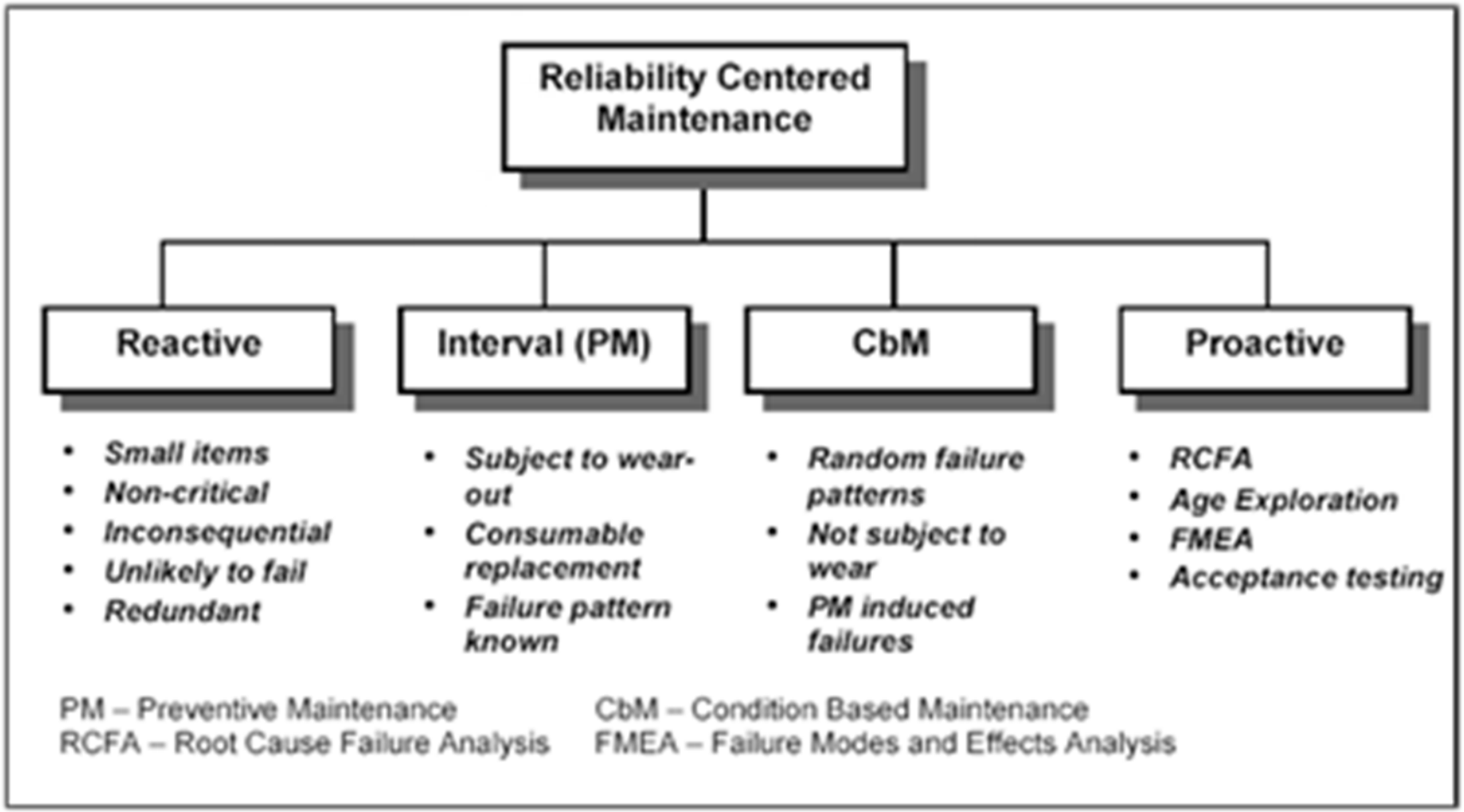
HIGH COST OF UNRELIABILITY

Proceedings of the Twenty First World Dredging Conference (WODCON XXI)

Purpose

- Highlight Reliability Centered Maintenance (RCM)
- What programs are most common?
- What is technically and economically feasible for your company?

