FLUKE
Reliability

Best Practices – Why balance your machines?

Step 1 of a Connected Reliability Solution

Meet the Speaker

John Bernet, CMRP

Reliability Application Specialist at Fluke Reliability (12 years)

- Previously worked at Azima DLI for 18 years
- Served 12 years in U.S. Navy on cruiser & aircraft carrier as electrical technician
- Has 30+ years of experience in preventive and predictive maintenance
- Written many technical articles for global trade publications and a 240-page vibration training program

Certified Maintenance & Reliability Professional (CMRP)

Vibration Analysis Category II certified

Ultrasound Category I certified

Thermal/Infrared Thermography Level I certified

FLUKE Reliability

emaint

AZIMA DLI

PRÜFTECHNIK

Innovative Software

Remote condition monitoring services

World-class hardware

FLUKE Reliability

Agenda

Common team challenges and struggles

- Solutions from Connected Reliability

Vibration analysis – diagnose machine faults

Balancing principles – how it works

Steps to Connected Reliability

Summary - questions

Customer Business Challenges

"69% of executives say improving operational availability or reducing process safety mechanical integrity risk is important for their operations and can be a challenge for their facility."

Source: Pinnacle Reliability Report

"… depending on the industry between 15 and 70 percent of total production costs originate from maintenance activities"

Source: Survey on Predictive Maintenance

Maintenance is one of the US Army's top five injury producing activities

Source: US Army

Reduce Costs (downtime, labor, parts)

Safety & Sustainability

Regulatory Compliance

Availability of skilled workforce

Reduce Spare Parts Inventory

Supply Chain Disruptions

Condition Monitoring helps to overcome these challenges

Every organization is somewhere on this journey …

Reactive	Preventive	Predictive/CBM
Corrective work orders after failure	**Calendar & meter based scheduling**	**Work orders from real-time asset data**
☒ Can be expensive	☑ Increased efficiency	☑ Increased uptime
☒ Shorter asset life	☑ Less downtime	☑ More productivity
☑ Appropriate for some assets	☒ Can perform too much / too little maintenance	☑ Data-driven maintenance decisions

Maintenance-centric → **Asset Health-centric**

Where are you in your reliability journey?

Where do you want to be in the future?

Why many teams struggle?

Predictive equipment vendors have been developing and improving tools / software

So why are most companies (in almost all industries) still mainly using reactive and preventive methods?

- *Today's tools are the most advanced, and training has never been easier, but the problem is always time and resources.*

1 **How do we grow a reliability program**
… when we are 100% busy?

We have no time to collect/analyze data and generate reports.

2 **How do we make the best decisions**
… when we have incomplete information?

We don't have time to conduct all the necessary routes, nor can we have access to all machines

3 **How do we monitor all critical assets**
… with limited resources?

We must allocate/balance resources needed for planned/calendar-based maintenance, repairs, and emergencies, etc.

So, what do we do?

Ideal world - sounds good:

All maintenance is done before downtime, proactively

- **Predictability increases**
- **Safer workplaces**
- **Increased maintenance intervals**
- **Reliability**
- **Boost to peace of mind**

3 real world choices:

Reactive (RM): No repair action until failure

- Increased cost due to last minute fixes
- **Unplanned downtime: longer lost production and time to get parts**
- **Stressful work environment**
- More severe failures affecting other parts or machines

Preventive (PM): Repair before failure (based on the calendar / history)

- **Failures are random 85% of the time**
- **Fault-free machines are overhauled unnecessarily because they're "due"**
- If it ain't broke, don't fix it

Predictive (PdM): Trend machine condition and repair only when needed

- Limited budget and time for creating history and measurement condition reports
- **Difficult to implement – hard to change company culture**
- Data is everywhere
- **Already busy with PMs/repairs**

Do we have to choose? No.
Here are some solutions that teams have found to be successful to overcome the challenges that they face . . .

How some teams succeed?

Reliability Best Practices— important cornerstones:

Learn from successful customers: start small and grow; select the right tool based on failures; get answers, not just data, and share with others on team

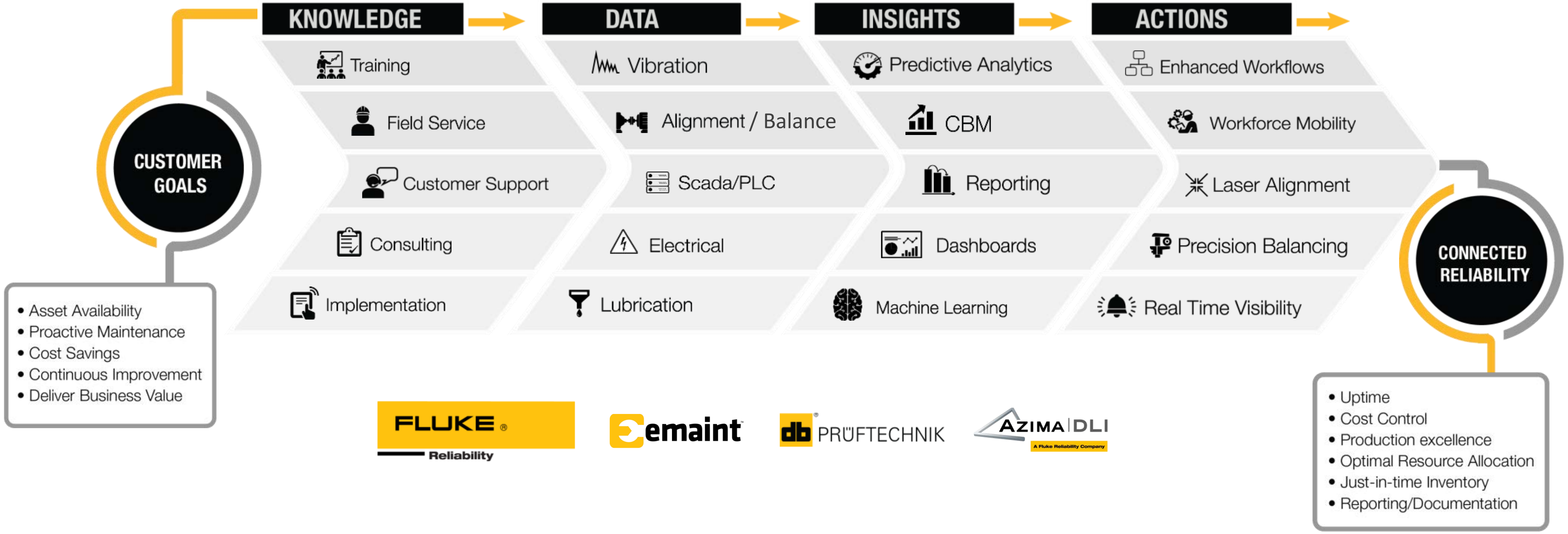
Evaluate your plant specifics: asset criticality, failure modes, risks to uptime, needs, etc.

Assess your company's resources, goals, success metrics, plan for implementation, etc.

Partner with a reliability consultant—get support to transition from goals to results

What is Connected Reliability?

Simplified solutions for the people who keep the world up and running



Helps guide the customer past the obstacles on their reliability journey from Point A to Point B

✓ Successful start-up → ✓ Successful implementation → ✓ Successful sustainment

FLUKE Reliability

Predictive Maintenance - A Connected Reliability Workflow

Work order

eMaint

1. Monitor Vibrations on Running Machines
3 Different Ways:

Workorders for
Walk-Around
Data Collection Routes,
Using ***Handheld*** Tools

eMaint + PRÜFTECHNIK

Online
Continuous Monitoring

PRÜFTECHNIK

Wireless
Periodic Monitoring

PRÜFTECHNIK

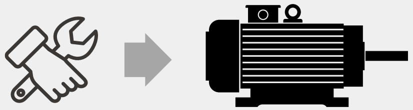
2. Data analysis and fault detection

AZIMA DLI

3. Assign Workorders and Optimize Planning, Scheduling, and Labor Costs

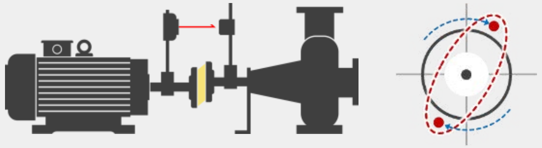
eMaint

4. Perform Preventive Or Corrective Maintenance



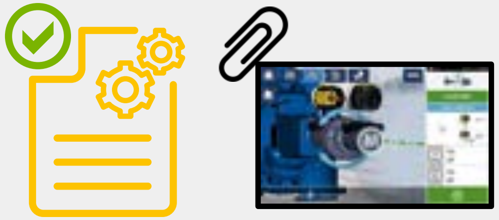
- Replace Bearings
- Rebuild Seals
- Overhaul
- Realign
- Rebalance
- Etc.

5. Re-Align and Re-Balance the Machine with Precision Devices



PRÜFTECHNIK

6. Attach or Link Device Results to Close the Work Order



eMaint + PRÜFTECHNIK

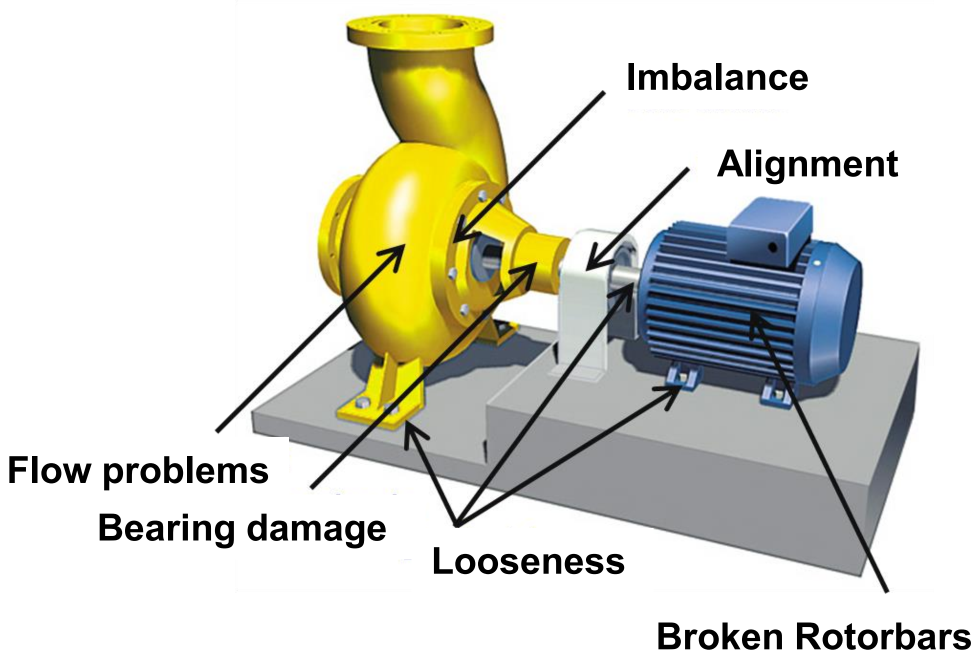
FLUKE Reliability

Vibration analysis

Why Measure Vibration?

