maintenance, New Faith in Maintenance".

Remco Jonker MSc is Partner in Mainnovation. Mr. Jonker is an international expert in maintenance management and he has assisted many organizations in Europe and Asia to improve their maintenance effectiveness. He contributes actively to the development of his field of specialization through published articles, seminars and training courses. In addition he is co writer of the VDM book.

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1. Mark Haarman and Guy Delahay, "Value Driven Maintenance – New Faith in Maintenance", Mainnovation, Dordrecht, the Netherlands, 2004.

The book is available exclusively in the US through RELIABILITY Magazine. For more information, visit www.reliability-magazine.com

Aligning at IMC-2006

by Terence O'Hanlon, CMRP, Publisher

As the political talking heads state: "It is the economy stupid!"

You can attend all of the maintenance conferences you want to learn modern maintenance and reliability theory – however – according to experts like Ron Moore, Author of *Making Common Sense Common Practice*, the most that the best maintenance improvement program can affect is a 10%-20% (perhaps 30% if you get everything right) cost reduction or downtime reduction.

Face it - maintenance has limited influence on overall performance – the other 70%-90% are influenced primarily by operation and design functions.

There is no business called maintenance and reliability. Maintenance and reliability professionals must align themselves with a higher business purpose. There are businesses called Refineries where they refine petroleum products. There are businesses called Food Processors where they process food products. There are Mines, Steel Mills, Power Plants, Paper Mills and many others. These are the businesses that make up the economy.

Maintenance does not make a product – maintenance is one of the services that enable operational capacity. Maintenance provides this service to operations and ultimately, to the asset owner.

A simple illustration would be that you are usually both the Asset Owner and the Operator of your automobile. Maintenance is usually provided by the mechanic. As the Operator, you will have a more dramatic effect on the reliability of your automobile than your mechanic will. If you stomp hard on the gas after each stop, if you fail to request or schedule fluid and filter changes and other recommended maintenance, you will eventually drive the reliability and value right out of the vehicle. The mechanic has no effect on reliability unless you – the operator – work in cooperation with him/her. Of course, we rely on the mechanic for recommendations and, when needed, action.

To support your interest in aligning operations and maintenance and to develop a sustainable strategy for maintenance at your company, please join us at IMC-2006 – The 21st International Maintenance Conference. Held in Daytona where teamwork between operations (driver) and maintenance (pit crew) are legendary, you will have an opportunity to learn from case studies, participate in discussions and open forums, participate in full day interactive workshops and meet top solution providers.

Earlier this year I was fortunate enough to be a part of PdM-2006, the Predictive Maintenance Technology Conference co-located with LubricationWorld in Chattanooga. This event was a very special convergence of 600 maintenance and reliability professionals who were committed to learning all they could from each other, the 40 presenters, PdM solution providers and the Uptime PdM Program of the Year winners. Many participants, including myself, noted that it was the best and most valuable conference they had ever attended. The management, structure and conference logistics teams were excellent, however we all agreed that it was the participants who lifted PdM-2006 to the heights it reached. We just provided the context.

That event set a pretty high bar. However we know that once we have a committed group of participants, IMC-2006 will accomplish similar results. If you prefer an event were you sit passively while so-called experts tell you what you should be doing as they present a cookie cutter approach to maintenance, this is NOT the event for you. IMC-2006 is a 4 day "Community of Learning" more akin to an interactive conversation than a pushed presentation.

IMC-2006 does feature several subject matter experts who you will want to sit and listen to because they have very important information to deliver to you. Your interaction with these subject matter experts will not be

Maintenance & Reliability

with

Operational Excellence

limited to simply listening – you will have ample opportunities to interact with each of them as they are also IMC-2006 conference participants. They are there to learn as much to share the information they can impart.

IMC-2006 also features "real world" case studies by maintenance and reliability professionals who are currently on their journey to improved reliability. Make no mistake – these companies have not reached maintenance "Nirvana" – they have experienced setbacks and challenges that would make lesser men fold. The lessons they have to share are not about the destination – they are about the journey – a much more interesting and valuable story for certain. Extended question and answer sessions allow participants enough time to enter meaningful discussion with presenters to look "behind the curtains" at these companies for even more learning.

IMC-2006 is also proud to host John Woodhouse, Director of the UK based Institute of Asset Management to formally introduce PAS 55 a Publicly Available Specification for carrying out asset management. This asset management specification is quickly gaining acceptance throughout Europe, Australia and New Zealand, especially in asset intensive organizations.

MIMOSA and the Open O&M™ Foundation will host an amazing practical hand's-on demonstration of open standards for industrial software applications including many of today's leading vendors. You have to see this if you want a glimpse of the future (that is actually here today) of plant information management.

Did I forget to mention fun? I know that "fun" is a dirty word and we do not want your bosses to know maintenance and reliability professionals ever enjoy themselves, but we have loads of good times on tap after the learning at IMC-2006. Networking events include a Chevron sponsored private party at Daytona USA International Speedway, a Timken sponsored Beach Party, an Alienware Laptop giveaway and the best food you will find at any maintenance focused event! You will also meet peers who face the same issues you do on a daily basis. These relationships will last well into the future and offer as much learning as formalized sessions.

Come to the International Maintenance Conference and leave with the tools to accomplish one or more of these goals:

1. Develop a strategic direction for your maintenance program.
2. Make the business case for reliability.
3. Diagnose the real problems that limit your results.
4. Design maintenance tasks that add value.
5. Create reliability at your facility.
6. Master cultural change in the workplace.
7. Manage maintenance information.
8. Overcome a limited maintenance budget.
9. Align maintenance to a business purpose
10. Evaluate maintenance results.

You choose the challenge that you want to tackle at IMC-2006 and we will show you the sessions, workshops, learning labs and vendors who will give you the tools, know-how, and resources you need to take back to the job and succeed.

Attendance is limited to ensure quality. It is important that you register quickly to avoid disappointment. Reliabilityweb.com events generally SELL OUT two - three weeks prior to the actual event.

Please call toll free **(888) 575 1245** to learn more about IMC-2006 at the Daytona Hilton or visit **www.maintenanceconference.com**

Get Focused

See Things Clearly by Understanding Resolution

by John Snell

Many of us are at the age where, during a trip to the eye doctor, we discover that our vision is not what it once was. The smaller rows of letters on the eye chart —once clear—are now impossible to decipher. Miraculously a prescription and corrective lenses often bring them back into high resolution.

Thermographers, whether or not they wear glasses, must deal with similar issues regarding the resolution of their infrared cameras. When the objects we want to look at are too small or too far away, we may not even be able to see them. Even when we can see them through the camera, we may not be able to recognize them clearly or measure them accurately.

Unfortunately many thermographers don't clearly understand camera resolution and how it affects their work. This means they may be making mistakes they have no idea they are making. Hopefully, this article will help bring these issues into "sharp focus" and improve the quality of your work.

Spatial and Measurement Resolution

Thermographers actually need to be concerned about two types of resolution. The first is termed "spatial resolution" and it describes the detail we can see with our cameras at a given distance from the object of interest. This is the equivalent of being able to just barely see small spots on the eye chart, regardless of being able to see what letters they are. In Figure 1, we can clearly see the hot hinge in the thermal image of this disconnect switch. What if we had been further away?

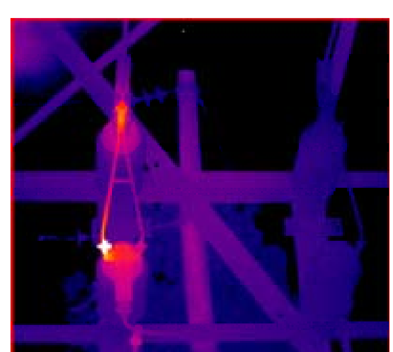


Figure 1 - Hot hinge in Disconnect Switch.

"Measurement resolution" describes the smallest size object for which we are able to measure temperature. Again, using the eye chart analogy, this would be the smallest row of letters we could correctly recognize as letters. Now let's ask ourselves "are we close enough to measure the temperature of the problem on the disconnect?"

What determines resolution and allows us to answer these questions? It is the "optical path" of the infrared camera—essentially the detector and the lens—that determines the ability to both resolve and measure detail. Of course the infrared radiation must also be sharply focused on the focal plane or the inherent resolution of the camera is degraded. Camera resolution is specified and can, to some extent, be compared objectively from one system to another.

Infrared camera manufacturers define resolution by the projection of a detector element through the lens onto the distant scene. This is sometimes termed "IFOV" but is, in fact, spatial resolution. It is specified either as the angle (in milliRadians[1], or mRad) of this projection or as a ratio of the measurement distance to the target size. Mysteriously camera manufacturers typically do not specify measurement resolution, leaving us on our own to fend for ourselves. More on this later.

Detector Array Size

Most of today's infrared cameras use a focal plane array detector. The array is composed of a number of individual detector elements formed into a rectangular matrix, typically having a size of 160x120 or 320x240 individual elements. Smaller (120 x120) and larger (640 x 480) array sizes have also recently come onto the market.

The theoretical resolution for arrays of different sizes can actually be identical, but, in that case, the image size, or field of view, will not be the same. If the field of view is the same, then the larger arrays will have greater resolution. It all comes back to how many detector elements are being projected onto a scene.

Many thermographers are concerned about which array

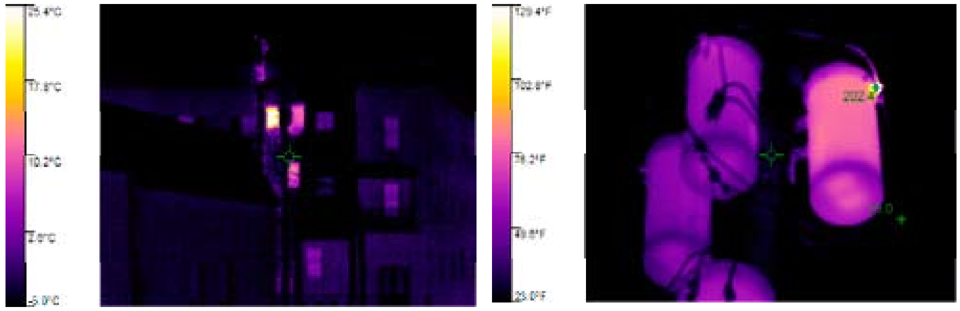


Fig 2 - The least expensive way to improve resolution, when possible, is to move closer. Both of these images are taken with the same camera and lens but at different distances. The resolution of the right image is clearly higher.

size to purchase. Why not just get a camera with a larger array? The simple reason is larger arrays are more expensive, but they also have a legitimate concern that the resolution of the smaller arrays may be inadequate for their applications. Unfortunately, a great deal of confusion exists. It is important, therefore, to understand what your actual resolution needs are and what camera can really deliver what you need. How?

What resolution do you need?

Think about what distance you will be working at and the size of the smallest object you want to see and measure. For many applications, you can easily move closer or farther away, but for some, such as in substations or inside a house, the viewing distance cannot easily be varied. If you know the specification for the camera/lens you are using, you can calculate either the minimum object size that can be detected or the working distance from the following formula:

Specified resolution (in radians)
x distance = Object size

Let's look at an example of a 320 x 240 camera with a 24° (horizontal) x 18° (vertical) field of view. The camera's spatial resolution is defined as 1.3 mRad (or .0013 radians). At 100", then, we can resolve an object that is as small as .13" (100 x .0013 = .13). At 200 meters we could resolve an object as small as .26 meters (200 x .0013 = .26). To calculate the minimum distance we can be from a target of a certain size, just solve for distance. For instance, if you want to be able to find an object that is .5" in size, you must be 32' or closer (.0013/.5" = 384" or 32').

A very useful way to state the resolution specification is as a distance-to-measurement ratio (X:1). The 1.3mRad camera above would have a 769:1 ratio (1/.0013 = 769), meaning we could see a 1" object at 64' (769"). This value is easy for most people to remember and allows them to quickly know if they are close enough to make an accurate measurement or not.

Using these simple relationships, it is possible to work with the realities of your situation, both working distances and object sizes, and get a good idea if you can see problems. If you cannot, there are three choices: move closer, buy another lens or buy a camera with a larger array.

What about measurement resolution?

Our discussion to this point has been about spatial resolution. Measurement resolution is typically 3-4 times less than spatial resolution. The exact figure varies with detector shape and density and object shape. Thus the camera used in the example above with a spatial resolution of 1.3mRad, may have a measurement resolution of 3.9-4.2mRad or greater (the larger the angle, the less the resolution). The only effective way to determine the measurement resolution of most infrared cameras is by experimentation using targets of different shapes.

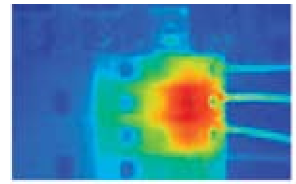
One thing you must be clear about: the temperature measurement "cross-hair", or spot, is only approximate. It may not define the actual minimum measurement size precisely, and area measurement functions give no indication what so ever! If you try to make a measurement of an object that is too small or too far way, you will probably be averaging the temperature of that object with the temperature of the surrounding area - even if it may all appear to be inside the measurement circle.

What about field of view?

It may not be obvious, but another part of the resolution issue is the field of view we'd like to have. If we wanted high resolution, we could simply use a telephoto lens all the time. But sometimes we want a larger field of view. So we must actually consider both the array size, which is fixed for a given camera, and the desired field of view which is determined by a lens that, for many cameras, can easily be changed. In some cases resolution drives the need, in other cases field of view is more important.