Maintenance



Predictive Maintenance Program Key Actions

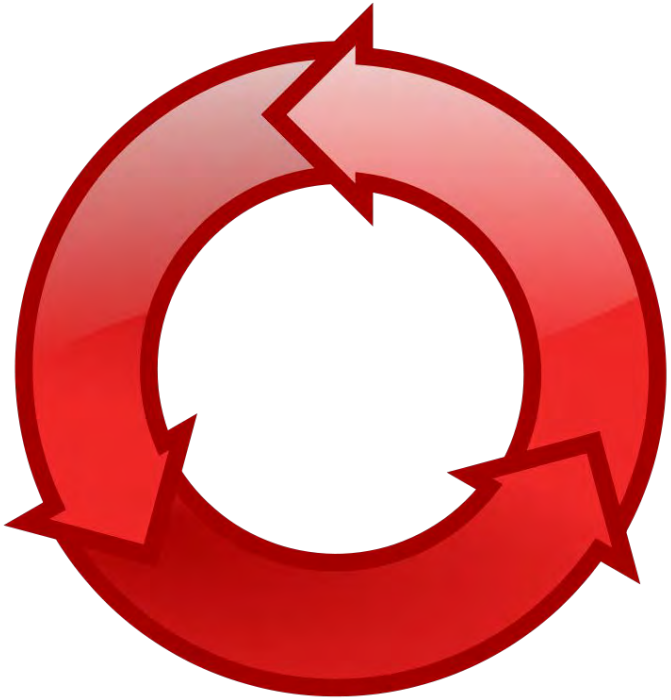
- *DETECTION*
- *ANALYSIS*
- *CORRECTION*
- *VERIFICATION*

Reactive

Merriam Webster dictionary defines reactive as *"done in response to a problem or situation: reacting to problems when they occur instead of doing something to prevent them".*

Reactive-Negatives

- Preventable failures occur
- Budget control issues
- Inefficient use of resources
- Safety
- Reputation



Interval (Preventative Maintenance)

- Goal here is to avoid failure or reduce the consequences of failure altogether
- Centers on components that wear, like pump wet-end components, pipeline and cutter parts
- Consumables such as oil and filters.
- Understanding actual wear life and adhering to recommended equipment manufacturer lubrication intervals.

Interval

- Equipment maintenance and repair logs must be maintained and USED

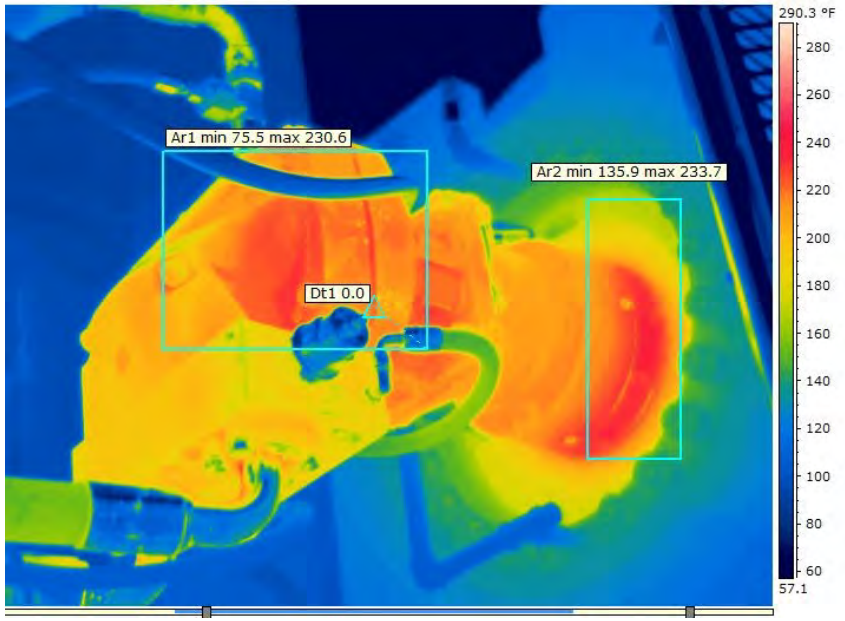
Condition Based Maintenance (CBm)

- This level of maintenance includes the addition of the condition based approach using CBm technolgies.