- Thermography (IR)
- Ultrasonic
- Oil Analysis
- Electrical / Current Analysis
- **Vibration Measurements**

(80% of all machine faults can be detected with vibration analysis)



NOTE: Vibration faults have directionality

Condition Monitoring using Vibration Analysis

Pro-active Maintenance

- Most damage to rotating machinery is detectable by Condition Monitoring
- Catch issues sooner than other techniques of maintenance prevention
- Plan shutdowns only when necessary and with fewer extra spare parts

How much vibration is bad? Many customers think:
Just watch the trend of every machine and you will quickly know what to do
But vibration data is not a simple number like temperature, pressure, current

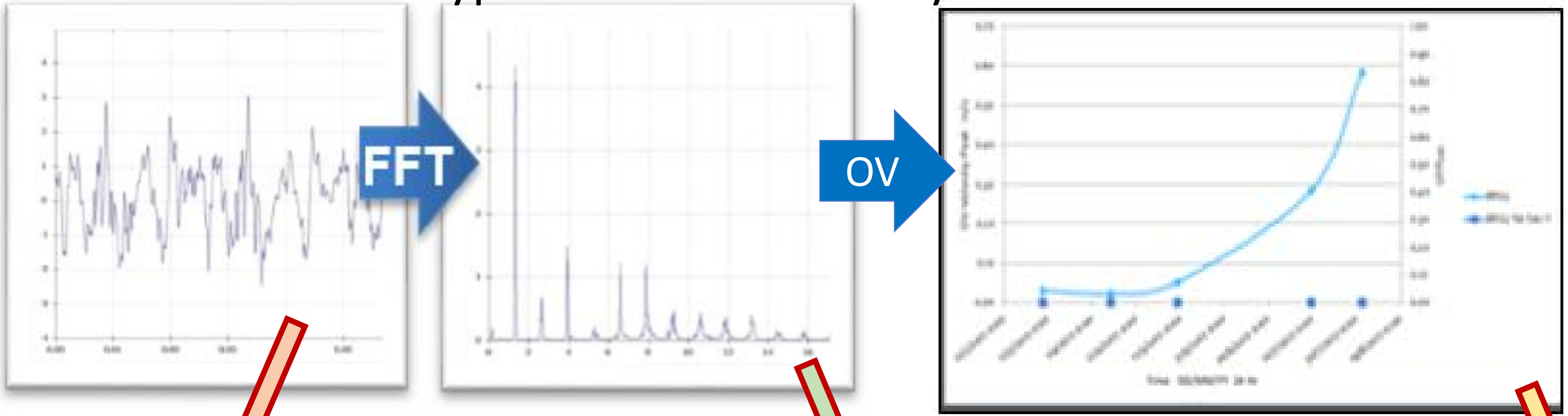
Taking vibration measurements will show the machine is dynamic like a living creature – there are many variables from background noise, adjacent machines, the structure, resonances, process, cavitation, changing load and speed, etc.

Experts have been analyzing hundreds of thousands of machines over the years, they have found that every mechanical fault has a pattern, and they have learned how to ignore the noise and other vibration that doesn't follow the algorithms.

There is no secret formula
… from lessons learned we can offer best practices to guide you
… don't go it alone – partner with experts to support you

Which tools are best? It depends . . . What kind on answer do you need?

- There are 3 types of vibration analysis – what is the difference?

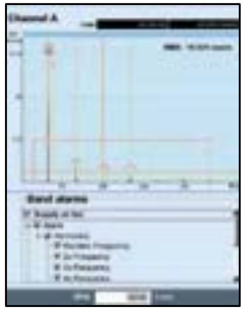


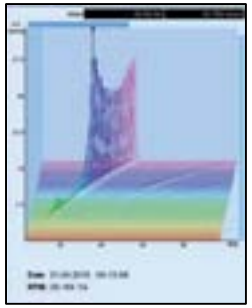
Time

Frequency

Overall Vibration

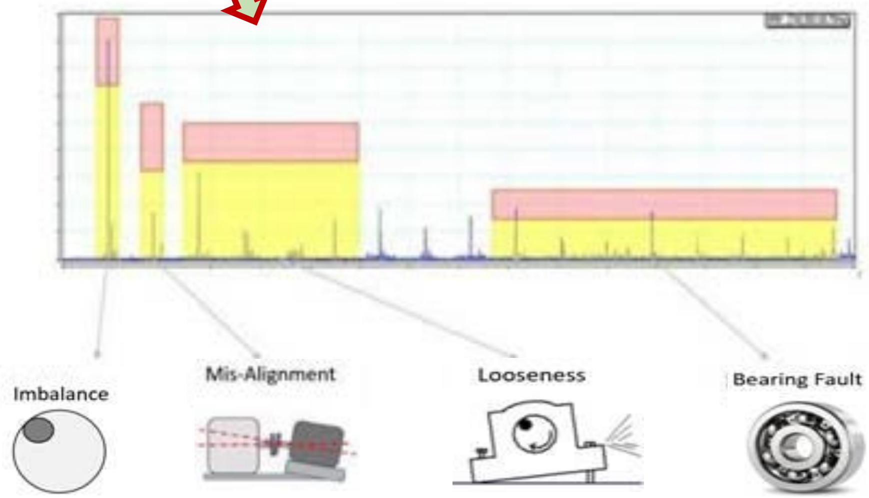
- <u>Time waveform</u> – raw data: Complex - transients, noise
- <u>Frequency spectrum</u> – converted: Simplified - patterns to diagnose faults
- <u>Overall Vibration</u> – calculated 10-1K: One number - trend to screen health





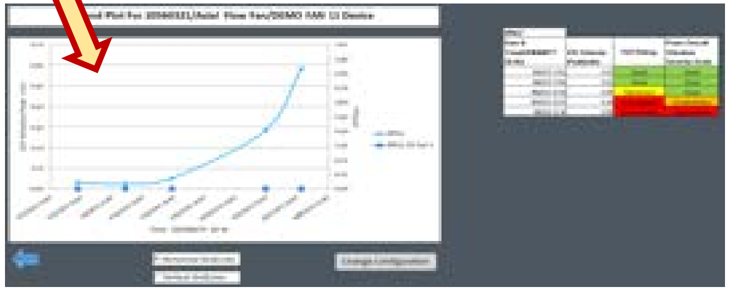
#2

- All faults detected
- Advanced analysis
- Experience / training
- Takes resources / hours
- Best for top tier machines



#3

- 4 common faults (ignores others / noise)
- Quick answer & action recommendation
- Best for mainstream machines



#1

- Simple number / trend
- Green, yellow, red
- Good or Bad: No answer or action
- Best for bottom tier machines

Simple colors may be what you want, but answers are what you need?

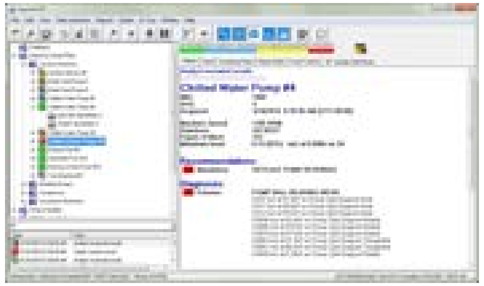
FLUKE Reliability

Full circle solution

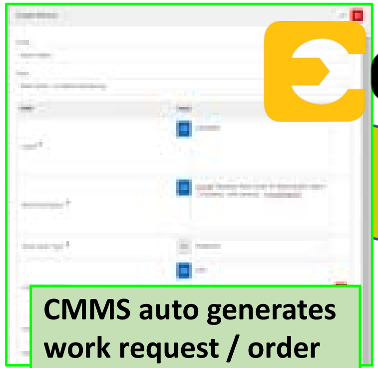
Watchman gateway sends data to cloud via Wi-Fi, Cellular LTE, or ethernet connection

User accesses data via secure connection to software portal

Expert Automated Diagnostic System



Narrowband alarm triggers notification

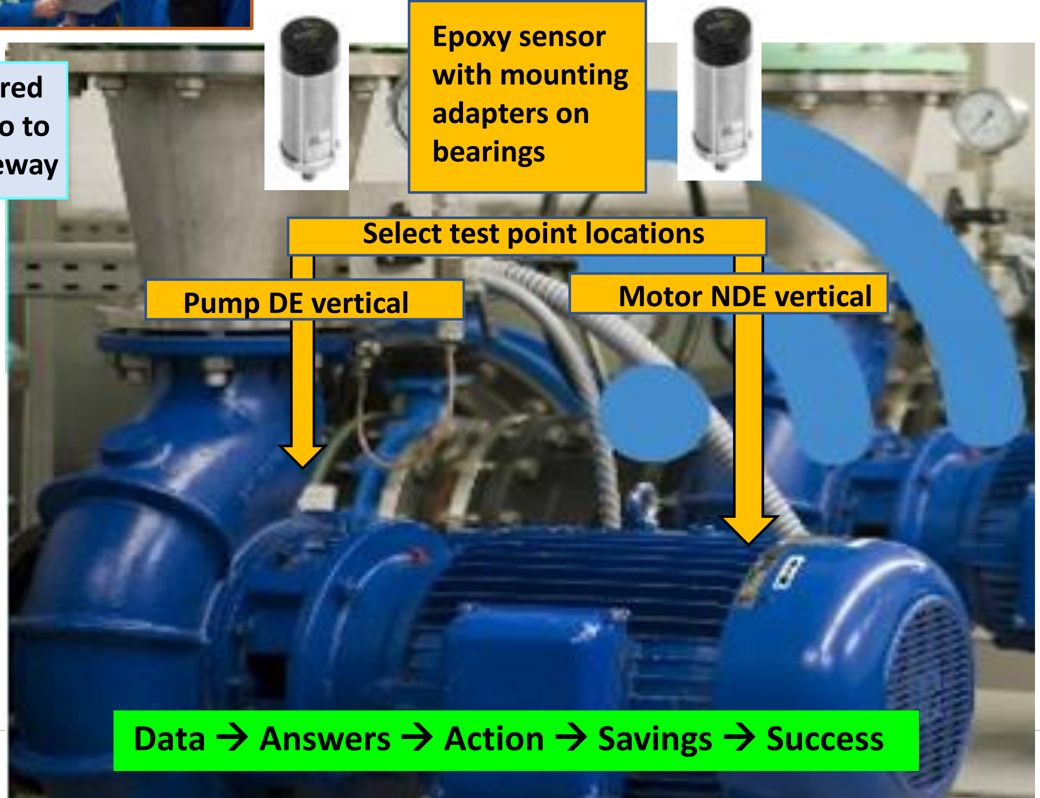


CMMS auto generates work request / order

Review data to confirm action needed
1. Customer – manual w/2day training
2. AI – Auto diagnose common faults
3. Customer – advanced w/ inhouse experts
4. Service – advanced w/ remote experts