Here is a good analogy. When we see a deer far off in the woods it looks small in a large field of view. When we then look at it through the scope on a rifle, we see more detail but we also see a much smaller field of view. If you had to look through your scope to spot a deer, you'd never find one because the field of view is too narrow. If you didn't have a scope when you shot, you're not likely to hit a deer in the distance! Typically there is a trade-off between field of view and the detail we see.

Thus for building work, where we often are inside and want to look



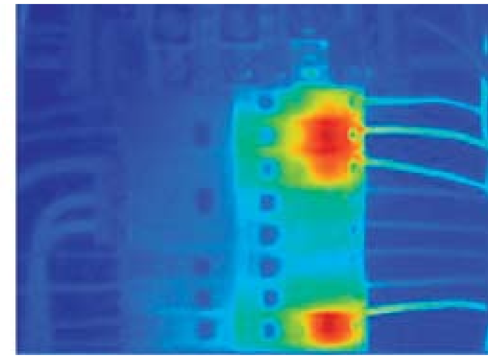


Figure 3A - Two cameras with different array sizes can have the same resolution but the field of view will be different.

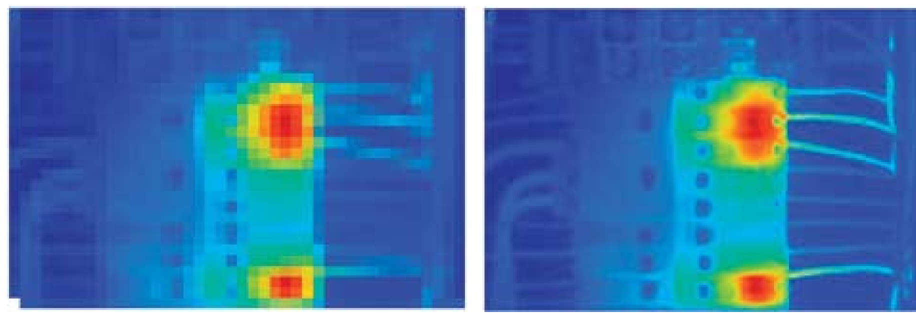


Figure 3B - If the field of view is the same, two cameras with different size arrays will yield images with different resolutions. The spatial resolution of the left image is clearly lower than that of the right.

Application	Array Size			
	120 x 60	160 x 120	320 x 240	640 x 480
Buildings, residential	Possibly	*	*	**
Buildings, larger commercial		Possibly	*	*
Buildings, high-rise, exterior			*	*
Roofs	Possibly	*	*	**
Electrical, industrial/commercial	Detection	*	*	**
Electrical, outdoor substations		Detection	*	*
Electrical, line			*	*
Mechanical		Some	*	*
Aerial			*	*
* recommended array size	**may be larger array size than is required			

Table 1 shows suggested detector array sizes for various applications.

at a large section of wall at one time—and we don't need to see minute detail—a moderate size array and a wide angle lens may work well. That same camera in an outside substation may be OK for detecting problems, but the resolution would not be good enough for a detailed analysis.

In some cases, we may need both high resolution and a large field of view, such as looking at high-rise buildings or aerial imaging of the environment. The obvious choice in these cases is to use a larger detector array. Some of the lower resolution arrays now on the market open up options for many thermographers because of their lower cost. While a detailed analysis of a finding may not be possible with these systems, detection may be and that alone, in many instances, can be useful and cost effective. Table 1 shows suggested detector array sizes for various applications.

Now what?

Understanding the specifications for a camera is important, but there are additional factors that may influence what the thermographer actually sees in the camera. These include image processing, the display, viewing conditions and the thermographer —all fairly subjective factors that are more difficult to quantify.

Smaller array sizes may be a viable option for many applications where the extra detail is not essential. If detail is needed, it may be possible to move closer to the target or use a more telephoto lens (with a smaller field of view). If neither of these are viable options, a larger array is required. Clearly there can be a cost savings to purchasing a smaller size array.

There is no doubt that specifications are important. However, in the end, you must also consider how the image looks. The image processing that takes place inside the camera is complex and well beyond an explanation in this article, but a side-by-side comparison suggests it can make a significant difference in image quality, especially for qualitative systems.

A number of factors need to be considered when purchasing an infrared camera. Think about the field of view you need, the distances at which you will be working and the size of the objects you need to see and measure. Also look at the specifications of the camera. It is also vital to actually test the camera in typical field conditions because that is often the best indicator of whether or not it will actually do what is required.

Resolution can be a complex subject, but not so complex that you can't figure it out and get the right camera for the job at the lowest cost. Bigger is not necessarily better, but you also don't want to buy a low-resolution system unless it meets your needs. While many camera sales people are knowledgeable, others may not be aware of your particular needs. So you would be well advsied to identify your particular needs before shopping for a camera.

If you already have an infrared camera, educate yourself so that you don't make errors in detection or measurement, either of which could be costly or dangerous. Take the time to learn what your camera can do and what it cannot do and then work within those limitations. There is no "prescription" that guarantees the results we will get, but understanding the basics of the resolution of our infrared cameras is an important first step to seeing the world more clearly.

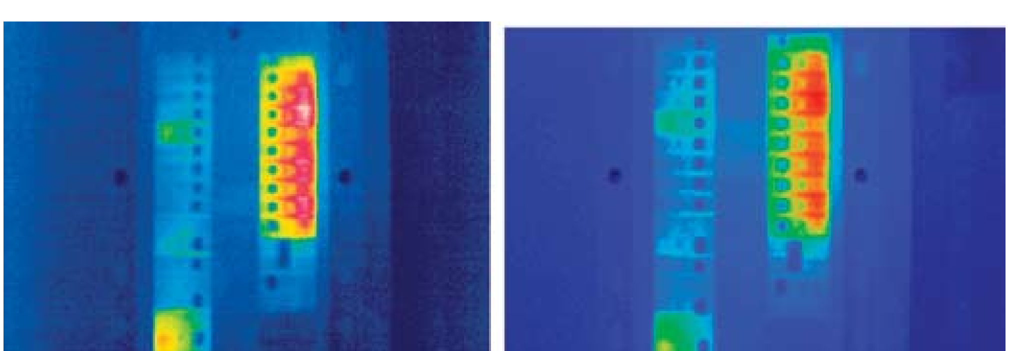
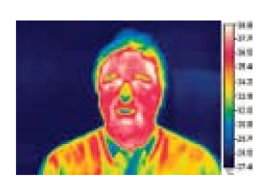


Figure 4 - Which image was taken with a 320x240 array and which with a 160x120 array?[2]

1. A radian is the radius of a circle laid on the circumference so 2π radians = 360 degrees or 1 radian = 57.3 degrees = 1000 milliradians (mRad). As a result, we can calculate there are 17.453 milliradians (mRad) per degree of angle (1000/57.3 = 17.453).

2. The right image was taken with the 160x120 array camera and left image was taken with the 320x240 array camera. (Images courtesy Dr. R Schmidt.)



John Snell, president and founder of Snell Infrared, has been teaching people to use this remarkable technology since 1983. He was the first person in the world to receive an ASNT Level III certificate in the thermal/infrared method and continues to be very active professionally on numerous standards committees and at conferences. To learn more about thermography and Snell Infrared visit http://www.snellinfared.com or call 800-636-9820.

Getting the Right Grade

Calculating the Correct Viscosity

by Mike Johnson, CMRP

There is a wide variety of lubricant related factors that can influence machine reliability. Providing the correct additive type for the expected lubricated film condition, keeping the oil clean, dry and cool (<130°F), and maintaining an appropriate film thickness are bottom-line requirements. Of these three, the last is the most important consideration, and selecting the right viscosity is paramount in getting it right. Without the correct operating viscosity, the lubricated machine surfaces won't reach the Original Equipment Manufacturer's (OEM) suggested lifecycles.

Depending on the machine operating conditions, the process may be simple and straightforward: match the OEM's suggested viscosity grade for 'normal' operating conditions to the available brand-equivalent grade. The hidden splinter in the thought process surfaces with the word 'normal'. What is a 'normal' operating condition?

With few exceptions, an OEM cannot account for the many varieties of installations, maintenance and operating practices. Regarding lubricant selection, the OEM will provide an expected operating temperature profile, but often the operating temperature falls outside of the proposed temperature profile. For these circumstances, the footnoted suggestion is to contact the OEM for advice.

Differences in product manufacturing further complicate the situation. For a given ISO 220 EP specification, one lubricant manufacturer may provide a product that would just barely qualify on the low end of the range specification with a 200 centistoke (cSt, or ISO 200) offering, while another supplier may provide a product that barely qualifies on the high end (240 cSt, ISO 240). As long as the provided product is with 10% above or below the specification number, it 'qualifies', but the difference between a 200 cSt product and a 240 cSt product is quite meaningful. In fact, this is equivalent to the difference in thickness between a medium grade hydraulic oil (ISO 46) and water (ISO 2).

Just this much variation can complicate the operating viscosity profile, and can mean the difference between marginal and wholly acceptable viscosity when the machine is running. The important questions are:

- For the given lubricated component, what is the minimum allowable viscosity to assure a continuous film?
- What is the actual viscosity for the machine's operating temperature?

The process to determine the 'minimum allowable' value differs between surfaces that slide together and surfaces that roll together. Fortunately, there are plenty of illustrations and guidelines provided by component manufacturers to help the engineer or mechanic make an appropriate selection.

In the October issue of Uptime, we reviewed the process for determining the allowable viscosity for the large plain bearings supporting a ball mill.

For the purpose of this discussion, assume that the theoretical minimum allowable operating viscosity is 18 centipoise. Also, for the purpose of this discussion, assume that an acceptable safety margin for the target viscosity is three times the allowable minimum. The objective for the balance of the exercise is to determine the actual viscosity, determine how close the current scenario is to the minimum in, and consider options for improvement to the tribo-system.

Determining Operating Viscosity Not Difficult

Step 1. Identify the viscosity across a temperature range. First, have the oil analysis laboratory run a viscosity check on the product under consideration at two different temperatures: 40°C and 100°C. Next, plot these two data points on a Viscosity-Temperature chart (shown in Figure 1). These can be purchased from a variety of locations, but the lubricant supplier should be able to provide one at no charge. Finally, draw a line from in front of the first data point to well beyond the second point. This line indicates the viscosity in centistokes at each temperature point on the chart.

Step 2. Identify the viscosity at the operating temperature. First, measure the operating temperature of the lubricant. If it is a non-circulated sump be sure to measure the lubricant temperature inside the sump with a submersible temperature meter. If it is a circulation system be sure to measure the temperature at a location as close as possible to the actual mechanical components, and certainly well in front of the point where the lubricant returns to the reservoir. If the lubricant temperature is subject to variation with operating load or ambient temperature, try to use the temperature that is likely to be the highest, as this will be the point where the lubricant poses the greatest risk to the machine.

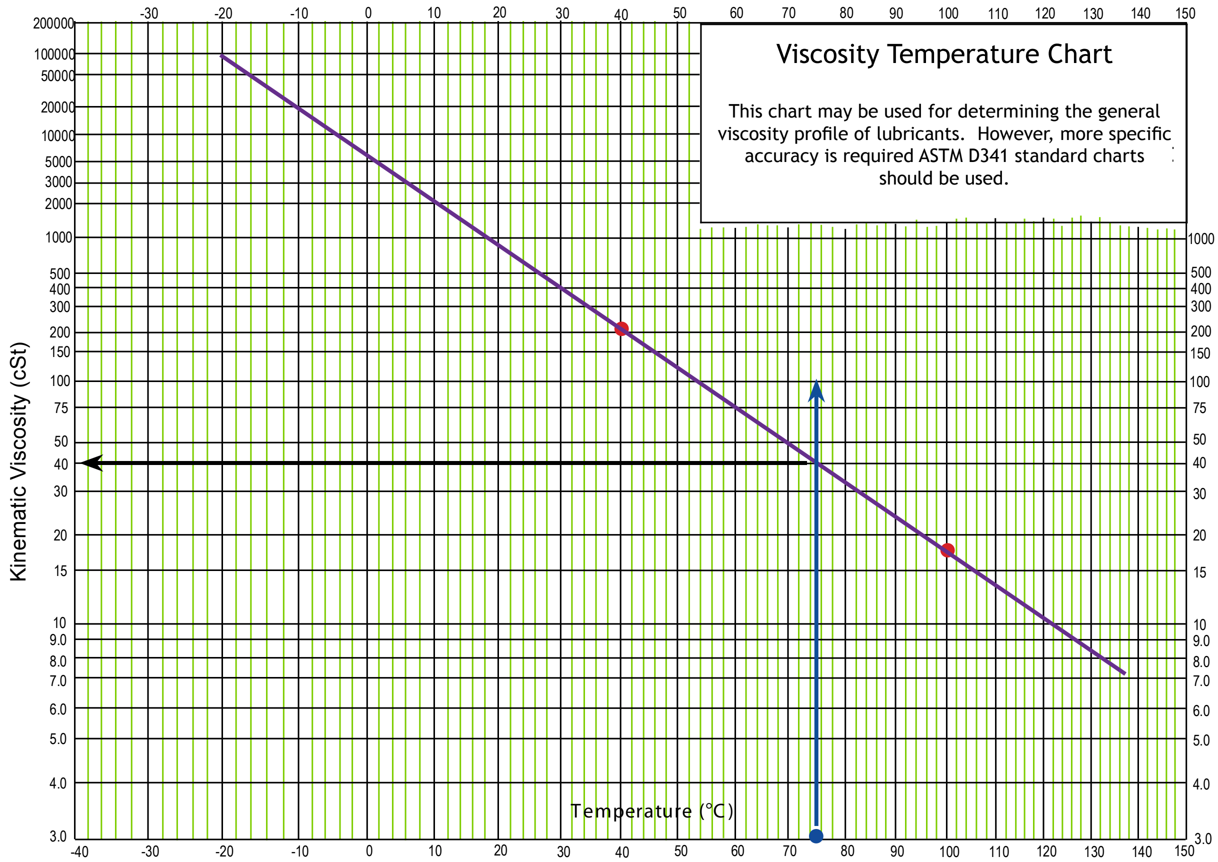


Figure 1 - Viscosity Temperature Chart

Step 3. Find the target temperature on the chart's temperature axis, as shown with a blue circle at the bottom of the chart in Figure 1. From the temperature plot point, draw a vertical line through the viscosity line that was plotted in Step 1. Where these two lines intersect represents the actual operating viscosity in centistokes.