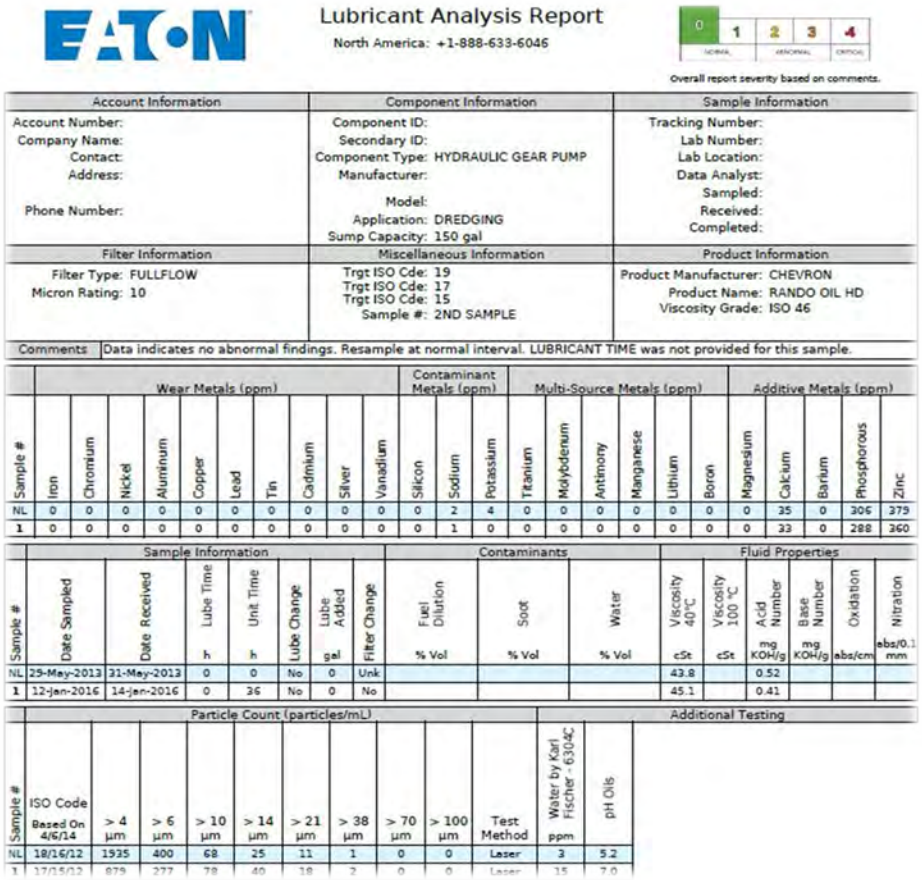
- The condition based approach generally centers on components that are not subject to wear

CBm Technologies

- Lubrication Analysis
- Vibration Analysis
- Thermography



Lubrication Analysis



EATON

Lubricant Analysis Report

North America: +1-888-633-6046

0 1 2 3 4

Overall report severity based on comments.

Account Information		Component Information		Sample Information	
Account Number:		Component ID:		Tracking Number:	
Company Name:		Secondary ID:		Lab Number:	
Contact:		Component Type:	HYDRAULIC GEAR PUMP	Lab Location:	
Address:		Manufacturer:		Data Analyst:	
Phone Number:		Model:		Sampled:	
		Application:	DREDGING	Received:	
		Sump Capacity:	150 gal	Completed:	
Filter Information		**Miscellaneous Information**		**Product Information**	
Filter Type:	FULLFLOW	Trgt ISO Cde:	19	Product Manufacturer:	CHEVRON
Micron Rating:	10	Trgt ISO Cde:	17	Product Name:	RANDO OIL HD
		Trgt ISO Cde:	15	Viscosity Grade:	ISO 46
		Sample #:	2ND SAMPLE		

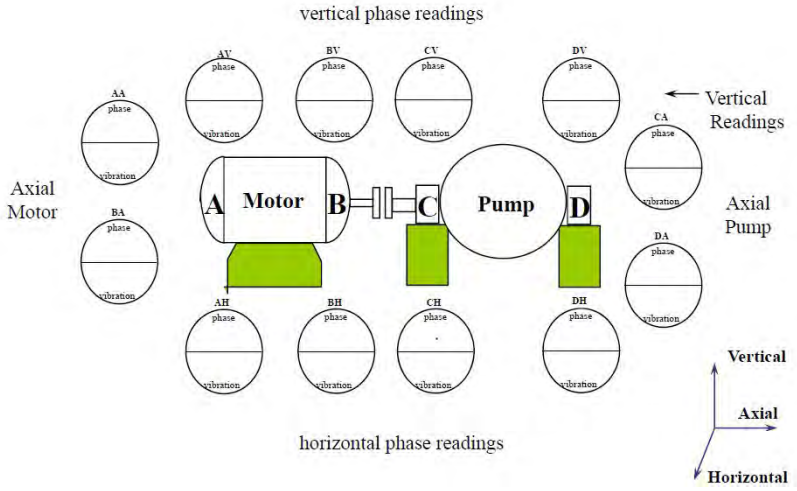
Comments: Data indicates no abnormal findings. Resample at normal interval. LUBRICANT TIME was not provided for this sample.