Onsite S/U by experts
- Commissioning
- Installation

Data is transferred by 2.4 GHz radio to Watchman gateway

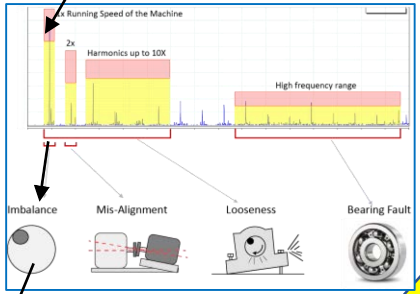


Epoxy sensor with mounting adapters on bearings

Select test point locations

Pump DE vertical

Motor NDE vertical

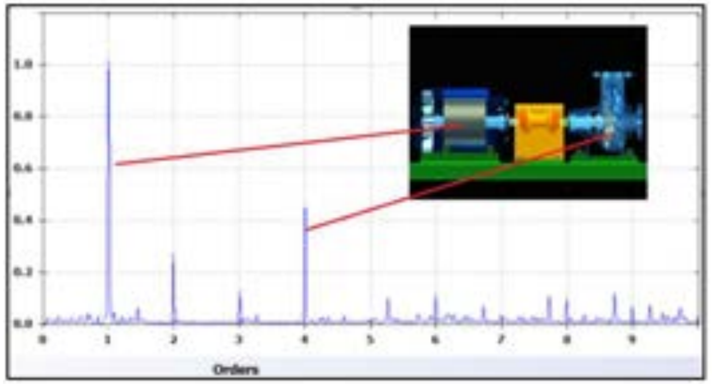


5 Months later . . .
EXTREME Imbalance
- Repair needed
- Approve work request
- Generate work order
- Balance machine
- Return to service

Data → Answers → Action → Savings → Success

Diagnosis machine faults

Diagnose faults – vibration analysis

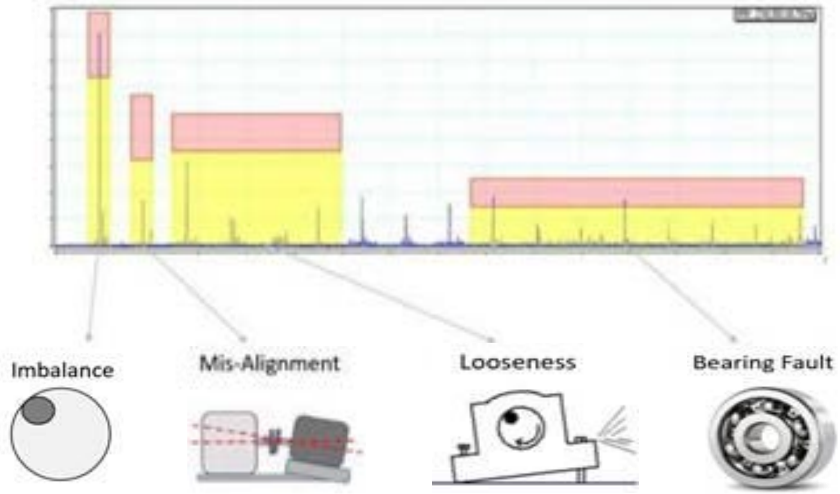


Vibration analysis can be simplified to a three-step process:

1. **Identify vibration peaks** as they relate to a source component on the machine.
2. **Look for patterns** in the data based on vibration rules.
3. **Measure the amplitude** of the vibration peak to determine the severity of the fault

Once the fault and severity are determined, a repair can be recommended, and a work order generated.
There are hundreds of faults, but most are infrequent or rarely seen. Instead of learning hundreds of rare faults, learn <u>the four most common machine faults</u> that you will find every day and are easy to correct:

	Machine fault	Frequency and Axis	Component found	Advanced Severity
1	Imbalance	1X - All radial directions	On affected component	Higher amplitude 1X
2	Misalignment			
	Parallel	2X - Radial and tangential	Both sides of coupling	Higher amplitude 2X
	Angular	1X - Axial	Both sides of coupling	Higher amplitude 1X
3	Looseness	1X harmonics—all directions	On affected component	Higher harmonics
4	Roller bearings	Non integer—all directions	On affected component	Harmonic, sidebands, noise hump, noise floor

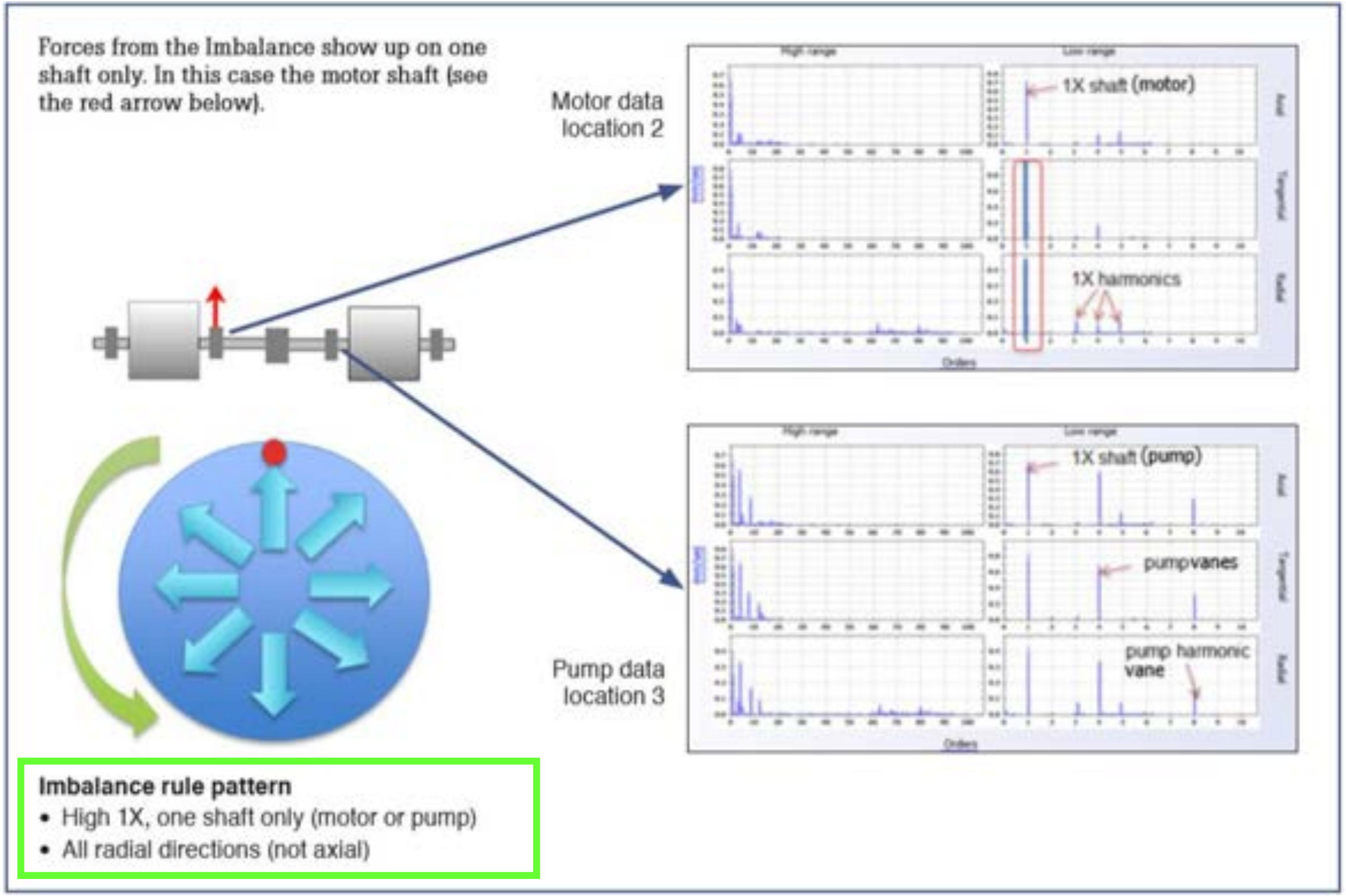


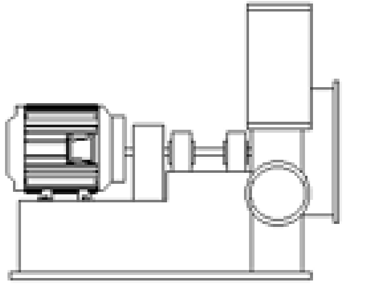
FLUKE Reliability

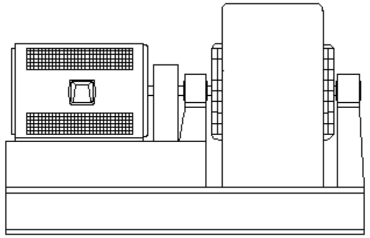
Imbalance (unbalance)

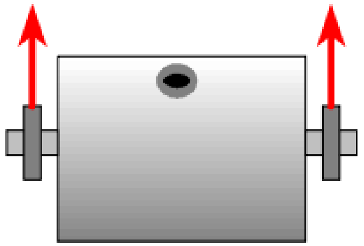
A heavy spot on the shaft causes forces in all radial directions that leads to excessive vibration and increases the wear of bearings, seals, etc.