Step 4. Finally, convert the observed viscosity from a kinematic value to dynamic value. This is necessary because the lubricant viscosity drops slightly when subjected to a dynamic force. (The kinematic viscosity grade that is represented on the package label is based on the lubricant flowing through the test system under the force of gravity. Ideally, all viscosities' values would be given in centipoise). To determine the dynamic viscosity at operating temperature, multiply the Kinematic value by the lubricant's specific gravity. Figure 2 shows a typical representation of specific gravity, and typical viscosity values on a lubricant product data sheet. The product data sheet will have a value that is a close estimate, and will suffice for this exercise.

TYPICAL PROPERTIES	1100/68	1100/100	1100/150	1100/220
ISO Viscosity Grade, ASTM D 2422	68	100	150	220
AGMA Lubricant Number	2EP	3EP	4EP	5EP
Food Grade	H2	H2	H2	H2
Density, DIN 51757, 15°C g/ml	0.893	0.896	0.901	0.905
API Gravity, ASTM D 1298 @ 15.6°C	27.1	26.5	25.5	24.9
Viscosity, ASTM D 445, D 2161:				
@ 40°C, mm²/s (cSt)	68	100	150	220
@ 100°C, mm²/s (cSt)	9.0	11.6	15.3	19.7
@ 100°F, cSt/SUS	76/352	112/519	170/788	250/158
@ 210°C, cSt/SUS	9.2/56	11.9/66	15.8/81	20.3/100
Viscosity Index, ASTM D 2270	106	104	103	102
Flash Point, ASTM D 92, COC, °C/°F	224/435	229/445	238/460	238/460
Fire Point, ASTM D 92, COC, °C/°F	249/480	249/480	249/480	263/505
Pour Point, ASTM D 97, °C/°F	-26/-15	-23/-10	-23/-10	-20/-5
Rust Test, ASTM D 665:				
Procedure A (Distilled Water)	Pass	Pass	Pass	Pass
Procedure B (Synthetic Sea Water)	Pass	Pass	Pass	Pass

Figure 2 - A typical Product Data Sheet representation of Viscosity and Specific Gravity (density) information.

In this instance, the lubricant in use is an ISO 220, with an actual viscosity at 40° C of 202, and at 100° C of 17, and a specific gravity of .855. The red dots in Figure 1 correspond with the viscosity at 40°C and 100°C. The purple line represents viscosity in centistokes at different temperatures. The blue dot and blue line represent the actual temperature at which the oil is operating. Assume the operating temperature is 75°C / 167°F. In this instance, the viscosity at operating temperature is about 42 centistokes.

Lastly, when we multiply the viscosity in centistokes, 42, by the lubricant specific gravity, .8550, we determine what the actual viscosity is inside the machine, which is 36 centipoise.


REDEFINING MAINTENANCE
- MOBILE OIL SERVICE UMFC 41/81 -
WSPS 03 - Watersensensor
MOBILE OIL SERVICE
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fluid management
Siemens-Pressebild
PFS 01 - Laser Sensor
INTER NORMEN
internormen electronics
CCT 01
PFS
CON 1
CON 2
USB
CAN
CCT 01 -
Contamination Class Transmitter
* Always equipped with Particle Counter Set CCT 01 and Watersensor WSPS 03
* PLC controlled * automatic shut-off service if programmed values are reached * easy and comfortable handling / no operator necessary
* available in 12.5 and 25 GPM * available from 1 µm to 20 µm glass fiber elements with ß x(c) ≥ 200
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fluid management

The most difficult part if this exercise remains. That is to decide if the actual condition is acceptable for long term reliability. For this step the oil analysis details would be most helpful. As stated previously, if the oil is clean, dry, and exceeds the minimum allowable, and the machine experiences no load or speed variation, then the surfaces would be sustained in a full fluid separation. However, if any of these factor interfere with the fluid film then metallic contact will produce wear debris and surface destruction.

At this stage, the lubrication technician should closely observe the sample collection process, and strive to collect samples that are highly repeatable (using a consistent sample method) and as close as possible to the actual lubricated component. The quality of the sample process can make or break this decision. If the sample process is reliable, and is producing dependable results, then the wear metals analysis can provide the key to our final decision.

It was stated previously that 3 times the minimum allowable viscosity would provide a slight safety margin. In these calculations we find the viscosity to be two times the minimum. If no evidence of machine stress exists, and there is no likelihood that the temperature would increase, then no change would be justified.

However, if there is evidence of stress, and change is justified, then the options are to either cool the sump by enough to increase the viscosity out of the trouble zone (a 15°C drop would bring the viscosity up to the 70 cSt range, which would provide three times the minimum), or increase the starting viscosity by one viscosity grade (ISO 220 oil to ISO 320 oil). If the latter option is chosen the engineering department should run cold flow calculations to assure that the piping diameter is sufficiently wide, and laid in a sufficiently steep slope to assure cold flow. The output limits of the pump should also be verified prior to actually making the switch to the higher viscosity grade.

This case analysis provides us with a typical scenario. The results do not demonstrate conclusively, from the available evidence, that a change is required, leaving a tough judgment call for the reliability engineer. By progressively eliminating the potentially problematic variables, or by collecting more or higher quality information on the front end, confidence in the ultimate decision will increase.

Mike Johnson is the founder of Advanced Machine Reliability Resources Inc., a firm that provides precision lubrication program development, consulting and training. He has written and presented numerous technical papers at symposia and conferences throughout North America about how to use machine lubrication to drive machine reliability. Mike is happily married, plays and coaches soccer, and has 3 young children that consume his remaining time and attention. He can be reached at mjohnson@amrri.com or 615-771-6030.

Going Back to Basics

Electric Motor Testing with a Volt Meter

by Howard W. Penrose, PhD, CMRP

Just because I don't have a budget for test equipment, am I lost? Do I always need advanced technology to accomplish my maintenance tasks? The answer is: No. You do not need advanced technology to accomplish general maintenance tasks. Sure, the newer technologies will allow you to identify problems that are difficult to find, before your equipment fails, and will provide more data than standard hand-held instruments. While I have spent many years discussing the advanced technologies, I am constantly asked what can be done with the traditional electrical maintenance test equipment. The purpose of this article is to discuss some of the 'tricks of the trade.'

In this article, we will discuss Volt Meter testing. The systems that we will be testing will be across the line, AC induction electric motors. Let's assume that we have a True RMS multi-meter, a True RMS current clamp, an Analog current clamp and a 500/1,000 Volt insulation tester with an analog display with a range from 0.01 to 1,000 MegOhms. We will also assume that we are following (as you always should) all appropriate safety and PPE requirements during testing.

The Power of a Volt Meter

For most applications, in modern electrical environments, a True RMS digital volt meter is important to give you accurate values. This is because older averaging volt meters would display inaccurate, non-repeatable, values on digital displays or the needle would bounce in voltage harmonic situations. The True RMS meter compensates for these variations and harmonics. You will also want a meter with a range 10 times more accurate than the value you are looking for. For instance, if you are looking for values to the nearest 1 Volt, you want a meter accurate to at least 0.1 Volt.

The most obvious methods of voltage testing are to check the voltage value and phase balance. In both cases, the proper method of taking voltage readings is to go phase to phase, which provides more accurate test values than phase to ground. The pattern is also important, if you are going to compare test results or analyze a system. A common pattern is Phase A to Phase B, Phase A to Phase C, then, Phase B to Phase C. Table 1 shows the test results we will be using as an example.

These three values can provide important clues as to the condition of the system and help identify some problems. For instance, over/under voltage conditions can change the operating conditions for the electric motor.

Phase	Voltage
A-B	460
A-C	458
B-C	466

Table 1 - Phase to Phase Voltage Test Results

NEMA identifies the maximum deviation from the nameplate of an electric motor as +/-10% for design purposes. In order to determine the maximum deviation, you must determine the nameplate voltage and then use the measured value that is the furthest from the nameplate (466V in our example). Formula 1 shows the calculations for maximum deviation of our example.

$$\frac{466V - 460V}{460V} * 100 = 1.3\%$$

Formula 1- Voltage Deviation (460 Volt Motor)

The impact as the voltage deviates from the nameplate can be significant (see Figure 1) with the maximum recommended deviation for energy purposes as 5%.

The next concern is Voltage Unbalance, which results in unbalanced currents and magnetic fields in the motor. As the unbalance becomes greater, the temperature rise of the motor increases, generating the need to de-rate the motor. Formula 2 shows how to calculate the aver-

$$(460V + 458V + 466V) / 3 = 461.3V$$

Formula 2 - Voltage Unbalance (1)
Determine the Average Voltage

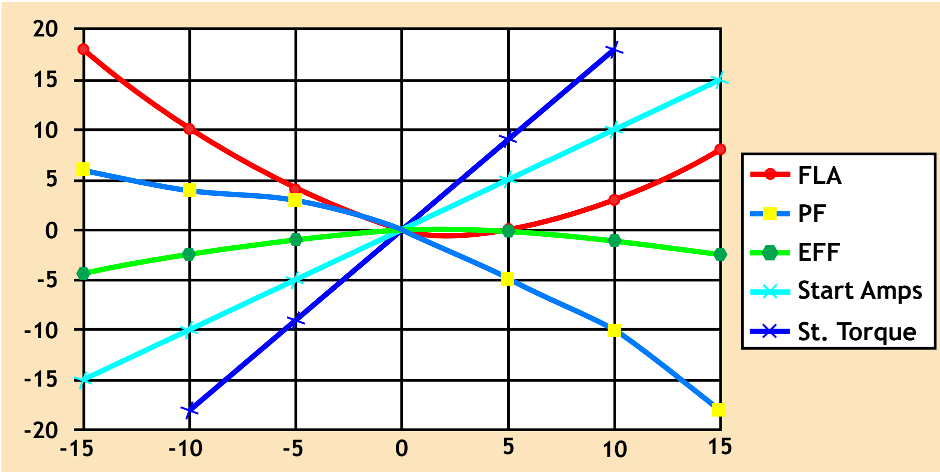

Figure 1 - Impact of Voltage Deviation

$$\frac{466V - 461.3V}{461.3V} * 100 = 1\%$$

Formula 3: Voltage Unbalance (2)
Determine the Unbalance

age voltage and Formula 3 shows the calculations to determine the unbalance.

The unbalance is then compared to Figure 2, which provides a multiplier against the motor horsepower. The electric motor is designed to work within 5% voltage unbalance, with an energy application recommendation of not more than 2% voltage unbalance.

NOTE: It is important to note that the motor may not be operated into its service factor in either of the conditions above. The motor service factor is only to be used at the motor nameplate voltage and frequency values.

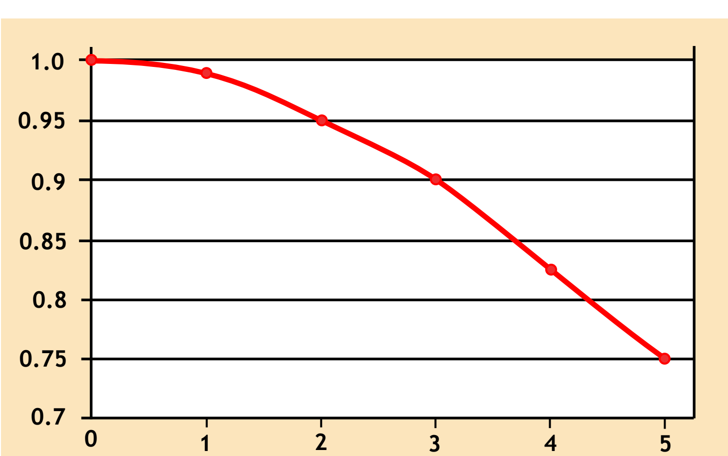

Figure 2: Voltage Unbalance Multiplier

Checking Contacts with a Volt Meter

One method of testing contacts in a motor starter is to use a volt meter. When an infrared camera is used, the operator is looking for the I2R losses which show as Watts or Heat. Damaged connections show as a loose connection and related resistance, as do conditions of glazing that can occur in some operating environments.

One way of detecting contact and connection problems without the use of an infrared thermometer or imager is to perform a voltage drop survey. When performing a survey, it is important to start with the volt meter set at a voltage equal to or larger than the circuit voltage. Check to ensure that voltage is being supplied to the starter or contactor by performing a phase to phase test on the supply side of the starter or contactor, as described above. Next, place one lead from the volt meter on the Phase A input side of the starter and one lead on the Phase A output side of the starter. Adjust the value of the volt meter downward, if no value shows, until you get to a value of less than one volt.

A good contact will have a value less than one volt. A poor, or failed, contact will have a value of one volt or greater. Perform the same steps across each phase of the starter or contactor. Once completed, check to ensure that you still have phase to phase voltage by re-testing the supply side phase to phase.