	Wear Metals (ppm)										Contaminant Metals (ppm)			Multi-Source Metals (ppm)				Additive Metals (ppm)					
Sample #	Iron	Chromium	Nickel	Aluminum	Copper	Lead	Tin	Cadmium	Silver	Vanadium	Silicon	Sodium	Potassium	Titanium	Molybdenum	Antimony	Manganese	Lithium	Boron	Magnesium	Calcium	Barium	Phosphorous	Zinc
NL	0	0	0	0	0	0	0	0	0	0	0	2	4	0	0	0	0	0	0	0	35	0	306	379
1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	33	0	288	360

	Sample Information						Contaminants			Fluid Properties					
Sample #	Date Sampled	Date Received	Lube Time	Unit Time	Lube Change	Lube Added	Filter Change	Fuel Dilution	Soot	Water	Viscosity 40°C	Viscosity 100 °C	Acid Number	Base Number	Oxidation	Nitration
			h	h		gal		% Vol	% Vol	% Vol	cSt	cSt	mg KOH/g	mg KOH/g	abs/cm	abs/0.1 mm
NL	29-May-2013	31-May-2013	0	0	No	0	Unk				43.8		0.52			
1	12-Jan-2016	14-Jan-2016	0	36	No	0	No				45.1		0.41			

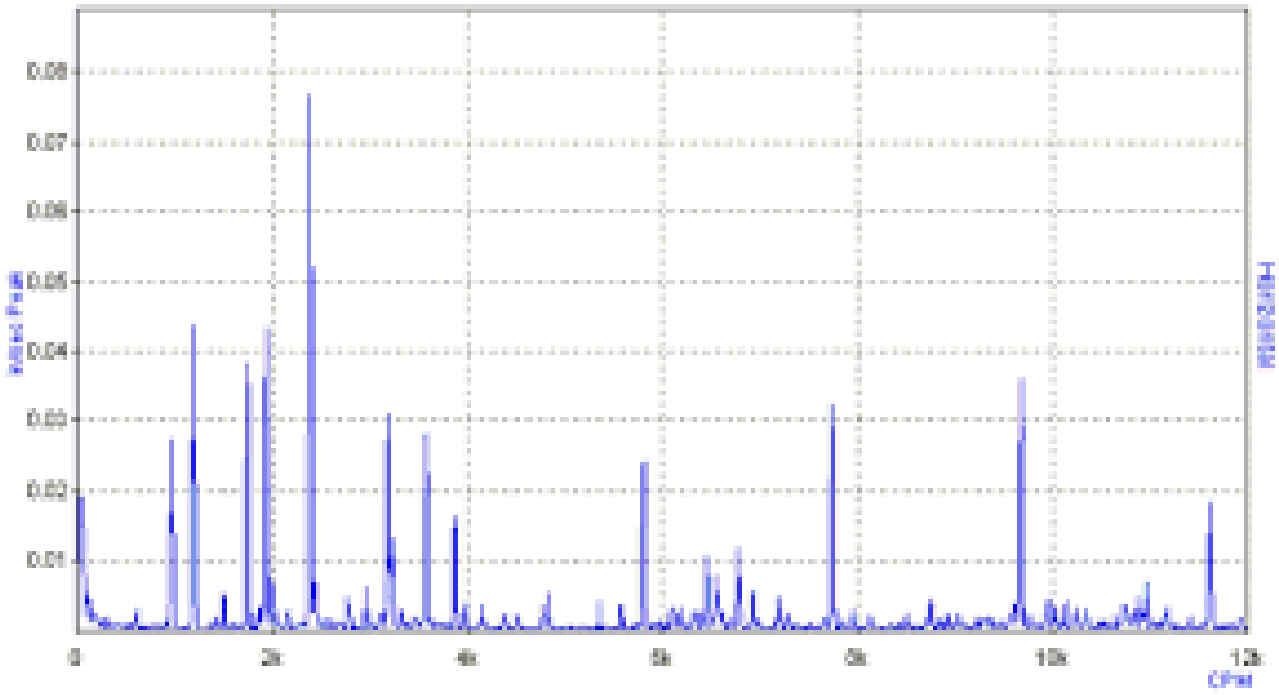
	Particle Count (particles/mL)										Additional Testing	
Sample #	ISO Code Based On 4/6/14	> 4 µm	> 6 µm	> 10 µm	> 14 µm	> 21 µm	> 38 µm	> 70 µm	> 100 µm	Test Method	Water by Karl Fischer - 6304C	pH Oils
											ppm	
NL	18/16/12	1935	400	68	25	11	1	0	0	Laser	3	5.2
1	17/15/12	879	277	78	40	18	2	0	0	Laser	15	7.0