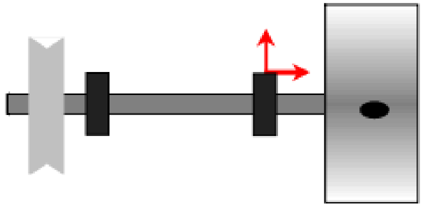
	Machine fault	Frequency and Axis	Component found	Advanced Severity
1	Imbalance	1X - All radial directions	On affected component	Higher amplitude 1X
2	Misalignment			
	Parallel	2X - Radial and tangential	Both sides of coupling	Higher amplitude 2X
	Angular	1X - Axial	Both sides of coupling	Higher amplitude 1X
3	Looseness	1X harmonics—all directions	On affected component	Higher harmonics
4	Roller bearings	Non integer—all directions	On affected component	Harmonic, sidebands, noise hump, noise floor









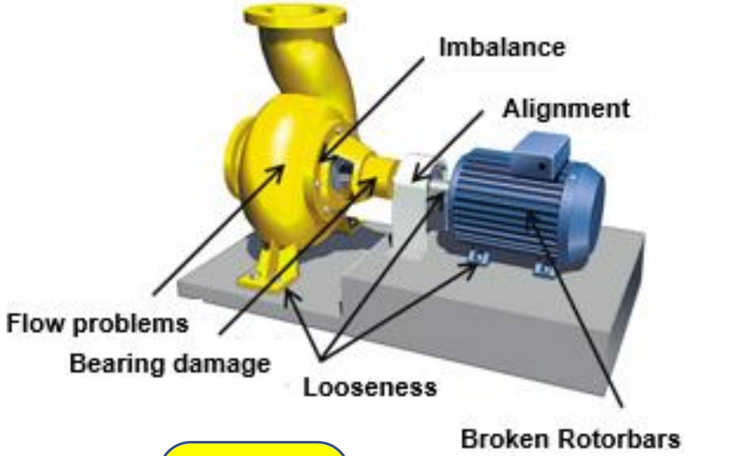


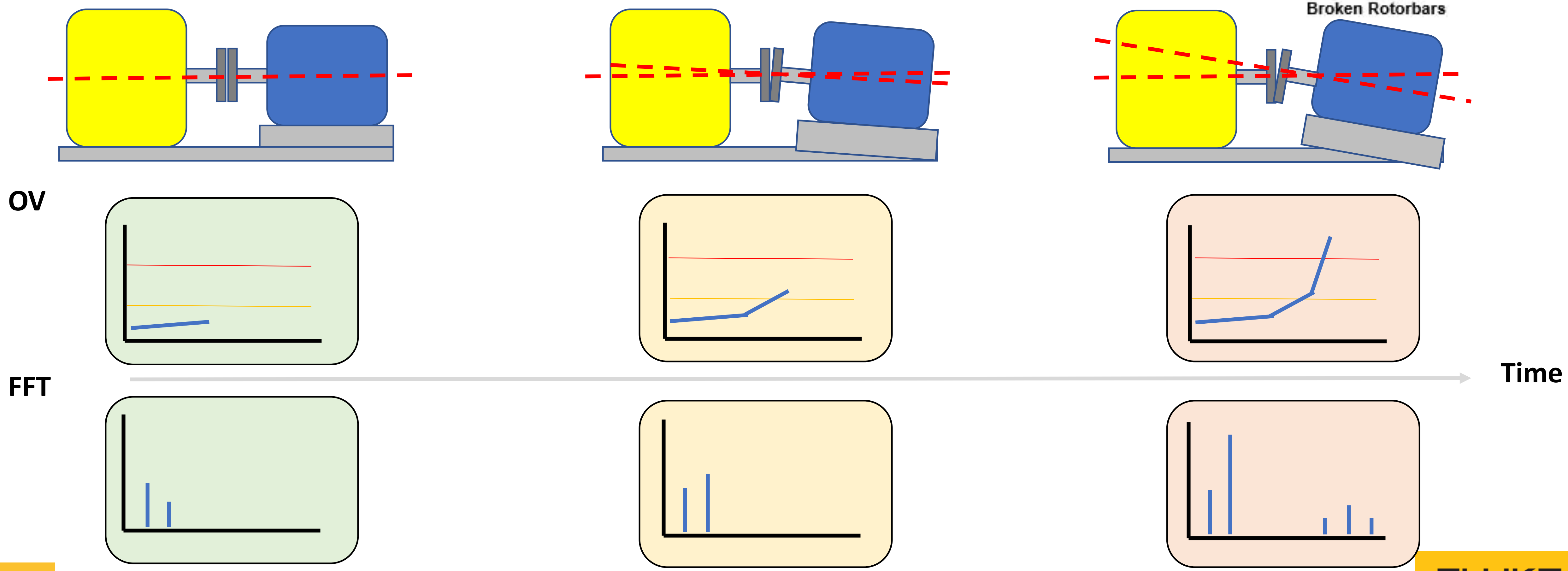
FLUKE Reliability

Condition Monitoring Example – misalignment

(same for imbalance, looseness, bearings)

Track the fault severity over the months or even a year or more





FLUKE Reliability

Why do teams keep replacing the same bearings and seals?

Need to find root cause of the problem – fix the root cause don't just fix the symptom

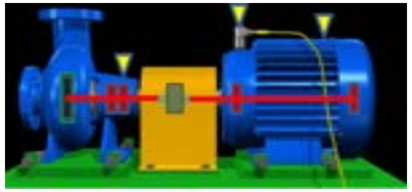
~50% of rotating machine damage is directly related to imbalance

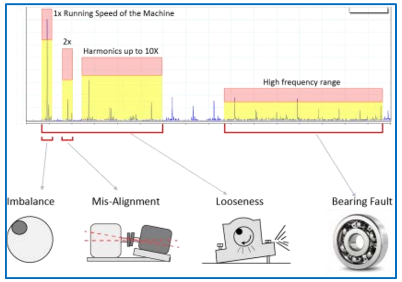
~50% of rotating machine damage is directly related to misalignment

Most teams just replace bearings and seals because alignment/balance takes too much time

Diagnose the root cause

Vibration detects all faults – don't ignore the root cause (misalignment, imbalance)





Correct the root cause on most machines

Step-by-step corrective tools provide quick, easy precision balance & alignment to fix root cause on most machines in the plant (not just a few)

Belt misalignment

Shaft imbalance

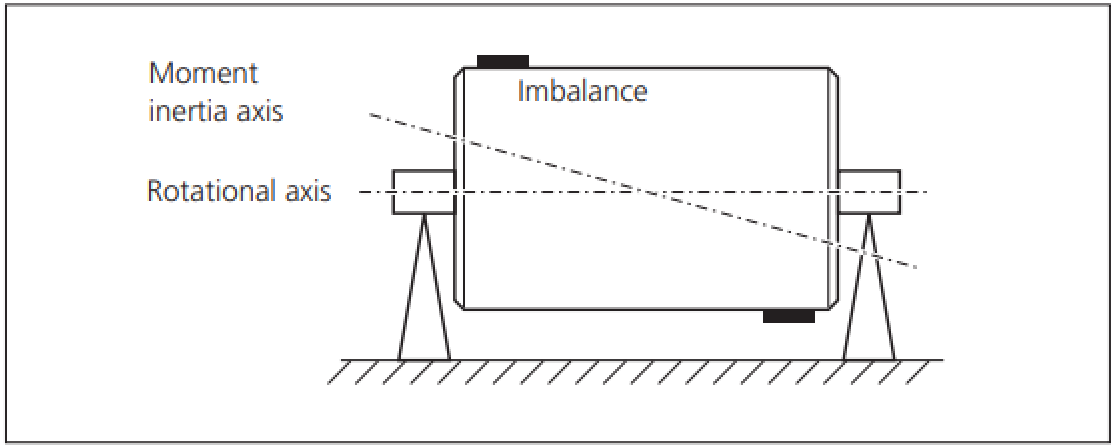
Shaft misalignment

"We electricians would replace the motor bearings and mechanics would replace the pump bearings and seals, and we'd slap it all back together. In a few months we would do it all over again. Then we learned to perform precision balance and alignments, and the bearings would last for years and years."
Maintenance Supervisor from US Navy

FLUKE Reliability

Balancing Principles

Balancing on shafts with rotating masses



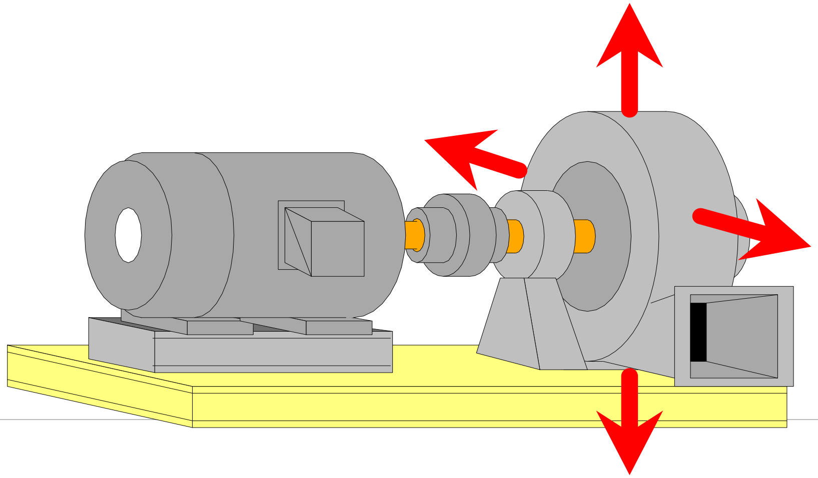
If a rotor is correctly balanced and this rotor is placed on balancing rollers, any additional mass placed on the rotor will cause this mass to immediately move downwards.

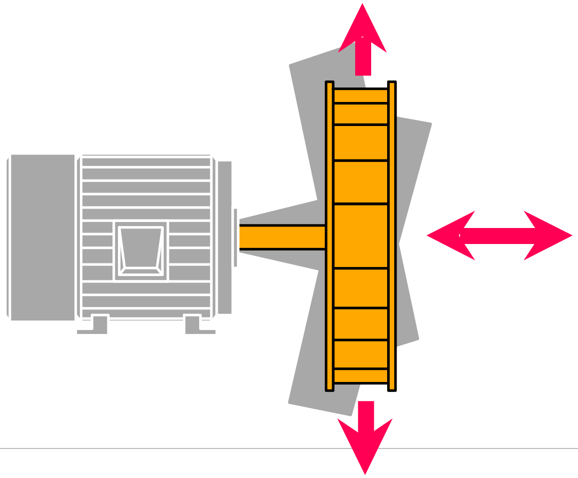
If this rotor is now turned with the balancing RPM, a centrifugal force is caused perpendicular to the rotational axis by the displacement of the center of gravity.