Checking Fuses with a Volt Meter

Testing fuses while equipment is running is a straight forward process. There are two steps that are performed including the phase to phase and line testing.

The phase to phase test for fuses involves 'cross checking' the fuses. Start by measuring phase to phase on the supply side of each fuse, as noted in the phase balance test. Place one lead of the voltmeter on the supply side of the Phase A fuse and the load side of Phase B fuse. You should see a full phase to phase voltage value. If you do not, then there is a problem with the Phase B fuse. Repeat the steps by placing one lead on the load side of the Phase A fuse and the supply side of Phase B fuse. Repeat the steps between Phase B and Phase C. Once finished, re-check phase to phase on the supply side.

A less accurate method of checking fuses, but important for control circuit fuses or single phase applications, is to measure across the fuse. The steps and resulting values should be performed and evaluated in the same way as starter or contactor testing, as described above.

Conclusion

While industry is continually moving toward higher technology testing, the older tried and true test technologies can still provide valuable troubleshooting data. In this, the first article of a series, we covered voltage testing using a standard True RMS volt meter. The volt meter can be used to test for voltage unbalance and variation, which can shorten the life of an electric motor, or cause it to run less efficiently, as well as check for loose connections/poor contacts or the condition of fuses.

Howard W Penrose, Ph.D., CMRP is the President of SUCCESS by DESIGN Reliability Services and the Executive Director of the Institute of Electrical Motor Diagnostics, Inc. For additional information contact Dr. Penrose at howard@motordoc.net.

Alignment Modeling Basics

An Excerpt from the soon to be released 3rd Edition of *The Shaft Alignment Handbook*

by John Piotrowski

The final desired alignment line (also known as the overlay line) is a straight line drawn on top of the graph showing the desired position both shafts should be in to achieve colinearity of centerlines. It should be apparent that if one machine case is stationary, in this case the fan shaft, that machine's centerline of rotation is the final desired alignment line as shown in Figure 8-13.

There is another way to correct the misalignment problem on this motor and fan that will be far less troublesome.

Since adjustments are made at the inboard and outboard feet of the machinery, some logical alternative solutions would be to consider using one or more of these feet as pivot points. Both outboard feet or both inboard feet, or the outboard foot of one machine case and the inboard foot of the other machine case could be used as pivot points. By drawing the overlay line through these foot points, shaft alignment can usually be achieved with smaller moves. In real life situations, you will typically have greater success aligning two machine cases a little bit rather than moving one machine case a lot. Figure 8-14 shows using the overlay line to connect the outboard bolting plane of the motor with the outboard bolting plane of the fan. The inboard bolting planes are then moved the amount shown in Figure 8-14 to correct the misalignment condition in the up and down direction. No shims had to be removed, and better yet, no baseplates had to be ground away.

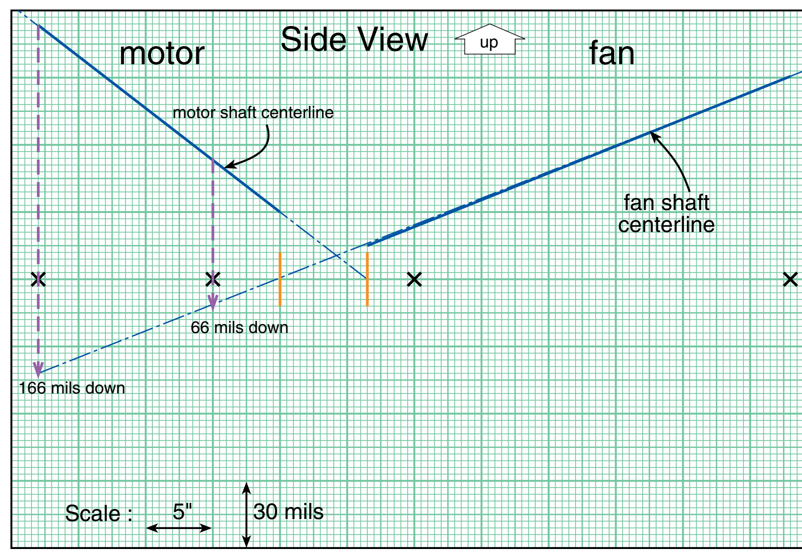

Figure 8-13 - Side View of Motor and Fan.

Superimpose your Boundary Conditions, Movement Restrictions, and the Allowable Movement Envelope

When viewing the machinery in the up / down direction (SIDE VIEW), the movement restrictions are defined by the amount of movement the machinery can be adjusted in the up and down directions.

How far can machinery casings be moved upward? There is a virtually unlimited amount of movement possible in the up direction. Within reason, that is. Machine cases are typically moved upward by installing shims (i.e. sheet metal of various thicknesses) between the undersides of the machinery feet and the baseplate.

How far can the machinery casings be moved downward? Well, it depends on the amount of shim stock currently under the machinery feet that are not "soft foot" corrections.

How far can you move a machine down? Uh, I don't know. You are going to have to look under the machine to see how much shim stock could be removed from under the machinery feet on every machine in the drive system. Maybe there are 10, 20, or 50 mils of shim stock that are not soft foot corrections under the machinery feet that could be taken out. You will have to see what's there. These shims define the "downward movement envelope", or as some people call it, the "basement floor", or the "baseplate restriction point".

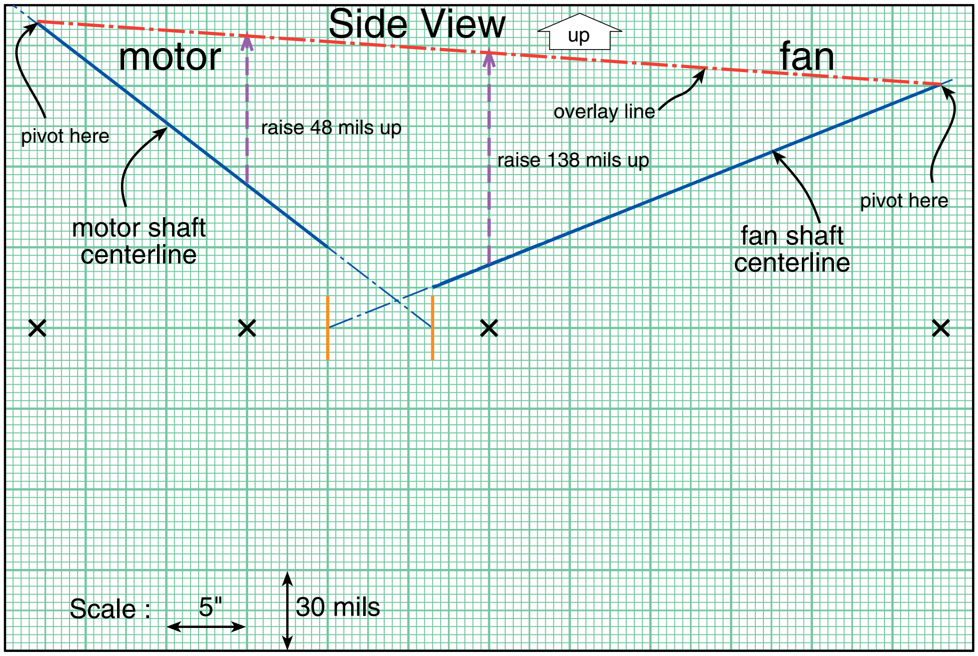

Figure 8-14 - Movement solutions for the inboard feet of both the motor and the pump by pivoting at the outboard feet of both machines.

Shim stock typically refers to sheet metal thicknesses ranging from 1 mil (0.001") to 125 mils (0.125"). There are several companies that manufacture precut, U-shaped shim stock in 4 standard sizes and 17 standard thicknesses. Once shim thicknesses get over 125 mils, they are typically referred to as spacers or plates and are custom made from plate steel.

If you want to move a machine downward and there are no shims under the machinery feet, you are already on the "basement floor", defined as a downward vertical movement restriction or a baseplate restriction point. Figure 8-15 shows the same motor and fan. However, we have now observed that there are 75 mils of shim stock under the outboard

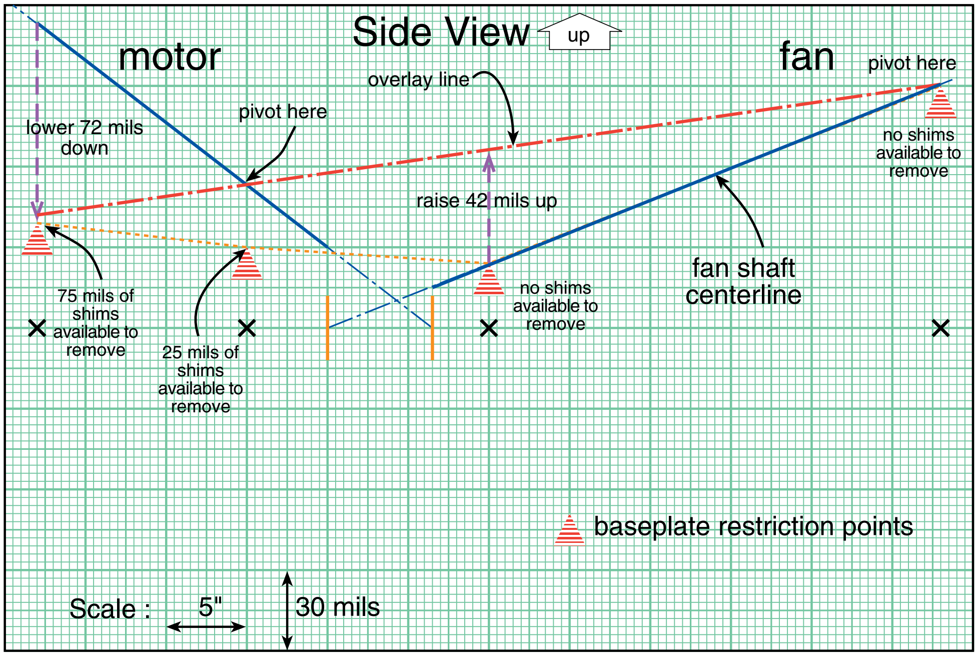

Figure 8-15 - Movement solutions using the outboard feet of the fan and the inboard feet of the motor as pivot points.

feet and 25 mils of shims under the inboard feet (not soft foot corrections) that could be removed, if need be. By counting down 75 mils from the centerline of the motor shaft and the outboard bolting plane and drawing a baseplate restriction point there, we can now see how far that end can come down without removing metal from the baseplate or machine casing. Similarly, by counting down 25 mils from the centerline of the motor shaft and the inboard bolting plane and drawing a baseplate restriction point there, we can now see how far that end can come down without removing metal. In this particular case, there were no shims under any of the feet of the fan, so its baseplate restriction points are positioned directly on the fan centerline at the inboard and outboard ends as shown in figure 8-15. Now that we know what the lowest points of downward movement could be, without removing metal, one possible solution would be to use the outboard feet of the fan and the inboard feet of the motor as pivot points, removing 72 mils of shims from under the outboard feet of the motor and installing 42 mils of shims under the inboard feet of the fan as shown in figure 8-15.

When you consider both machine cases movable, there are an infinite number of possible ways to align the shafts...

Lateral Movement Restrictions

In addition to aligning machinery in the up/down direction, it is also imperative that the machinery be aligned properly side to side. Machinery is aligned side to side by translating the machine case laterally. This sideways movement is typically monitored by setting up dial indicators along the side of the machine case at the inboard and outboard hold down bolts - anchoring the indicators to the frame or baseplate, zeroing the indicators, and then moving the inboard and outboard ends the prescribed amounts. This is where realignment typically becomes extremely frustrating, since there is a limited amount of room between the shanks of the hold down bolts and the holes drilled in the machine case feet.

For example, let's say you wanted to move the outboard end of a machine 120 mils to the south. While monitoring the move with a dial indicator, you began moving the outboard end and the machine case stopped moving after 50 mils of translation. This would be considered a movement restriction commonly referred to as a "bolt bound" condition. The problem when moving machinery laterally is that there is a limited amount of allowable movement in either direction. The total amount of side to side movement at each end of the machine case is referred to as the "lateral movement envelope". To find the allowable lateral movement envelope, remove a bolt from each end of the machine case, look down the hole, and see how much room exists between the shank of the bolt and the hole drilled in the machine case at that foot. If necessary, thread the bolt into the hole a couple of turns, and measure the gaps between the bolt shank and the sides of the hole with feeler or wire gauges.

It is very important to recognize that trouble free alignment corrections can only be achieved when the allowable movement envelope is known. Perhaps one of the most important statements that will be made in this chapter is this...

When you consider both machine cases to be movable, there are an infinite number of possible ways to align the shafts, some of which fall within the allowable movement envelope.

It seems ridiculous, but many people have ground baseplates or the undersides of machinery feet away because they felt that a machine had to be lowered. When machinery becomes "bolt bound" when trying to move it sideways, people frequently cut down the shanks of the bolts or grind a wider opening in a hole.

There is typically an easier solution. Disappointingly, many of the alignment measurement systems shown in this book force the user to name one machine case stationary and the other one movable, which will invariably cause repositioning problems when the machine case has to be moved outside its allowable movement envelope. This may not happen the first time you align a drive system, or the second or even the third time, But if you align enough machinery, eventually you will not be able to move the movable machine the amount prescribed. Once the centerlines of rotation have been determined and the allowable movement envelope illustrated on the graph, it becomes very apparent what repositioning moves will work easily and which ones will not.