Vibration Analysis-Typical Data Collector Output



MEASUREMENT POINT		ANALYSIS PARAMETER	PARAMETER VALUE		ALARM/FAULT LEVELS		ALARM CODE-SEV	DAYS TO ALARM
M1H	---	OVERALL VALUE	.183	In/Sec	.163	.200	C - 21	???
		2xRPM	.179	In/Sec	.130	.160	D - 42	0
		Crest Factor	3.304		2.000	4.000	C - 26	???
M1V	---	Crest Factor	3.120		2.000	4.000	C - 22	???
M2H	---	Crest Factor	3.075		2.000	4.000	C - 22	???
M2V	---	Crest Factor	2.932		2.000	4.000	C - 19	???
M2A	---	Crest Factor	3.751		2.000	4.000	C - 35	???
P1H	---	OVERALL VALUE	.205	In/Sec	.163	.200	D - 41	0
		2xRPM	.201	In/Sec	.130	.160	D - 43	0
		Crest Factor	2.975		2.000	4.000	C - 20	???
P1V	---	OVERALL VALUE	.185	In/Sec	.163	.200	C - 24	???
		2xRPM	.176	In/Sec	.130	.160	D - 42	0
		35.5-100 x RPM	.048	In/Sec	.033	.040	D - 43	0
		Crest Factor	3.125		2.000	4.000	C - 22	???
P1A	---	OVERALL VALUE	.169	In/Sec	.163	.200	C - 6	???
		35.5-100 x RPM	.160	In/Sec	.033	.040	D - 70	0
		WAVEFORM P-P	9.763	G-s	8.000	12.00	C - 18	???

Vibration Spectrum Analysis



Various Equipment Alarms

Overall Vibration Alarms and Machine Condition Rating Chart (PEAK OVERALL VELOCITY, IN/SEC)*

1. Assuming Machine Speed = 600 to 60,000 RPM.
2. Assuming Measurements by Accelerometer or Velocity Pickup securely mounted as Close as Possible to Bearing Housing.
3. Assuming Machine Is Not Mounted on Vibration Isolators (for Isolated Machinery - Set Alarm 30% - 50% Higher).
4. Set Motor Alarms the Same as that for the Particular Machine Type unless Otherwise Noted.
5. Consider Setting Alarms on Individual External Gearbox Positions about 25% Higher than that for a particular Machine Type.