If two equally heavy masses are attached to a completely balanced rotor so that they lie exactly opposite in two separately lying radial planes, this is called a couple imbalance (or a dynamic imbalance).

The center of gravity of the rotor remains on the rotational axis.

The imbalances cause a centrifugal torque that gives rise to opposing forces of the same size in the bearings.





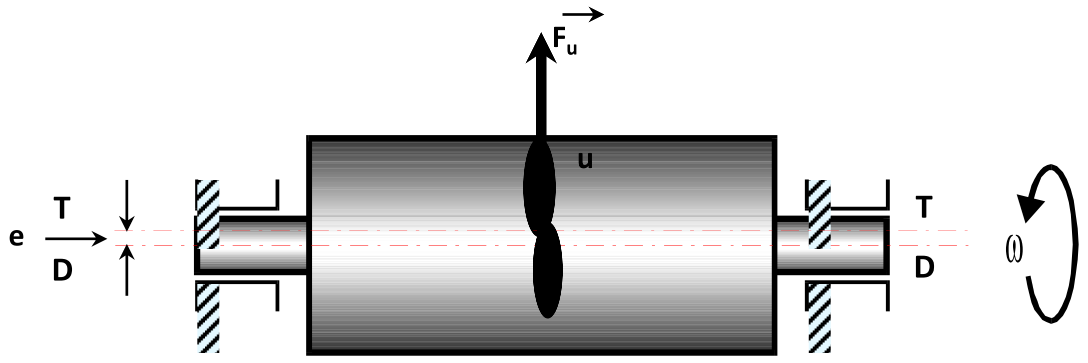
Static vs Couple imbalance

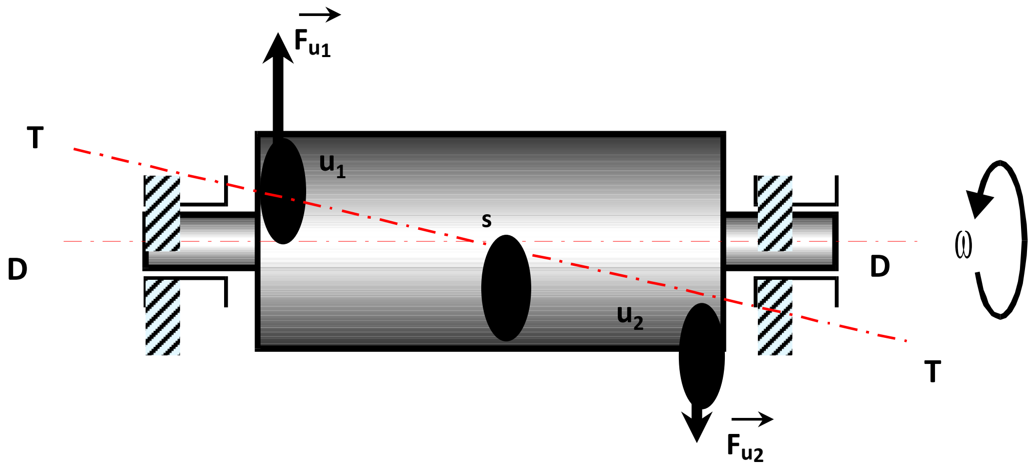
Static imbalance

Causes steady vibrations in a single plane

Couple imbalance

Generates cyclic vibrations in two perpendicular planes due to the equal and opposite masses





D-D.... Shaft axis
T-T.... Main axis of inertia
u.... Imbalance mass
s... Center of gravity
e... Center of gravity offset

D-D.... Shaft axis
T-T.... Main axis of inertia
u.... Imbalance mass
s... Center of gravity

$u_1 = u_2$

Both static and couple imbalance problems can be detrimental to the health and performance of rotating machinery, requiring proper balancing procedures to rectify the issues

Causes of imbalance

Construction and design errors

- e.g., asymmetric construction, fit tolerance too large, uneven mass distribution in electric motor rotor bars or windings

Material faults

- e.g., cavities, blowholes, material fatigue, uneven erosion and corrosion, cracks and fractures

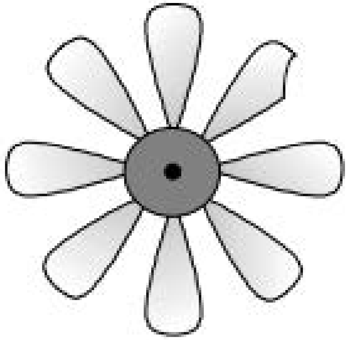
Production and mounting errors

- Bearing seats not machined with the same setup (eccentric), unmachined external contour, parts not centered, mounting of unbalanced individual parts

Operation related issues

- e.g., Contamination, wear and tear, poor maintenance practices, excessive corrosion, material deposits, missing balance weights

Example of caking on fan impeller



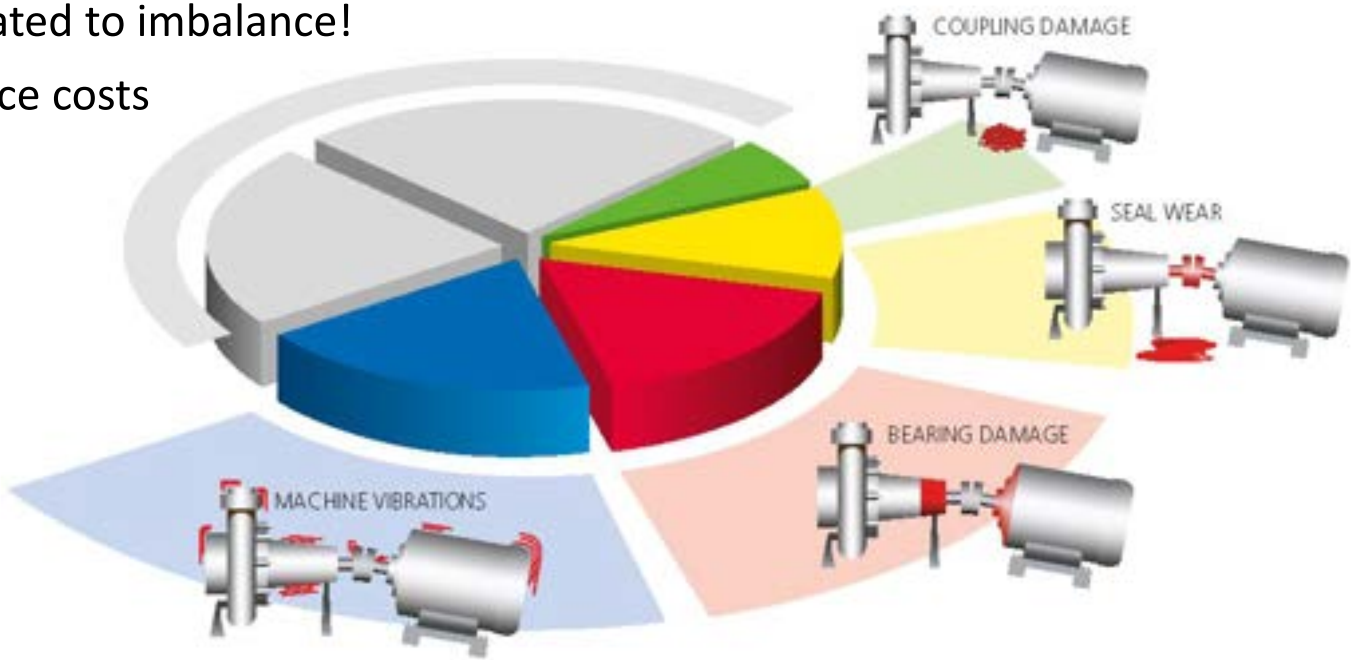
Why is shaft balancing needed?

Get more out of your rotating machines through proper balance:

- ✓ A balanced shaft reduces bearing and coupling wear, and vibration of machinery, which in turn leads to improved machine performance.
- ✓ You could be losing thousands of dollars per year in replacement bearings and hours of unnecessary repair time
- ✓ Today's maintenance departments can't afford crippling unplanned downtime and wasted energy
- ✓ See the benefits of precision balancing on most of your machines not just a few of the most critical

Benefits: Cost savings:

- Up to 50% of damage to rotating machinery is directly related to imbalance!
- Well balanced machines reduce operating and maintenance costs
- Reduced bearing and mechanical seal repairs



Benefits: Why precision balance is so crucial:

- Decreased power consumption
- Longer machine lifecycle
- Less vibration leading to less wear (other faults)
- Lower temperatures on bearing, coupling and lubrication
- Reduced costs for storing spare parts

Field balancing customer pain points

Machine vibration levels

- Reducing machine vibration levels

Machine failure

Identifying the cause of machine failure and if they are related to unbalance

Skill and experience requirements

Lack of experience can lead to improper balancing and further exacerbate the issues

Time constraints

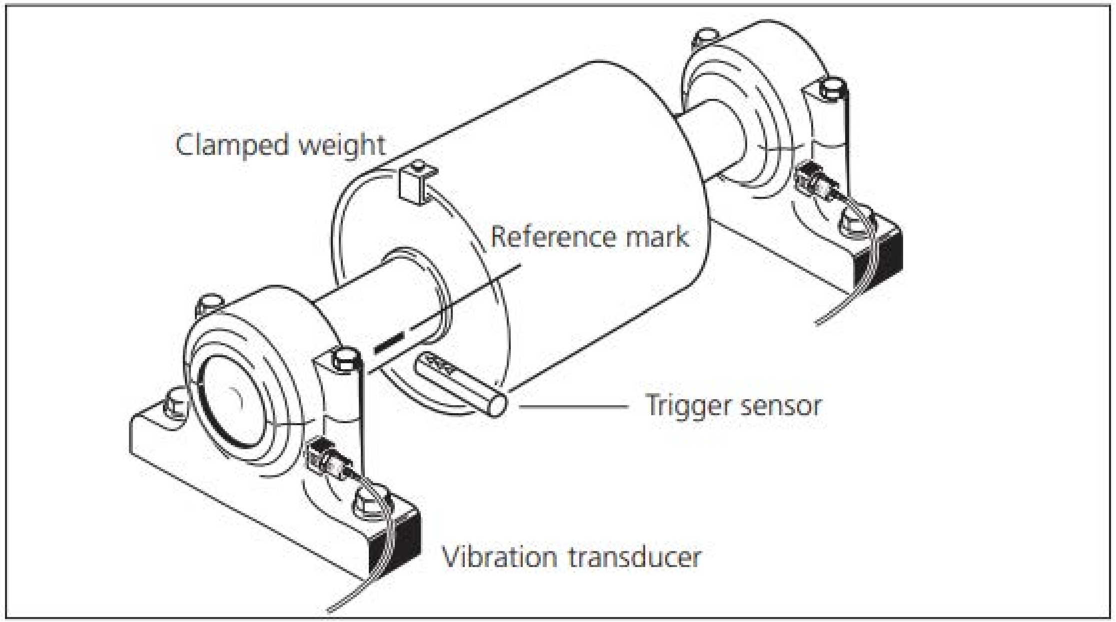
Field balancing often needs to be performed quickly to minimize downtime