Figure 8-16 shows the Top View alignment model of a motor and pump. Not knowing any better, it appears that all you would have to do is move the outboard end of the motor 14 mils to the east and the inboard end of the motor 4 mils to the west. Easy enough. But

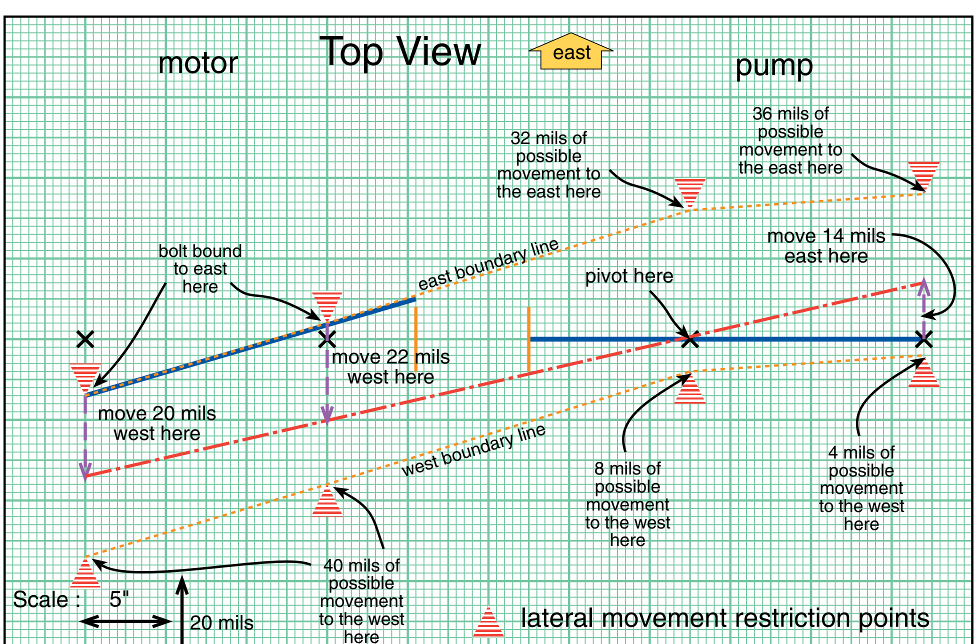

Figure 8-16. Applying lateral movement restrictions to arrive at an easy sideways move within the east and west corridors.

what if the outboard end of the motor is bolt bound to the east already?

By removing one bolt from the inboard and outboard ends of both the motor and pump, the lateral movement restrictions can be observed. In this case the following restrictions were observed:

outboard end of motor - bolt bound to east and 40 mils of possible movement to the west

inboard end of motor - bolt bound to east and 40 mils of possible movement to the west

inboard end of pump - 32 mils of possible movement to the east and 8 mils of possible movement to the west

outboard end of pump - 36 mils of possible movement to the east and 4 mils of possible movement to the west

By plotting the eastbound and westbound restriction onto the alignment model, you can now see the easy corridor of movement. One possible solution (out of many) is shown in figure 8-16.

Please, for your own sake, follow these four basic steps to prevent you from wasting hours or days of your time correcting a misalignment condition ...

1. Find the positions of every shaft in the drive train by the graphing / modeling techniques shown in this and later chapters.
2. Determine the total allowable movement envelope of all the machine cases in both directions.
3. Plot the restrictions on the graph / model.
4. Select a “final desired alignment line” or “overlay line” that fits within the allowable movement envelope (hopefully) and move the machinery to that line.

If you are involved with aligning machinery, by following the four steps above, it is guaranteed that you will save countless hours of wasted time trying to move one machine where it doesn’t really want to go.

Where Did the Stationary - Movable Alignment Concept Come From?

I don’t know. Every piece of rotating machinery in existence has, at one time or another, been placed there. Mother earth never gave birth to a machine. They are not part of the earth’s mantle nor are they firmly imbedded in bedrock. Every machine is movable, it’s just a matter of effort (pain) to reposition it. So why have the vast majority of people who align machinery called one machine stationary and the other machine movable?

The only viable reason that I can come up with is this ... in virtually every industry there is an

electric motor driving a pump. When you first approach a motor pump arrangement, you immediately notice that the pump has piping attached to it and the only appendage attached to the motor is conduit (usually flexible conduit). From a limited vantage point at this time, it would appear to be easier to move the motor because there is no piping attached to it. You would prefer to move the motor simply because it looks easier to move than the pump (and so would I). Thus, the assumption is made that the pump will not be moved, no matter what position you find the motor shaft in with respect to the pump shaft.

But what do you do when you have to align a steam turbine driving a pump? Uh-oh, they're both piped! Which machine do you call the stationary machine ... the pump or the turbine? No matter what your answer is, you are going to have to move one of them and they both have piping attached to their casings. Piping is no excuse not to move a piece of machinery, particularly in light of what many of us know about how piping is really attached to machinery. Some people are afraid to loosen the bolts holding a machine with piping attached to it because they fear the piping strain is so severe that the machine will shift too far to ever get it back into alignment. So is the problem with the alignment process or the piping fit-up? (Refer to Chapter 3 for more information on this subject.)

If you align enough machinery and insist that one machine will be stationary, eventually you will get exactly what you deserve for your shallow range of thinking.

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Parabolic Fever

Catch It Today to Enhance Ultrasound Results

by Jim Hall

You have seen them attached to roofs, on the side of homes, in yards and on radio towers. Parabolic reflectors are used almost everywhere for both transmitting and receiving today's communications signals. These units are low-frequency instruments. In today's predictive maintenance world, the parabolic reflectors or microphones in use are the are high-frequency variety. These reflectors are designed in the shape of a "paraboloid of revolution"[1]. Like their low-frequency brethren, the high-frequency or ultrasonic parabolic microphones have a receiver aimed toward the center of the dish. These receivers may employ one or multiple piezoelectric transducers mounted within the receiver housing. One ultrasonic reflector/microphone employs the use of seven miniature piezoelectric microphones.

The receiver is positioned at a set distance towards the center of the parabolic dish. Frequency adjustments are made at the factory by moving the transducer closer or further away from the center of the dish for optimum reception. A transducer mounted closer to the rim of the dish seems to be more favorable for low-frequency reception. Transducers moved closer to the bottom or center of the dish favor high-frequency reception.

Sound in the air travels at about 1000 feet per second, while the wavelength of a 1000 Hertz (1 kHz) signal is about one foot. Thus, objects smaller than a few feet across cannot be expected to reflect sounds of frequencies below 1 kHz. At frequencies above 10 kHz, the same object may reflect quite uniformly making the parabolic reflector more suitable for higher frequencies or ultrasonic scanning.

The ultrasonic parabolic reflector or microphone comes in different sizes. Some are small measuring 10-12 inches in diameter and others 18-20 inches in diameter. There is even one manufacturer who has a collapsible parabolic reflector.

In addition to the parabola dish there is also the parabolic horn, which uses the same geometry as the dish, except the center is stretched so it is longer with a smaller opening (see Figure 1). Several ultrasound manufacturers make these horns. They are found in lengths of 7-10 inches, with 2.5 to 3 inch openings and a piezoelectric transducer positioned in the bottom, or apex, of the horn to receive the sound wave.

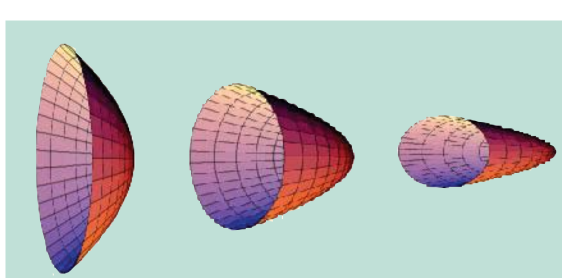

Figure 1 - From reflector to Horn. A Series of parabolas designed from the shape of a Paraboloid of Revolution.

Want Attention?

Pick-up the dish, you will be noticed. Parabolic reflectors do tend to draw attention to the user. Especially if you are using it to scan overhead power lines for corona, tracking or arcing. Kids will follow you, dogs will bark at you and the neighborhood watch may call the police on you. But you're on a mission to locate the reason why the retired electrical engineer has a horrible picture on his residential non-cable, non-satellite television screen.

Here is an interesting story. Late one Friday afternoon a major power provider called me to Hartsfield International Airport in Atlanta, GA to demonstrate how the ultrasonic parabolic/microphone could find the source of radio-interference. Apparently, pilots were complaining about radio interference when using a certain flight path.

There were visual indicators that day as well, but the visual indicators went unnoticed. After scanning the power lines in front of a substation between two aircraft hangars, I heard arcing coming from the direction of the substation. As we approached the substation I targeted what I thought was the source - a pole top transformer. However, once inside the substation, I was able to pinpoint the true source. It turned out to be a bushing behind the transformer. The bushing had a loose bolt and the locking tabs were spread open. When the wind blew, the bushing caused an arc that created the interference.

Figure 2 - Bushing had lose bolts which created arcing and caused radio interference.
Photos courtesy of Ultra-Sound Technologies, Woodstock, GA.

The parabolic reflector/microphone was the correct tool to use that day to locate the source of the interference.

But don't think that the ultrasonic parabolic reflector is used only for scanning electrical power lines. The parabolic dish can be used to locate air leaks in the overhead, hear steam leaks at a distance or scan for mechanical sounds or anomalies in a plant. Other applications include scanning a vacuum tower for leaks from great distances, scanning relief valves on large tanks or towers or (as I have also done) scanning a refinery for leaks after an earthquake.

Parabolic reflectors have been around, and have been evolving, for many years. Some of these instruments are equipped with laser sightings (Figure 5) while others have simple cross-hairs for finding the target.

Figure 3. Parabolic Reflector/Microphone used for radio interference.
Photo courtesy of Ultra-Sound Technologies, Woodstock, GA

Why Are Parabolic Dishes So Effective?

The parabolic reflector or microphone is able to focus exclusively those sound waves whose wavelength is considerably smaller than the diameter of the parabola (see Figure 6.). Keep these relationships in mind:

- the larger the aperture of the reflector, the higher the gain;
- the truer the reflecting service, the sharper the definition of focus:
- the larger the diameter of the reflector, the greater the directivity.

Figure 5: A Parabolic reflector and ultrasonic receiver with laser sighting.
Photo Courtesy of CTRL Systems, Inc., Westminster, MD

Parabolic Horns

Ever notice in the old pictures of Great Grandma and Grandpa, they are using a hearing aid that resembled a horn? These were called "ear trumpets". Dating back hundreds of years, ear trumpets were made from the hollowed-out horns of cows, rams and other animals.

Well, very similar to the ear horns of yesteryear, the predictive maintenance world has the parabolic horn. Like the parabolic reflector/microphone, the horn is designed in the shape of 'Paraboloid of Revolution'. These parabolic horns are used to locate anomalies such as air leaks, electrical discharge and mechanical problems.

Parabolic Horn Problem

In Figure 7 you will see two horns attached to ultrasonic receivers. Note the distance the leak source is from the horns. Parabolic horns are not the best attachment to use to locate near-field, point-of-leak sources. If the leak source is near the entrance of the parabolic horn, the parabola will not reflect the sound to the detector in an efficient manner. The ultrasonic waves go through multiple reflections within the horn and eventually bounce back out of the horn. However, when the leak source is far away, the ultrasonic wave is nearly planar as it enters the parabolic horn. The unique shape of the parabola is then ideal for reflecting these rays down onto a single small piezoelectric sensor.

The parabolic horn is best used several inches to several feet away from the target. Provided the parabolic horn you are using is designed properly, you can expect as much as a 6- to 10- fold increase in signal.

In Figure 8, this particular horn, due to the size of the opening, shorter length and signal strength, has performed well finding air leaks in this individual's facility.

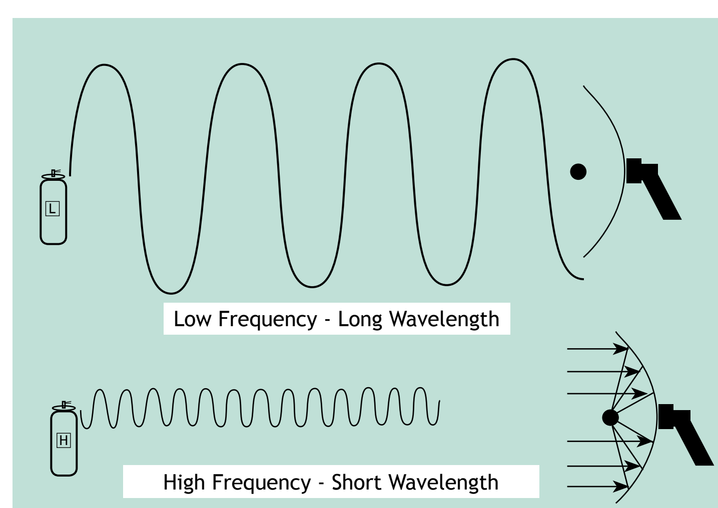

Figure 6: Low frequency sound is long wave length. High frequency sound is short wave typically 1/8" to 5/8" long.
Drawings courtesy of Ultra-Sound Technologies, Woodstock, GA

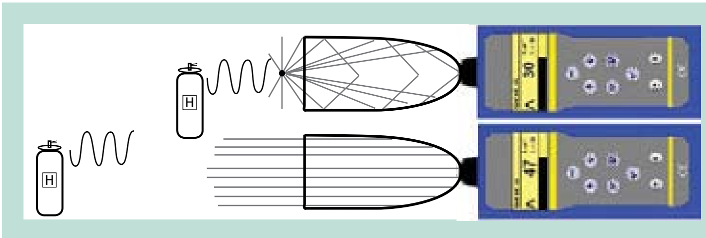

Figure 7 - Keep Target at a Distance of Several Feet, Not Inches.