MACHINE TYPE	GOOD	FAIR	ALARM 1	ALARM 2
COOLING TOWER DRIVES				
Long, Hollow Drive Shaft	0 - .375	.375 - .600	**.600**	.900
Close Coupled Belt Drive	0 - .275	.275 - .425	**.425**	.650
Close Coupled Direct Drive	0 - .200	.200 - .300	**.300**	.450
COMPRESSORS				
Reciprocating	0 - .325	.325 - .500	**.500**	.750
Rotary Screw	0 - .300	.300 - .450	**.450**	.650
Centrifugal With or W/O External Gearbox	0 - .200	.200 - .300	**.300**	.450
Centrifugal - Integral Gear (Axial Meas.)	0 - .200	.200 - .300	**.300**	.450
Centrifugal - Integral Gear (Radial Meas.)	0 - .150	.150 - .250	**.250**	.375
BLOWERS (FANS)				
Lobe-Type Rotary	0 - .300	.300 - .450	**.450**	.675
Belt-Driven Blowers	0 - .275	.275 - .425	**.425**	.650
General Direct Drive Fans (with Coupling)	0 - .250	.250 - .375	**.375**	.550
Primary Air Fans	0 - .250	.250 - .375	**.375**	.550
Vacuum Blowers	0 - .200	.200 - .300	**.300**	.450
Large Forced Draft Fans	0 - .200	.200 - .300	**.300**	.450
Large Induced Draft Fans	0 - .175	.175 - .275	**.275**	.400
Shaft-Mounted Integral Fan (Extended Motor Shaft)	0 - .175	.175 - .275	**.275**	.400
Vane-Axial Fans	0 - .150	.150 - .250	**.250**	.375
MOTOR/GENERATOR SETS				
Belt-Driven	0 - .275	.275 - .425	**.425**	.675
Direct Coupled	0 - .200	.200 - .300	**.300**	.450
CHILLERS				
Reciprocating	0 - .250	.250 - .400	**.400**	.600
Centrifugal (Open-Air) - Motor & Compressor Separate	0 - .200	.200 - .300	**.300**	.450
Centrifugal (Hermetic) - Motor & Impellers Inside	0 - .150	.150 - .225	**.225**	.350
LARGE TURBINE/GENERATORS				
3600 RPM Turbine/Generators	0 - .175	.175 - .275	**.275**	.400
1800 RPM Turbine/Generators	0 - .150	.150 - .225	**.225**	.350
CENTRIFUGAL PUMPS				
Vertical Pumps (12' - 20' Height) [Height from Grade to Top Motor Bearing, May be Necessary to Spec. Lower Alarm for Lower Motor Bearing & for Upper Pump Bearing (depending on height)]	0 - .325	.325 - .500	**.500**	.750
Vertical Pumps (8' - 12' Height)	0 - .275	.275 - .425	**.425**	.650
Vertical Pumps (5' - 8' Height)	0 - .225	.225 - .350	**.350**	.525
Vertical Pumps (0' - 5' Height)	0 - .200	.200 - .300	**.300**	.450
General Purpose Horizontal Pump - Direct Coupled	0 - .200	.200 - .300	**.300**	.450
Boiler Feed Pumps - Horizontal Orientation	0 - .200	.200 - .300	**.300**	.450
Piston Type Hydraulic Pumps - Horizontal Orientation (under load)	0 - .150	.150 - .250	**.250**	.375
MACHINE TOOLS				
Motor	0 - .100	.100 - .175	**.175**	.250
Gearbox Input	0 - .150	.150 - .225	**.225**	.350
Gearbox Output	0 - .090	.090 - .150	**.150**	.225
Spindles:				
a. Roughing Operations	0 - .065	.065 - .100	**.100**	.150
b. Machine Finishing	0 - .040	.040 - .060	**.060**	.090
c. Critical Finishing	0 - .025	.025 - .040	**.040**	.060

*NOTE: The "ALARM 1" and "ALARM 2" overall levels given above apply only to in-service machinery which has been operating for some time after initial installation and/or overhaul. They do not apply (and are not meant to serve as) Acceptance Criteria for either new or rebuilt machinery.

Condition Based Maintenance (CBm)

- Baseline data
- Trending

Proactive

- As components fail, Root Cause Failure Analysis (RCFA) that results in unrepeated failures
- Age exploration and evaluation- Was the design life exceeded?
- Failure modes and effects analysis are understood and remedial plans procedures and processes can be developed to mitigate their effects
- Future replacements can be specified at a level that ensures quality and functionality

Best Affordable Practice

What program makes economic sense for your company?

Does movement towards proactive result in increase availability, better fleet, increase morale and future growth?

Dredging Transient Events

- Upset conditions associated with transient events, such as reverse flow and pressure spikes, can damage equipment resulting in premature failure. These cases should be understood, documented and utilized as a training tool and safety topic.
- Transient events sometimes result in equipment failure and a Reactive response to elevating machine may be required

Dredges - Vibration

- Dredges are vibrating machines and further study of adequate alarm levels should be reviewed and addressed accordingly
- Cutters generate peaks at 5X-6X running speed depending on blade quantity
- Pumps generate pulses at 3X-5X running speed depending on number of vanes

Questions?