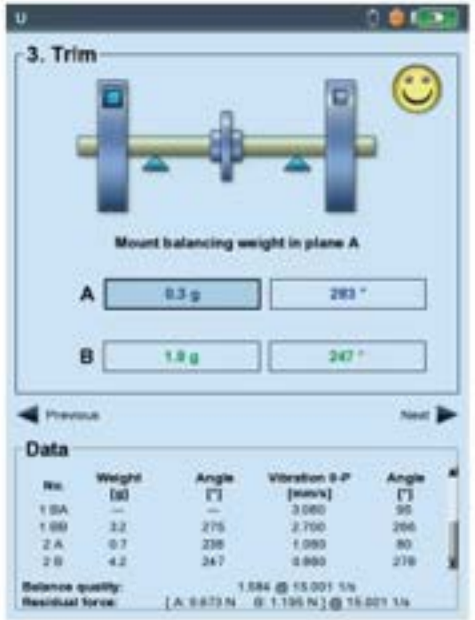
Environmental conditions

Impact on accuracy of measurements and the safety of technicians

Other pain points include equipment complexity and limited or inadequate documentation on rotating equipment

Balancing on shafts with rotating masses





The balancing module is based on the well-known 'influence coefficients method':

First, the tool measures the vibration amplitude and phase angle and the vibration caused by the imbalance or so-called 'initial imbalance'.

A defined trial weight* is then attached and the instrument measures the resulting change in amplitude and phase.

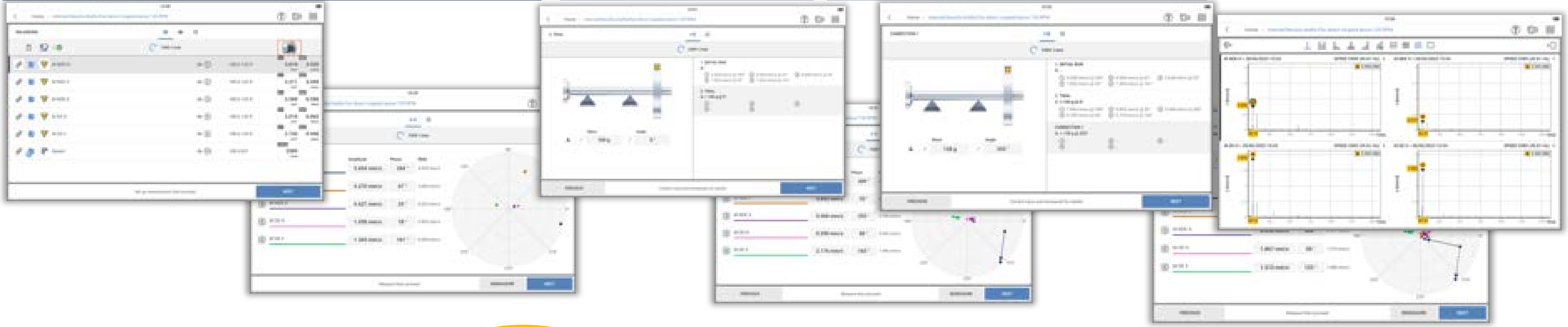
The program calculates the influence coefficients from the difference between both vibrations according to magnitude and phase which precisely indicates the location and magnitude of the balancing weight about the position and size of the trial weight.

In the case of two-plane balancing, the calculation of the influence of the mass is also considered in the other plane.

All 'rigid' rotors are balanced using this method.

Simple steps to balance your machines

Initial run | Trial run | Correction run | Verification



Steps

1.Initial run
- Select points and connect sensors
- **Start balancing procedure and take initial run**

2.Trial run
- Add trial mass and enter in system
- Measure trial mass influences and check the vectors

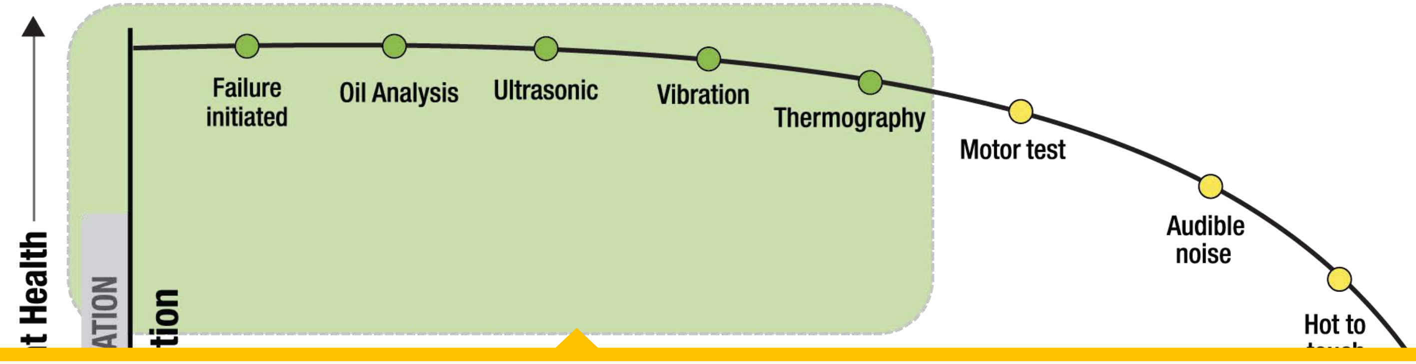
3.Correction run
- Add correction mass (calculated by program) and enter value
- Measure the correction and check improvements

4.Verification
- Verify the improvements

Simplified balancing process, leading to faster workflows whilst minimizing the potential for user errors

Steps to Connected Reliability

Connected Reliability



***Install** with precision → then **operate** at the top-left of the P-F Curve*

Install	Acquire	Enrich	Act
Setup	Connected Data	Connected Systems	Connected Teams

Connected Knowledge Services

FLUKE Reliability

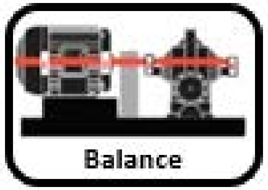
Precision Alignment & Balance: Peak Performance from Day 1

Install

Acquire

Enrich

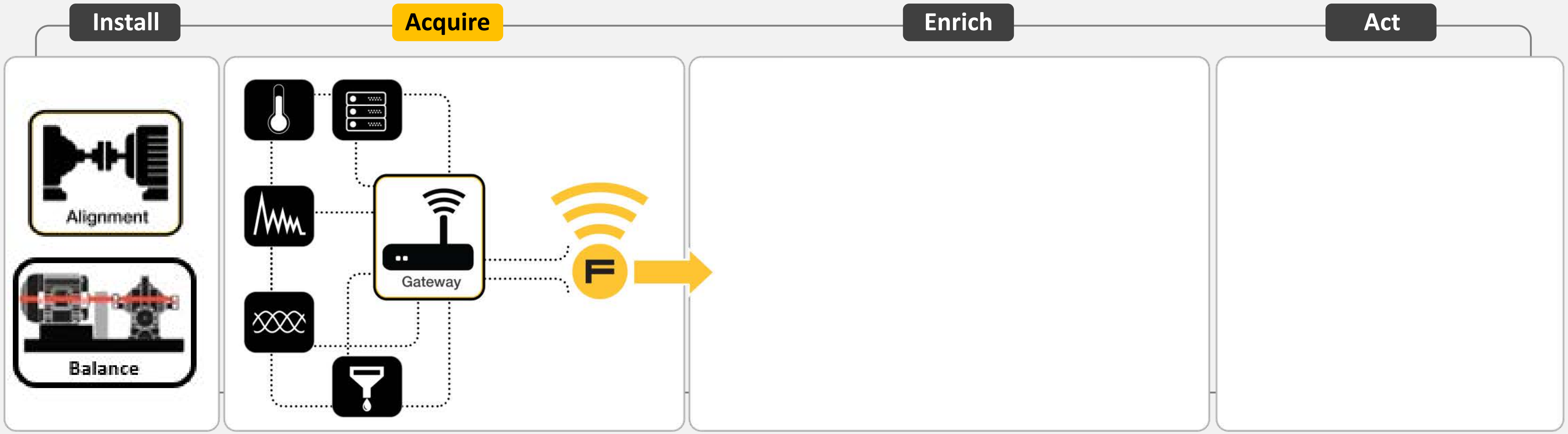
Act



Laser Shaft Alignment | Intrinsically Safe | Shaft Balance | Geometrical Alignment | Pulley Alignment

FLUKE Reliability

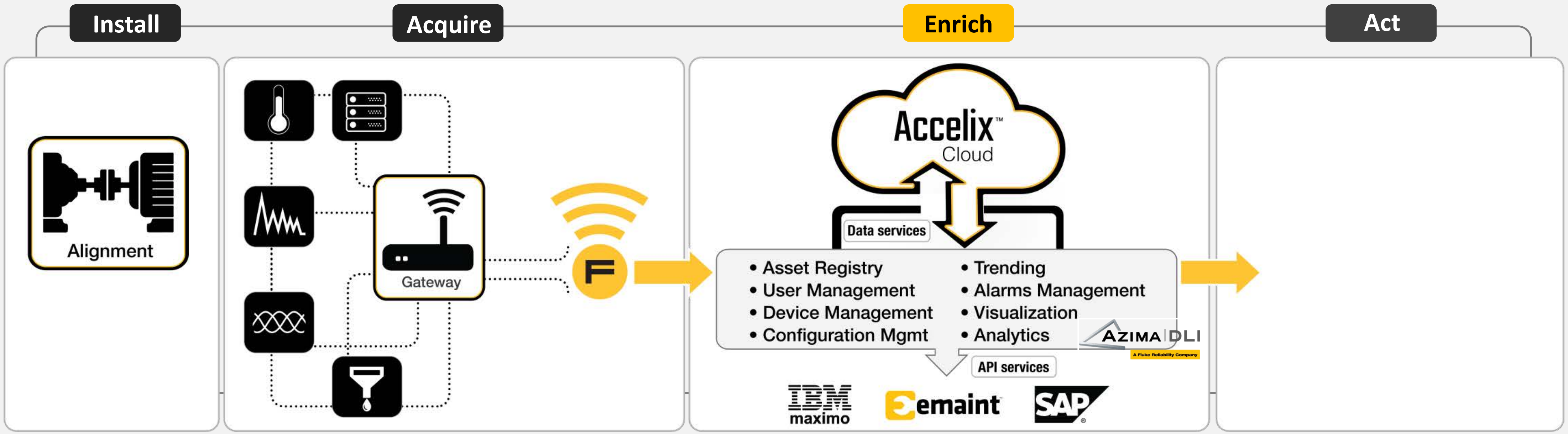
Connected Data



Handheld Tools | **Wired Sensors** | **Wireless Sensors** | **Automation & Controls**

- Route- and sensor-based tools
- Simple to complex measurement
- Multiple P-F Curve modalities (vibration, ultrasound, oil analysis, etc.)