So whether you have a parabolic reflector dish or a parabolic horn, unless you use them you will not realize their actual potential value in your plant or field. It takes only a few minutes to master the use of one of these reflectors or horns, so if you can't find one in your plant, get one. You will be pleasantly surprised at what you have been missing.

References

(1) Acoustics Properties of Parabolic Reflectors, Randolph Scott Little Laboratory of Ornithology, Cornell University.

Paraboloid of Revolution - In mathematics, a paraboloid is a quadric, a type of surface in three dimensions, described by the equation:

$$\left(\frac{x}{a}\right)^2 + \left(\frac{y}{b}\right)^2 - z = 0$$

(this elliptical paraboloid, opens upward)

With a = b an elliptic paraboloid is a paraboloid of revolution: a surface obtained by revolving a parabola around its axis. It is the shape of the parabolic reflectors used in mirrors, antenna dishes, and the like.

(2) Ellipsoidal Collecting Horns for Ultrasonic Leak Detectors, NASA Tech Briefs KSC-12082.

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A 17-year civil service veteran, Jim served as an aerospace engineering technician for Naval Aviation Engineering Service Unit (NAESU) and with the Naval Aviation Depot Jacksonville Florida (NADEP). Jim is also president of All Leak Detection, LLC an underground leak detection company. Jim can be reached at 770-517-8747 or at jim.hall@ultra-soundtech.com

Figure 8 - Parabolic horn used for air leaks. (Even though the air leak could be heard, this horn is best used for greater distances.)

The Time Waveform

Improve Accuracy of Diagnoses In No Time

By Jason Tranter

A great many fault conditions reveal themselves via the time waveform, yet many vibration analysts do not even save it. I hope this article will convince you to start saving and analyzing the time waveform. You might be surprised at how useful it is!

In reality, time waveform data is easy to collect, easy to interpret, and can contain information that is not available in the spectrum. Time waveform analysis is particularly useful when testing gearboxes and very low speed machines and when diagnosing looseness, bearing faults, cavitation and rubs.

What are time waveforms?

When you collect vibration data from a bearing, the data collector first digitizes the analog signal from the accelerometer, and then performs the Fast Fourier Transform (FFT) to produce the spectrum. The data collector will repeat that process a number of times, averaging the spectra together, resulting in one averaged spectrum. That spectrum is stored in the collector for later analysis. Many people believe that the spectrum contains all of the information that you could possibly need from the machine. That is simply not true.

The time waveform is the digitized signal that is used by the data collector to perform the FFT calculation. For example, if you collect an 800 line spectrum, the data collector will collect a time waveform with 2048 samples (numbers). Normally this data is discarded by the data collector after the FFT calculation has been performed.

If you opt to save the time waveform for later analysis, the 2048 numbers are also saved in the data collector. That data will be saved in the software database and can be viewed on screen.

Once upon a time, data collectors had limited memory, so analysts would opt not to save the time waveform in order to conserve memory. But most modern data collectors have ample memory, and a time waveform will only require a few kilobytes – which is next to nothing in this day and age.

Some people are also under the impression that it takes longer to collect time waveform measurements. However, given that the data collector has to collect the time waveform anyway, it does not take any extra time at all. (Later we will discuss reasons why you might like to collect a separate time waveform, but it is a very fast measurement in any case.)

What is time waveform analysis?

Time waveform analysis is the process of studying the waveform data in order to look for patterns that may indicate a fault condition. Time waveforms show precisely how the vibration changed from one split-second to the next. Every time gear teeth mesh together, or balls roll across cracks in bearing raceways, or bubbles implode during cavitation, the vibration will change – just for a split-second. The time waveform captures those instantaneous changes.

Why perform time waveform analysis?

This is not the place to explain the FFT process. However it is worth saying that the FFT process is excellent for capturing linear (smooth) periodic events. Events in the data that are linear and periodic will be represented

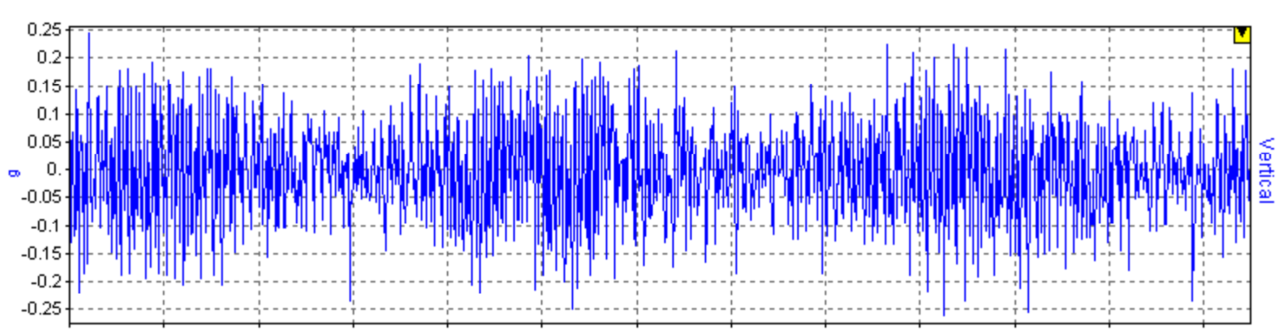


Figure 1 - A Typical Time Waveform

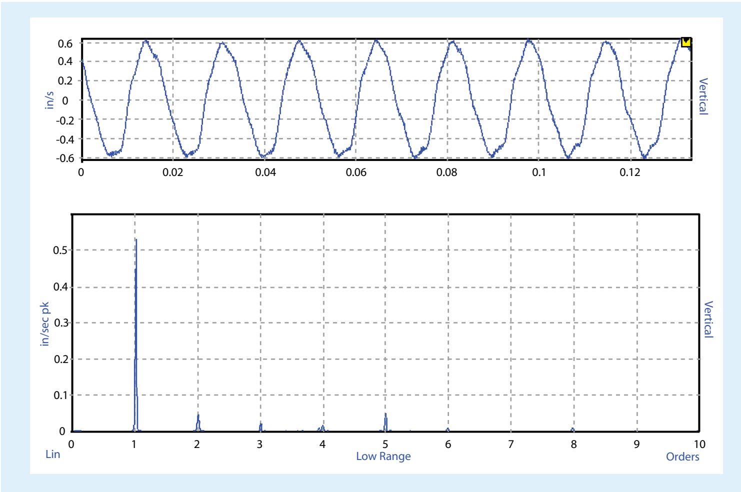


Figure 2 - A simple spectrum computed from the smooth time waveform

by peaks in the spectrum. For example, if a machine is out-of-balance, or there is a misalignment problem, or a rotor is eccentric, the vibration amplitude rises and falls periodically.

When we see 'clean and strong' peaks in the spectrum we can be sure that there were sources of periodic vibration (See Figure 2). If we see sidebands, it is likely that the periodic source of vibration itself periodically rose and fell in amplitude. In this instance, time waveform analysis is useful, but we can do without it.

However, when we see harmonics, a raised noise floor, broad peaks, 'haystacks' and/or 'ski-slopes' in the spectrum, the chances are that the vibration was not entirely smooth (linear) and periodic. Instead there may have been impacts, transients, random bursts of energy, varying machine speed and/or other sources of non-periodic or non-linear vibration.

Most analysts will attempt to interpret these patterns from the spectrum alone. For example, a raised noise floor may be interpreted as looseness. A 'ski-slope' may be interpreted as a bad transducer. A raised area around the pump vane rate frequency may be interpreted as cavitation. And 'haystacks' may be interpreted as a bearing fault.

Now, the analyst may very well be correct. From past experience and other evidence the analyst may be able to diagnose the condition from the spectrum. But every analyst should be willing to consider methods that increase the likelihood of an accurate diagnosis, and time waveform analysis is one such method.

Assuming the measurement setup is satisfactory, the time waveform will provide clear indications of impacts, transients, modulation, beating, and bursts of energy. Time waveforms can help you to diagnose a wide range of fault conditions including bearing damage,

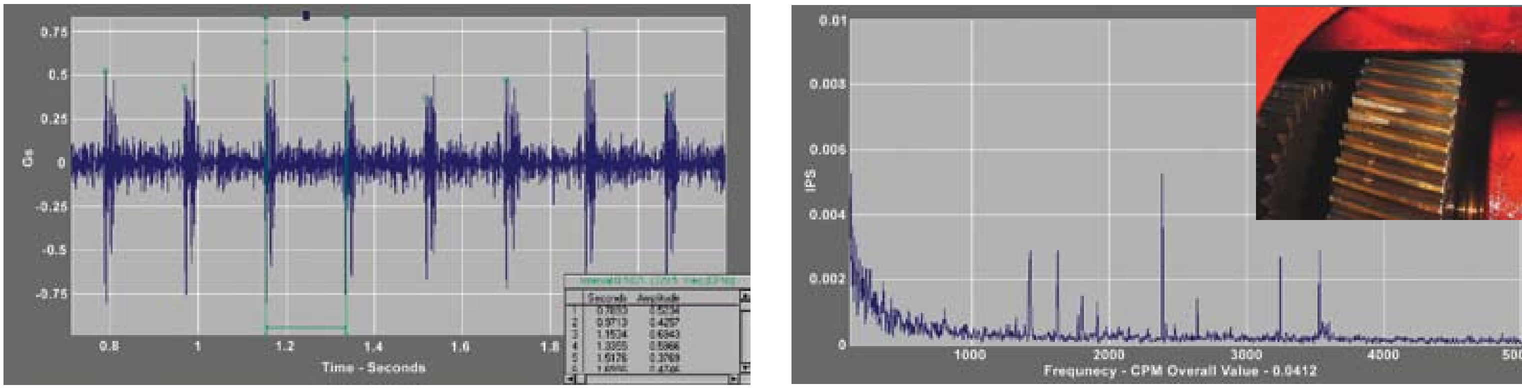


Figure 3 - Time Waveform analysis pointed toward damaged teeth in gearbox. Looking at the Spectrum provided no evidence of this fault.

looseness, gear damage, cavitation, and the reason for measurement errors. Time waveform analysis is also very useful when analyzing very low speed machines.

Examples of Time Waveform Analysis

Let's have a look at a few examples where time waveform analysis revealed information that would otherwise have been missed with spectrum analysis alone.

In Figure 3, we can clearly see that there are damaged teeth in the gearbox, which was proven to be correct when the gearbox was opened. The spectrum did not provide any evidence that there were damaged teeth in the gearbox. (Thanks to Larry Massey for the sample.)

Figure 4 is an example of a different type. If you look at this spectrum you would never imagine that the peak levels in the time waveform were 10 g!

In the example shown in Figure 5, you can see evidence of modulation. The inner race of the bearing was damaged. The vibration amplitude rises and falls as the damaged area moves in and out of the load zone.

If you examine the waveform in Figure 5 closely, you can see that the pulses are not evenly spaced. The pump was cavitating. The spectrum showed indications of cavitation, but the waveform proved it.

There are many more examples that I could present, all demonstrating the ability of the time waveform to either reveal information that would not have been known with the spectrum alone, or to provide supporting evidence to the hypothesis established while studying the spectrum.

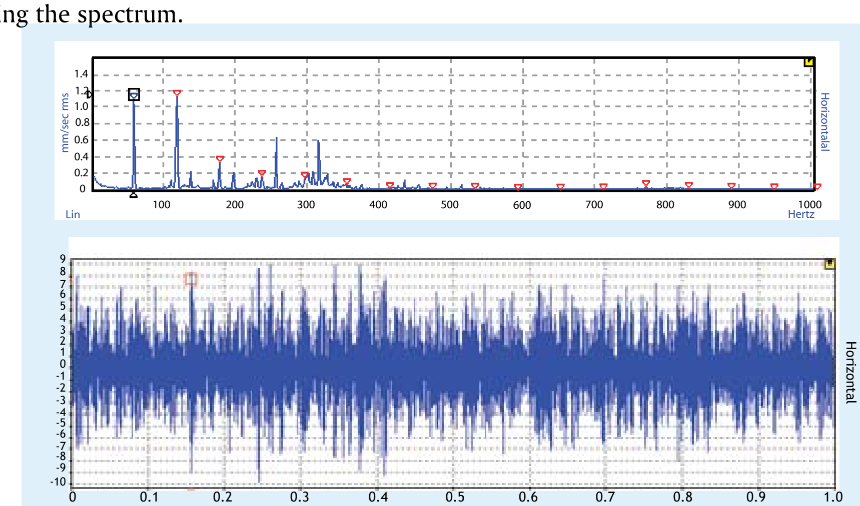


Figure 4 - The Spectrum hides the peak levels in the Time Waveform.