Connected Systems



Data and API services provided by the Accelix Data Platform

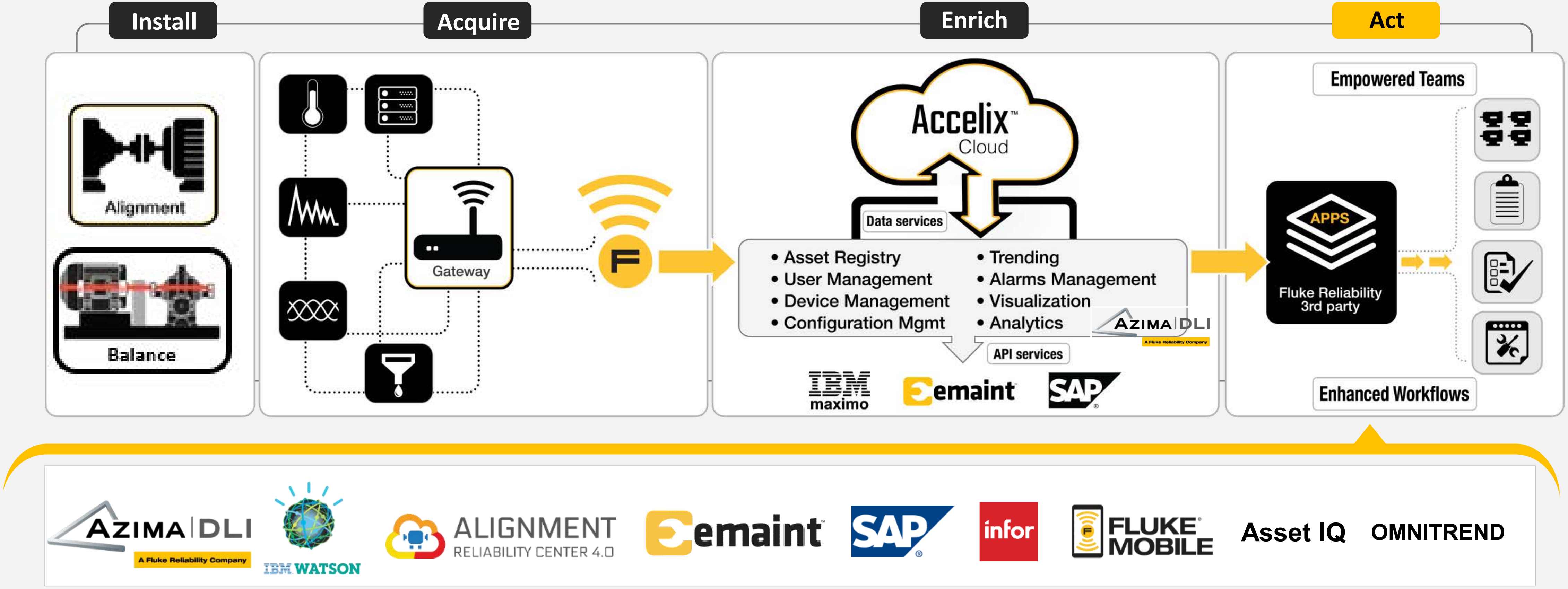
Aggregated data supports long-term trend analysis and machine learning

Enriched condition data via integration with CMMS/EAM systems

Result:

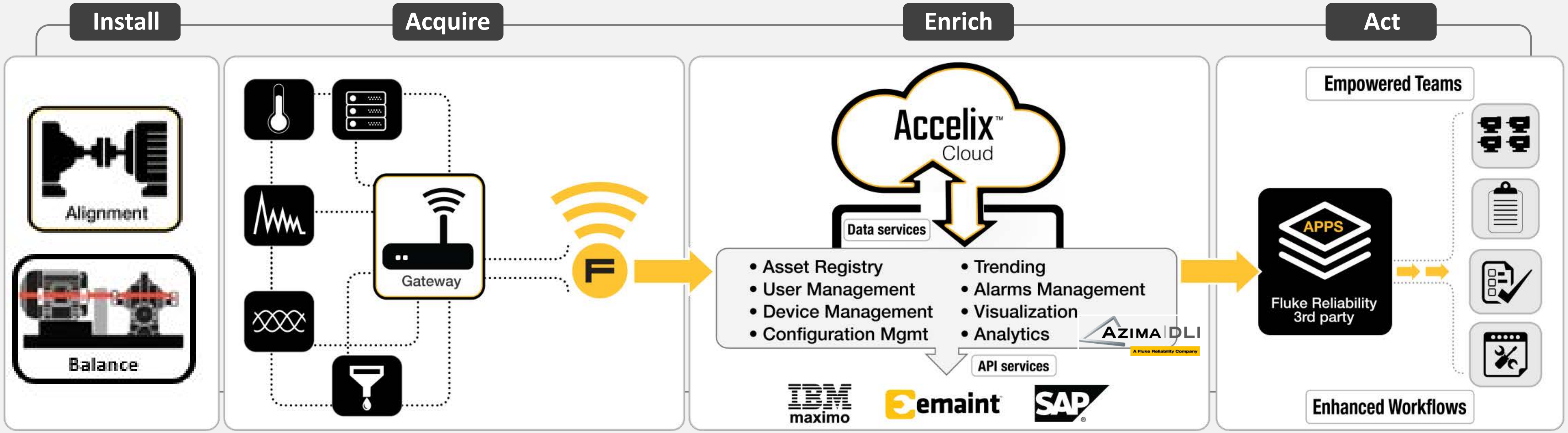
- A more complete picture of asset history and current health
- A solid basis for decision support and maintenance actions

Connected Teams



Reliability-centered maintenance actions | Mobile workforce enablement | Enhanced workflows

Connected Knowledge



Connected Knowledge Services

Active Assistance

- Onsite Machinery Services
- PARALIGN
- TELEDIAGNOSIS
- Remote Condition Monitoring

On-Demand Expertise

- ISO CAT Training
- Online & In-Person Courses
- Reliability Program Consulting
- Customer Success Team

FLUKE Reliability

Summary

All maintenance teams struggle with business challenges and lack of resources

Condition monitoring using vibration analysis helps teams diagnose root cause faults, then use corrective tools like balancing to quickly correct and return to service

Precision balancing and alignment are the first steps towards a Connected Reliability solution at your facility.

Fluke Reliability: One mission, one shared purpose

We simplify connected reliability solutions for the people who keep the world up and running

emaint AZIMA DLI PRÜFTECHNIK

FLUKE Reliability

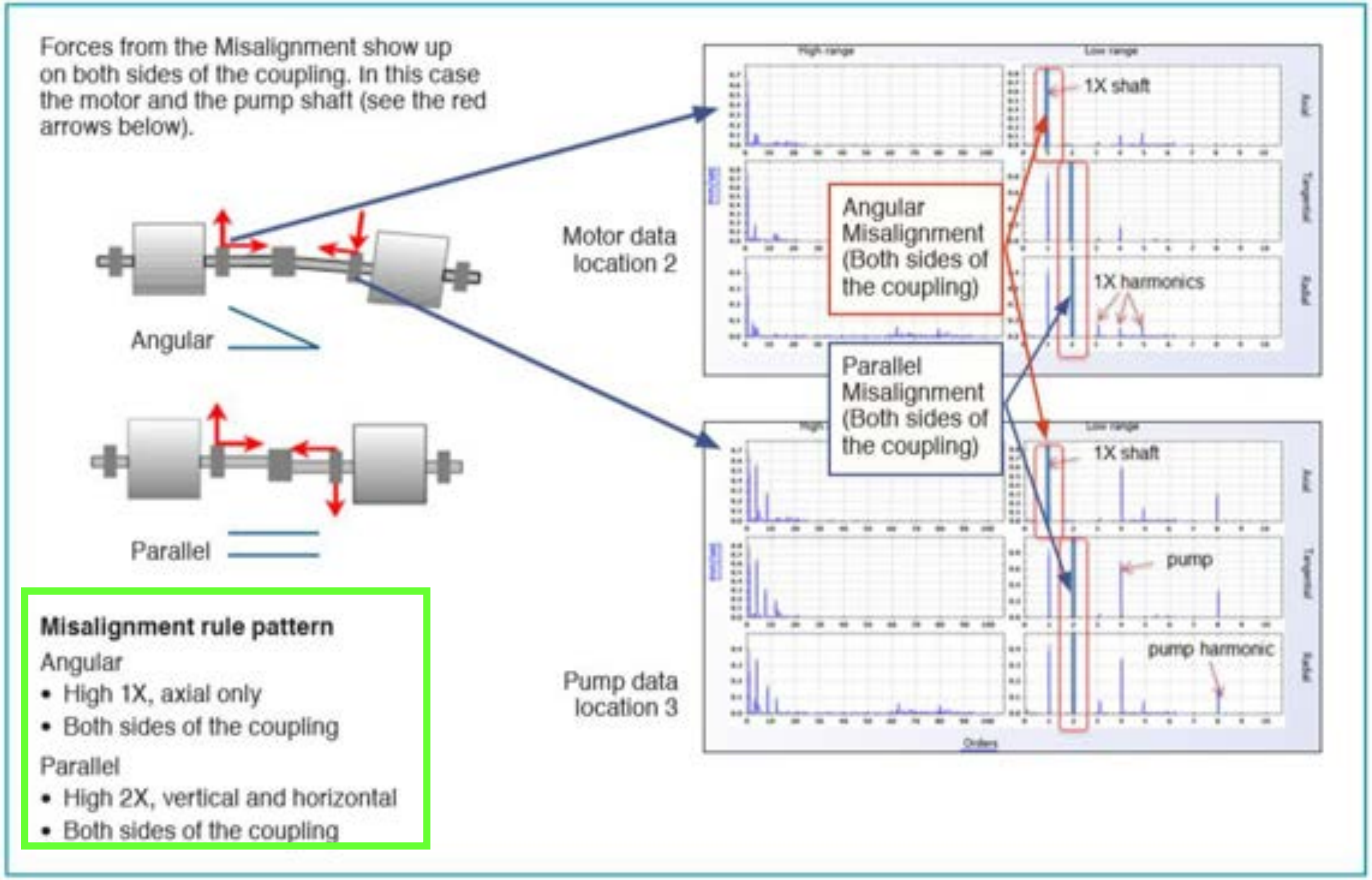
FLUKE Reliability

THANK YOU!