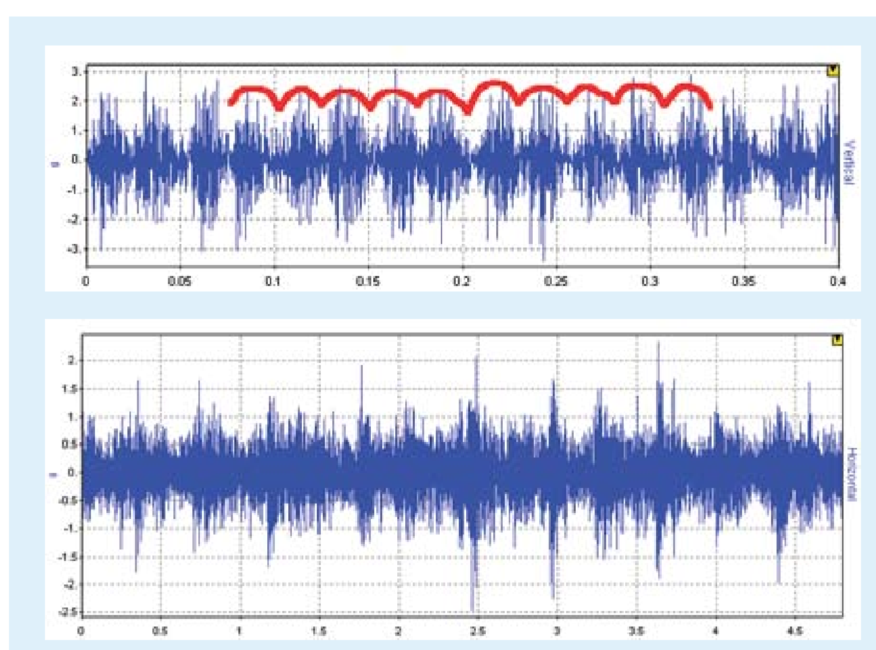


Figure 5 - Waveform solidifies evidence from the Spectrum indicating pump cavitation.

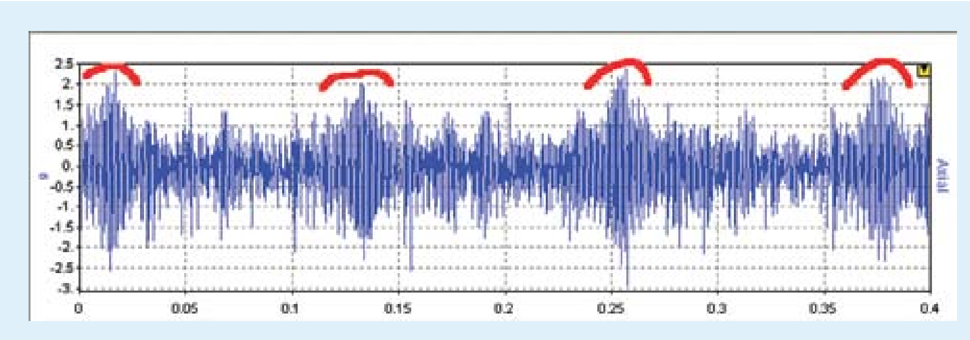


Figure 6 - Analyzing the Waveform can be the first step to identifying the nature of a fault condition.

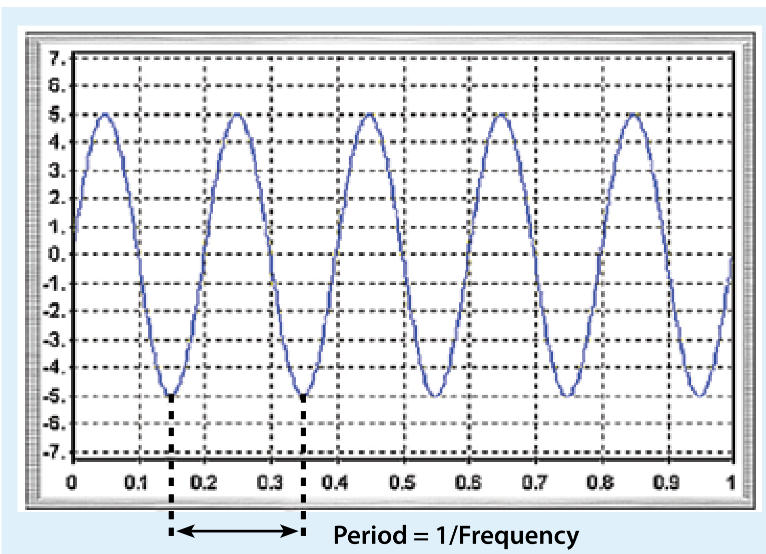


Figure 7 - Identifying the Period will lead you to the Frequency of the Fault.

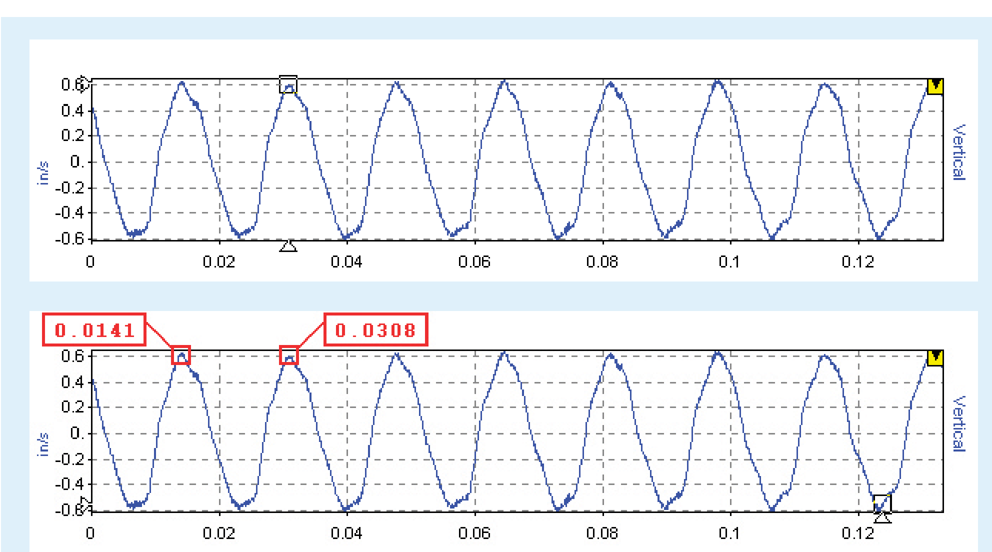


Figure 8 - Simple Waveform of Ash Hopper Sluice Pump

Analysis Techniques

There are two basic aspects to time waveform analysis. First, by simply looking at the data you can get a clear indication of the nature of the vibration. For example, was the waveform smooth or were there transients; were there periodic transients or random pulses; was there one pulse per revolution or multiple pulses, and so on. This form of observation allows you to better understand the nature of the vibration, and thus, the nature of the fault condition.

Second, it is necessary to identify the source of any transients or pulses. By determining the time between each event (or period, see Figure 7), we can compute the frequency (frequency is the reciprocal of period). From the frequency we can match it to the source: running speed, bearing inner face frequency, gear mesh frequency, etc.

Let's take a simple example first. In the top part of Figure 8, we can clearly see a strong sinusoidal signal. If we place the cursor on the time waveform we will get a time relative to the beginning of the record (Figure 8, bottom). We don't really care what the time is. The importance of the time value is that it allows us to measure the time difference between two events.

Let's take the time at the top of two cycles. We can see that the samples are at 0.0141 seconds and 0.0308 seconds. The difference is 0.0167 seconds. We know that the frequency is the reciprocal of the period, so the frequency must be 1/0.0167 or 59.88 Hz (3593 CPM).

Now let's move to a slightly more complicated waveform. In Figure 9, we can see that there are spikes in the time waveform. If we look at the sample-time of any two neighboring pulses, and then compute the difference in time, we have the time between the two events.

In this case the difference is 0.0109 seconds. This would suggest that the period of this vibration source is 0.0109 seconds. The frequency is therefore 1/0.0109 or 91.74 Hz

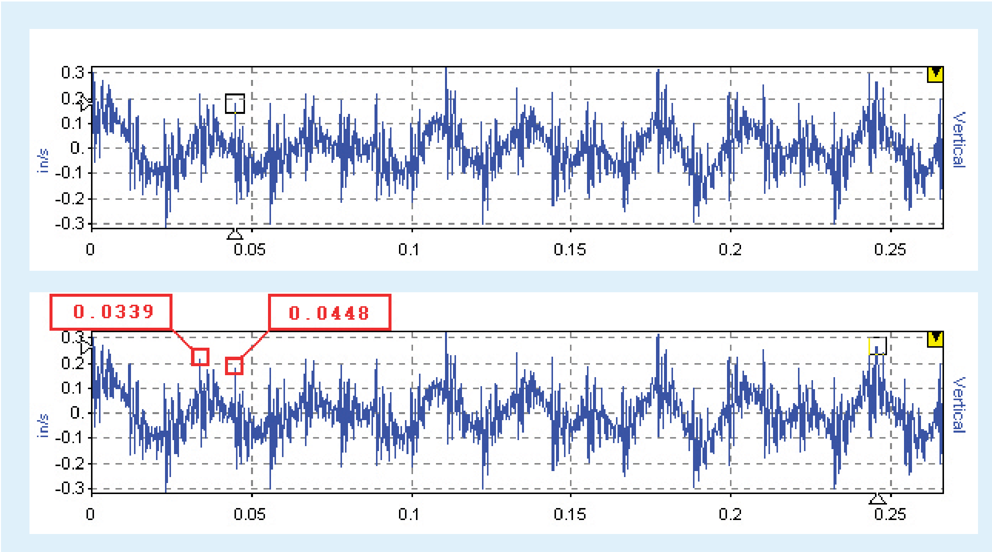


Figure 9 - Using the difference between spikes in this waveform, we can calulate the period to be 0.0109.

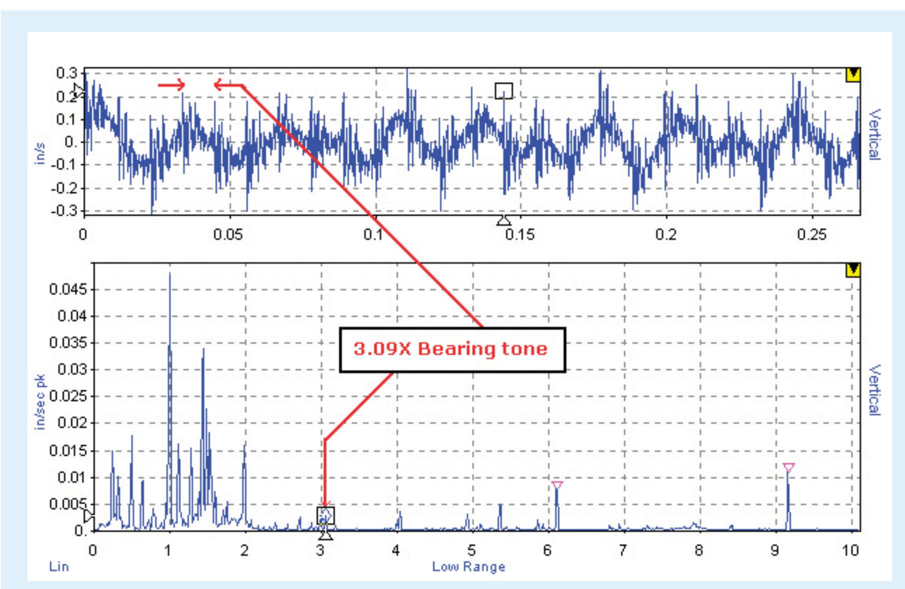


Figure 10 - Using the inverse of the period, we calcuate the frequency to be 3.099, which confirms the problem where a peak was seen in the spectrum.

(5504 CPM). The running speed of this machine is 1776 CPM, so this signal is 3.099X the running speed.

In the spectrum we also find a peak at this frequency (see Figure 10). In this case we have verification – there was a peak in the spectrum at the same frequency. This is not always the case, and that's why this method is so powerful.

Measurement Setup

The way in which the time waveform is measured has a large bearing on how useful that data will be. Of course, you can always go back to the machine to collect more data, but it would be most efficient to collect everything you are likely to need during the routine test.

There are three ways to collect time waveform data:

1. The easiest option is to simply save the waveform that was used to compute the FFT (spectrum). The data collector has the waveform in memory, so you could just save it for later analysis. As I will discuss momentarily, the 'default' time waveform may or may not be useful.

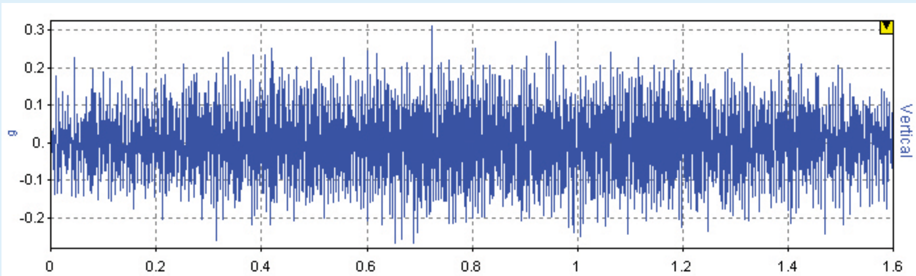
2. If the 'default' waveform is not ideal for analysis purposes, some data collectors allow you to add a separate waveform test to your route setup. Once the spectrum measurement is complete the data collector will automatically acquire a time waveform with different settings. It should not add very much time to your route.

3. For completeness, I should mention that some data collectors allow you to perform special tests which capture a time waveform that may represent many minutes of vibration data. This test may be used to capture the vibration from a machine as it is starting up or shutting down, or during some other transient event. The software should then allow you to analyze the time waveform data in its entirety and extract small 'blocks' of data for detailed spectrum or time waveform analysis.

The settings used to acquire the spectrum dictate the settings used to collect the time waveform. Those settings, in turn, dictate what you will learn from the time waveform. Figure 11 gives us a good example. The top waveform was acquired when the spectrum was set up for 800 lines and an Fmax of 500 Hz. There are 2048 samples over 1.6 seconds.

In the bottom waveform of Figure 11, the settings were changed to 6400 lines, with the same Fmax. Now there are 16384 samples over 12.8 seconds. The box overlaid on the graph indicates just 1.6 seconds and 2048 samples – i.e. the same as the previous waveform.