Misalignment

The axes of rotation of two shafts are not collinear when the machine is running under normal operating conditions which causes forces that lead to excessive vibration and increases the wear of bearings, seals, etc.

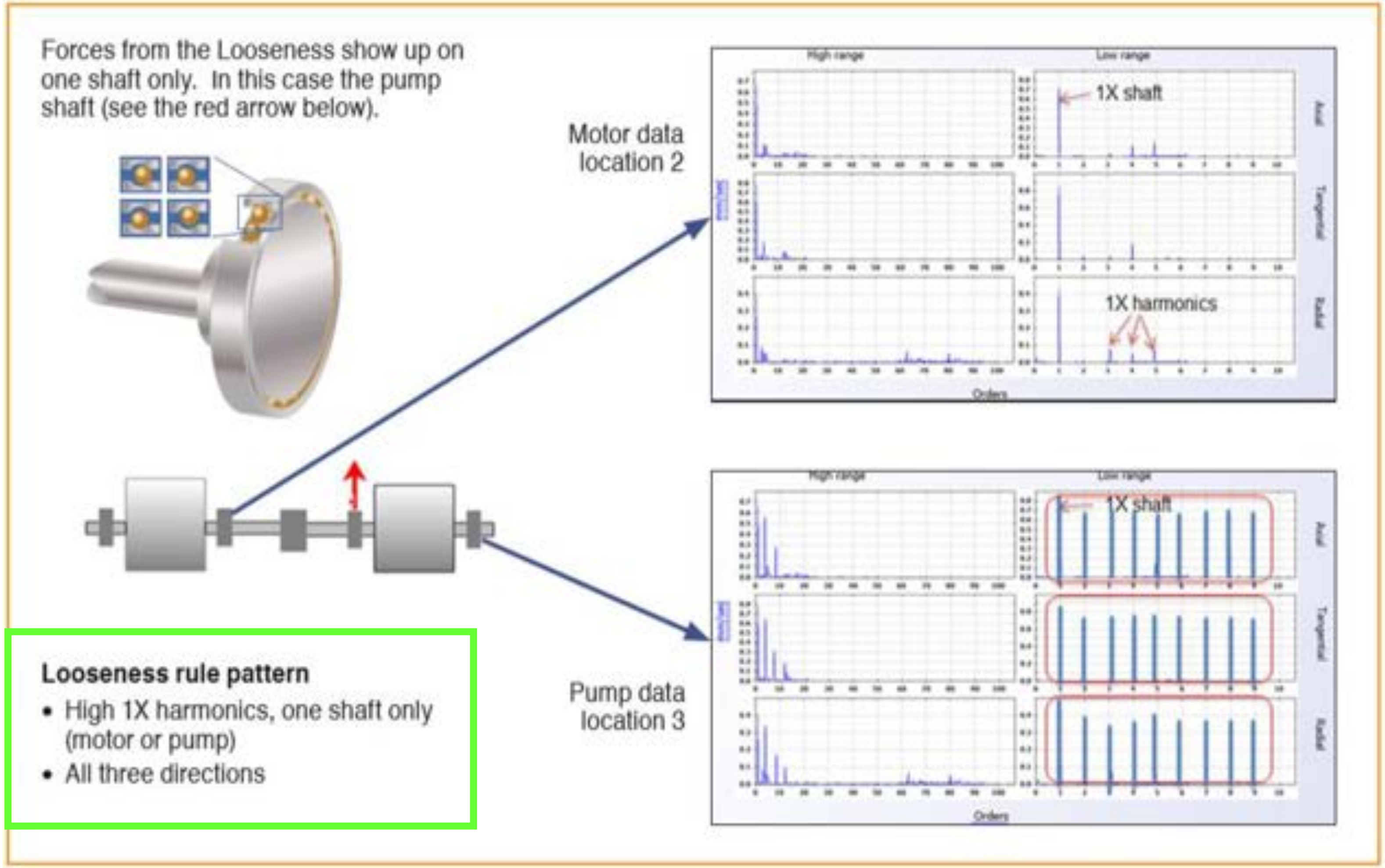
	Machine fault	Frequency and Axis	Component found	Advanced Severity
1	Imbalance	1X - All radial directions	On affected component	Higher amplitude 1X
2	Misalignment			
	Parallel	2X - Radial and tangential	Both sides of coupling	Higher amplitude 2X
	Angular	1X - Axial	Both sides of coupling	Higher amplitude 1X
3	Looseness	1X harmonics—all directions	On affected component	Higher harmonics
4	Roller bearings	Non integer—all directions	On affected component	Harmonic, sidebands, noise hump, noise floor



Looseness

The shaft, foundation, or a component has become loose which causes forces that lead to excessive vibration and increases the wear of bearings, seals, etc.

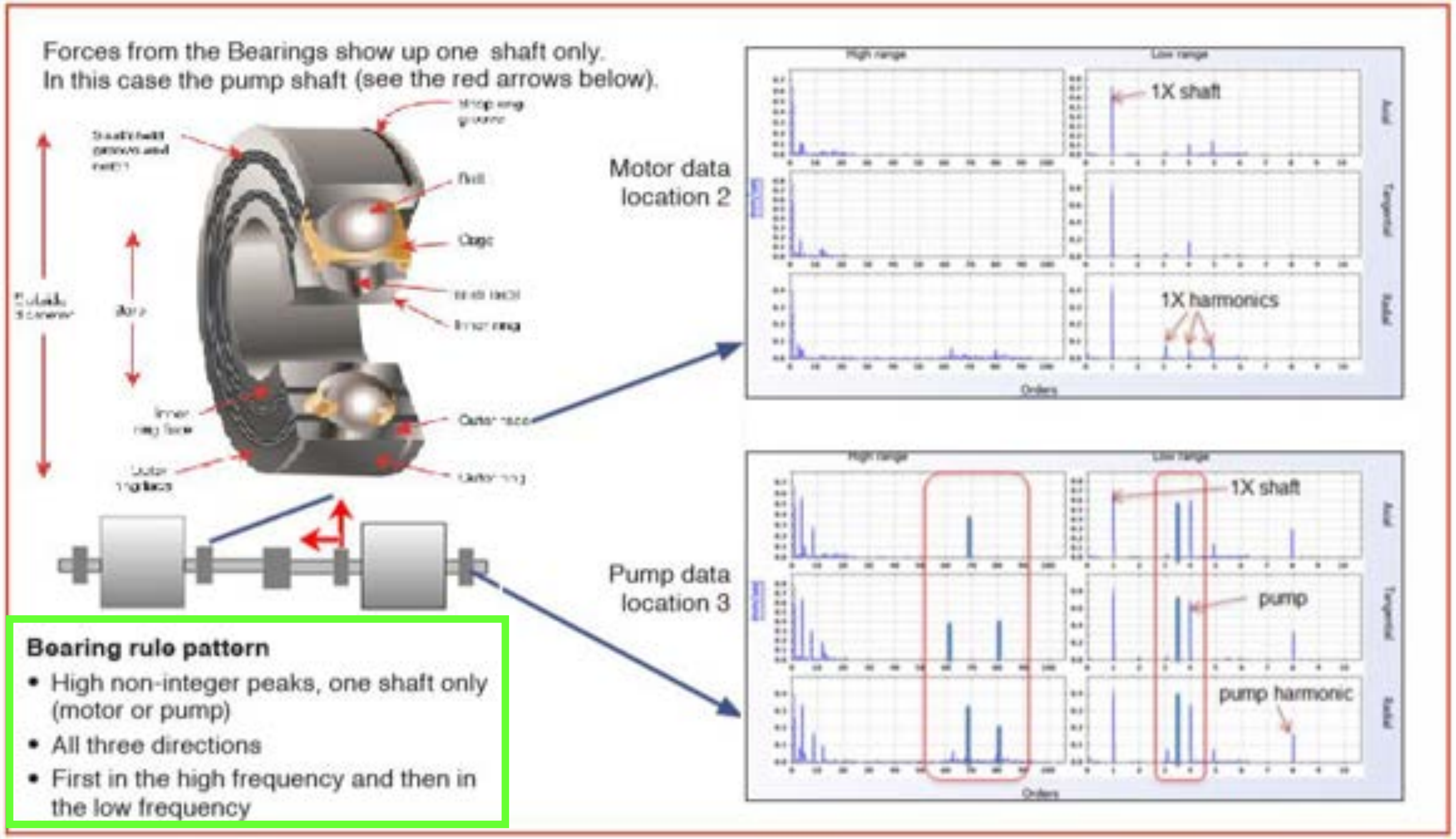
	Machine fault	Frequency and Axis	Component found	Advanced Severity
1	Imbalance	1X - All radial directions	On affected component	Higher amplitude 1X
2	Misalignment			
	Parallel	2X - Radial and tangential	Both sides of coupling	Higher amplitude 2X
	Angular	1X - Axial	Both sides of coupling	Higher amplitude 1X
3	Looseness	1X harmonics—all directions	On affected component	Higher harmonics
4	Roller bearings	Non integer—all directions	On affected component	Harmonic, sidebands, noise hump, noise floor



Bearing failure

Bearings will wear from excessive loads, other machine faults, poor lubrication or installation, etc. If not corrected, the bearings will eventually fail.

	Machine fault	Frequency and Axis	Component found	Advanced Severity
1	Imbalance	1X - All radial directions	On affected component	Higher amplitude 1X
2	Misalignment			
	Parallel	2X - Radial and tangential	Both sides of coupling	Higher amplitude 2X
	Angular	1X - Axial	Both sides of coupling	Higher amplitude 1X
3	Looseness	1X harmonics—all directions	On affected component	Higher harmonics
4	Roller bearings	Non integer—all directions	On affected component	Harmonic, sidebands, noise hump, noise floor



FLUKE Reliability