So you can see that the second waveform reveals something that is very important (the



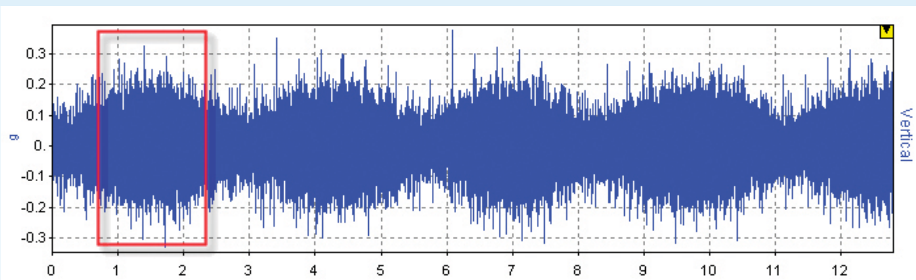


Figure 11 - By changing the Lines of Resolution (LOR) and Fmax settings when acquiring the spectrum (and waveform), you can reveal different qualities within the same vibration data.

beating), however it did require an additional 13 seconds of data collection time.

Understanding the Settings

Up to this point time waveform analysis has been pretty straight forward. Now, this is where time waveform analysis becomes a little tricky…

When you select an Fmax setting for your spectrum, the data collector determines the appropriate 'sample rate' – the number of samples collected per second. For example, when you select an Fmax of 1000 Hz the sample rate is 2560 samples per second. All you have to do to compute the sample rate is to multiply the Fmax by 2.56.

When you select the lines of resolution (LOR) for your spectrum, the data collector determines the number of samples that must be acquired in order to compute the spectrum. For example, an 800 line spectrum is computed from a time waveform with 2048 samples. All you have to do to compute the number of samples is to multiply the number of lines (LOR) by 2.56.

So, now that we know the number of samples that need to be collected, and we know the sample rate (number of samples acquired per second), we can determine the length of time that it takes to acquire the time waveform. Without boring you with all of the equations, the solution is simply to divide the lines of resolution by the Fmax. So, if we choose a resolution of 800 lines, and an Fmax of 1000 Hz, the time waveform will take 0.8 seconds (800/1000). The formula is:

Length of Measurement = LOR/Fmax

As you can see, when the Fmax is higher, the measurement takes less time. When you increase the resolution, the measurement takes longer. But why is this important?

We will use the time waveform to study the events that occur while the shaft is turning, the gears are meshing, and the balls are rolling around the race way. We want to collect enough data to see at least ten rotations of the shaft, and we wish to collect enough data to see the events in detail.

Many data collectors do not allow you to specifically set the length of the waveform and sample rate. Instead you must set the Fmax and LOR. In order to select the appropriate Fmax so that you can view the desired number of shaft rotations, you can simply perform the following calculation:

$$\text{Fmax} = \text{LOR} \times \text{Machine speed} \,/\, \text{Number of Revolutions}$$

(Note: Fmax and Machine speed must either both be in units of Hz or in units of RPM or CPM.)

Measurement Directions and Storage

The other question you will have to ask yourself is whether you will collect time waveform data with every spectrum you collect or just in a single axis on any one component (motor, pump, etc.).

In the author's opinion, the 'cost' associated with collecting time waveform data is so small that you should always collect time waveforms. As stated earlier, the time waveform has to be collected in order to compute the FFT (the spectrum), so you might as well just save the data.

However, if you have chosen a setup for the time waveform that is different to the setup for your spectra, then you may prefer to collect the waveform in just one axis on each bearing in order to reduce data collection time.

Choice of Vibration Units

In general, if you are using an accelerometer

Time waveform analysis is not required in all situations. However, in the right situation it is a very powerful tool.

then you should leave the waveform in units of G's (or mm/s/s) instead of IPS (or mm/sec). When using proximity probes, you should use units of mils (or micron). It is best to use the 'raw', unfiltered vibration. Some vibration analysis software allows you to change from acceleration to velocity during analysis, and this will have the effect of 'attenuating' the higher frequency signals.

Conclusion

I hope you have seen how time waveform analysis can help you to diagnose a wide range of fault conditions with a new level of accuracy and confidence. It is not difficult or time consuming to collect the data, and the analysis process is not complicated. Time waveform analysis is not required in all situations, however in the right situation, it is a very powerful tool.

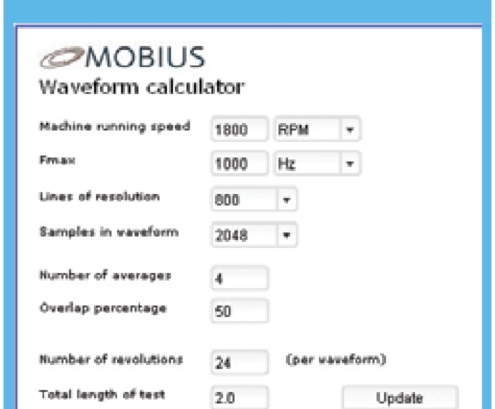
Jason Tranter is the founder of Mobius (in 1999) and the Mobius Institute (in 2004). Jason developed both the iLearnVibration and ILearn Alignment computer-based training systems, which are now used by companies in over 65 countries and have been translated into Spanish, Chinese, Korean and French.

Jason earned his Bachelor's Degree in Electrical/Electronic Enigineering (with honors) in 1983. He formed his first business, ARGO, in 1986 and developed the ALERT series of vibration analysis software products. He sold ARGO to DLI Engineering Corp in 1990. He was Director of Vibration Products for DLI when he left in 1996. He continued consulting with DLI until 1999 and helped to develop ExpertAert, the DCX data collector anf the DCX on-line monitoring system. Jason can be contated in his home country of Australia at +61 3 5989 7285 or by e-mail at jason@iLearnInteractive.com

On-Line Waveform Calculator

For those that like convenience, Mobius has a waveform calculator available on-line. Just go to the following link:

www.ilearninteractive.com/calculator



A tool that will help anyone in your organization realize the benefits of reliability and proactive maintenance? And they'll have fun while learning it? Amazing but true.

The Reliability Game™

Convincing people - especially the non-maintenance variety - of the true benefit that proactive maintenance and reliability provide can sometimes seem like a never ending uphill climb. The Reliability Game can turn that tortuous climb into a downhill coast. It provides a fun environment that clearly shows the consequences of real life maintenance decisions. We talked with the folks at MRG, Inc about their game...and about how and why it can kickstart a whole new outlook on maintenance. Wouldn't it be nice if everyone in your organization understood the value of proactive maintenance? Now they can....and it only takes one day.

What is the Reliability Game?

The Reliability Game™ is a simulation designed to teach participants how to make the transition from a reactive to a proactive maintenance environment. It is often a challenge to make this transition because people have a hard time seeing the objective and rewards. MRG's Reliability Game™ is the solution to this problem. It is an interactive board game that demonstrates the value of proactive reliability practices and the positive effect on the bottom line—an educational, fun way to create a common understanding of your goals.
The Reliability Game™ is played by teams of four people who try to determine the best way to manage their equipment, money, time, labor and material resources. It also simulates real business pressures, production requirements and financial results of reliability practices (both positive and negative). Throughout and following each round, each team's financial progress is tracked and discussed. By the game's end there is typically a greater appreciation for the value of reliability and the entire reliability philosophy.
It is so effective that organizations can use it for any number of purposes including corporate training, team building exercises and introduction to the proactivity philosophy. In every case, participants will realize that it's perfectly normal to get excited about reliability.

How did the idea for this develop and evolve into a game?

In the mid 1980s a Fortune 100 company began to examine the increasing cost of maintenance and hired an MIT computer modeler to create a simulation of the company's plant environment. The simulation revealed that the plant's inability to plan any maintenance combined with the poor health of the plant's assets led to an inefficient use of resources, time and money. The organization's leadership attempted to explain the results of the simulation to their maintenance personnel, but graphs and statistics could only go so far; they needed something interactive that allowed them to experiment and see the effects of their decisions unfold before them. Enter the Reliability Game.

How many people play the game at one time?

Each team has four people, each of whom assume one of the identities of Finance Manager, Purchasing Coordinator, Maintenance Resource Planner and Operations Coordinator. They compete (in a spirited, friendly way) against the other teams located at separate tables throughout the room. MRG can facilitate the game with any number of people as long as they can be divided evenly into teams of four. Non-participating observers from the organization are also welcome to the sessions.

How long does a session take to get the maximum benefit from playing the game?

Each session lasts approximately eight hours, or one full workday. It is important that each team and participant remain for the full session in order to gain the most benefit and see the results of the game.

Who are the optimum people in a company to have play the Reliability Game?

Anyone from the organization would benefit from playing the game, but MRG recommends that decision-makers and managers from major departments such as Finance, Purchasing, Maintenance and Operations be involved in playing the game. Of course, alongside the decision-makers, supervisors and managers, should be the engineers, craftspersons and technicians: in order to institute a change management program, the entire team should participate.

In your experience who benefits the most from playing the Reliability Game?

Although everyone comes away from the Reliability Game with a fresh perspective on maintenance and a new attitude toward proactive maintenance practices, the game itself doesn't benefit one person more than another. In fact, it is the culture, or the organization in general, that benefits. If the fundamental principles the Reliability Game sets forward are faithfully followed throughout the organization, the flow from a reactive to a proactive culture will be much smoother and the results will be realized much quicker. Smoother workflows, the increased acceptance of new ideas, the impact on the bottom line: The Reliability Game enables the culture to flourish.

How do they benefit? What knowledge do they leave the session with that they didn't have before?

Participants leave the Reliability Game believing that reliability principles can be applied to their environment and that results are possible. They see how waste can be identified and eliminated as the game takes them on a three- to five-year journey; they understand that the results may not be immediate, but that, in the end, their organization will reap the benefits and their efforts will be rewarded. Participants also can look through the lens of a different position, learning about everyone's responsibilities and day-to-day activities as well as the consequences of their decisions. They will leave the session with the understanding that co-workers and supervisors are on the same page; everyone is working toward a proactive maintenance environment, we are all on the same team.

What kind of impact do you see in a company or facility after playing the Reliability Game?

There is a noticeable increase in energy. When employees feel they are a part of something and if they believe in something (and they do, since they have just experienced the Reliability Game, which showed them how the results are possible and sustainable) they will focus their participation and efforts. The initial stages of any organizational change can be difficult, but the Reliability Game builds the foundation for change and the process goes much more smoothly since people trust the process. This is essential. People who haven't experienced the Reliability Game may expect immediate results and may prematurely give up on the idea. Reliability Game veterans, however, know that staying the course will inevitably yield results.

Share a success story or two from people or companies who have played the Reliability Game?

One success story comes not from a participant, but an observer. An executive from a large power generation organization sat through an afternoon session and, after seeing the attitude changes and possibilities inherent in proactive maintenance, he stayed "after school" with MRG consultants, discussing reliability as a top-down process. The potential for his organization intrigued him enough that he circulated an internal memo stating his enthusiasm for the game and its principles.

Another successful facilitation happened at a large chemical company where leaders recognized the possibilities a license provided and the game was rolled out throughout their organization. They effectively employed the game at their locations in five different countries translated into five different languages and presently use the game to generate credibility and excitement for reliability initiatives. The license provides them with the freedom and flexibility to deploy the game whenever necessary, whether they are training new employees or reinforcing reliability principles across their enterprise.

How can interested people get more information about the Reliability Game?

Please visit our website www.mrginc.net to view an interactive display of the Reliability Game or to view the Reliability Game iPresentation. For more information, please contact Pam Lynch at 203.264.0500 or lynchp@mrginc.net

The Watchdog® EX Series Breathers for extreme humidity applications incorporate two check valves, one to control airflow into the protected reservoir and one to control airflow out. This prolongs the life of the desiccant by allowing the air to flow through the breather only when needed to protect the integrity of the tank. Unlike a membrane system, which does not allow internally generated gases and contaminants to exit the system, the Watchdog EX Breather offers all of the advantages of breathing air in and out of the tank while removing water vapor and solid particles before they contaminate the fluid.

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Emerson Process Management now offers two new safety-rated versions of the CSI 2130 Machinery Health™ Analyzer for evaluating the condition of a broad range of equipment types in hazardous work areas.

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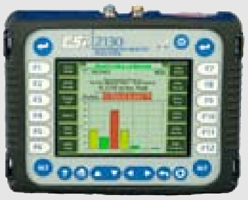

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This new and exciting learning opportunity will augment the already highly successful International Maintenance Conference. From start to finish, this focused track will provide participants with the instruction and tools to build a business case for a fictitious company based on data provided throughout the conference. By using the same methods applied to the fictitious company, participants will be able to develop a business case for reliability for their own organization.

An entire day of the Reliability Excellence Experience will be presented by companies that have been successful in their corporate reliability improvement implementations - Alcoa, Dofasco, and Cargill. These companies will identify the common characteristics for successfully implemented improvements in manufacturing process reliability. They will determine the key milestones for implementing Reliability Excellence in your organization.

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SMRP Establishes New Chapter in Indiana

The Society for Maintenance and Reliability Professionals (SMRP) has established a new local chapter in the state of Indiana. This is the first chapter in Indiana and its third nationwide. In September, 30 SMRP members gathered to conduct the first chapter meeting in Indianapolis. SMRP is an independent, non-profit society by and for practitioners in the Maintenance & Reliability Profession. The society is nearly 2,000 members strong with global penetration. To learn more about joining the Indiana Chapter contact:

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