

SLOW ROLL RUN OUT PROBLEM OF ROTOR – GENUINE OR BENIGN

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Abstract The issue of Rotor “run-out” which causes high overall vibration (displacement) readings on rotor has always been a point of concern during spin test and site acceptance test of turbo-machines. Rotor run-out is sub-divided to TIR (total indicated run out) commonly known as Mechanical run out and electrical run out. While API (American Petroleum Institute) standards have mandated a certain limit of Slow roll run out, the proposed paper discusses to find which of contributing factors of high run-out should be considered as genuine or benign during machinery health assessment and monitoring as its main objective. Proposed paper differentiates rotor bow and slow roll run out, effect of run out during rotor balancing and points out the lacunae of understanding exists for point / stage of such measurement. A short case study is presented to explain the issue and delays caused for repeated repair works due to such misunderstanding. The paper discusses the feasibility and overall technical effectiveness of eddy current probe, capacitance probe and other devices used. The proposed paper suggests the use of various diagnostic tools such as band and envelope spectrums for creating pre-alarm set up, using shape identification algorithm in diagnostic system based on reference data captured by initial slow roll measurement with a detailed set up.

Keywords - Mechanical run out, electrical run out rotor bow and slow roll eddy current probe, capacitance probe, laser triangulation

Introduction Slow roll run out is a combination of electrical and mechanical run out measured as shaft dynamic motion by vibration sensor at slow speed where the dynamic effects associated with rotation are negligible. The measured vibration signal of a rotating shaft will contain the run out of the probe target track area so the actual shaft vibration (irrespective to its geometrical cross-sectional shape / profile) is always different than measured shaft displacement as microns / mils pk-pk. A high value of slow roll run out is not damaging to rotor although interferes with actual vibration readings.

Slow roll run out termed as the vectorial sum of mechanical run out (MRO) and electrical run out (ERO) and is measured for a full rotation with an electronic device such as eddy current proximity probe. The signal from an eddy current proximity probe is a function of the gap between the probe tip and the target material. However, it is also a function of the electrical conductivity and magnetic permeability of the target material. These metallurgical variations lead to variations in the electrical conductivity and magnetic permeability of the shaft, affecting the proximity probe signal which is known as

electrical run out. The electrical component of run out, in contrast, is not dimensional and instead represents metallurgical variations around the circumference of the shaft.

For a rotating shaft, a physical out-of-roundness result is a change in gap read by shaft displacement sensor. However, a perfectly round shaft with non-uniform electro-magnetic properties will also result in a change in probe output, even though the physical gap is uniform. In some cases two shafts may give identical probe outputs even though they have different physical shapes.

In practice, mechanical run out can be somewhat sinusoidal whereas electrical run out is characterized by a noisy waveform with numerous spikes. The combined run out shall have a waveform with numerous spikes riding on 1x and / or 2x waveform.

With Slow Roll run out, two possible extreme scenarios exist. If the slow-roll run out vector is additive to the vibration vector, then the proximity probe will report larger vibration amplitude than truly exists. This could lead to the situation where the machine goes into an alarm or trip condition prematurely. If, on the other hand, the slow-roll run out vector is subtractive to the vibration vector, then the proximity probe will report smaller vibration amplitude than truly exists. In this scenario, the true vibration may actually exceed an alarm or trip condition, but the monitoring system will not detect this due to the slow-roll vector making apparent vibration less than real vibration.

Scratches in the rotor surface viewed by the probe are another form of mechanical run out. Scratches(indentations) will produce negative-going voltage spikes on the transducer signals as instantaneous gap increases.

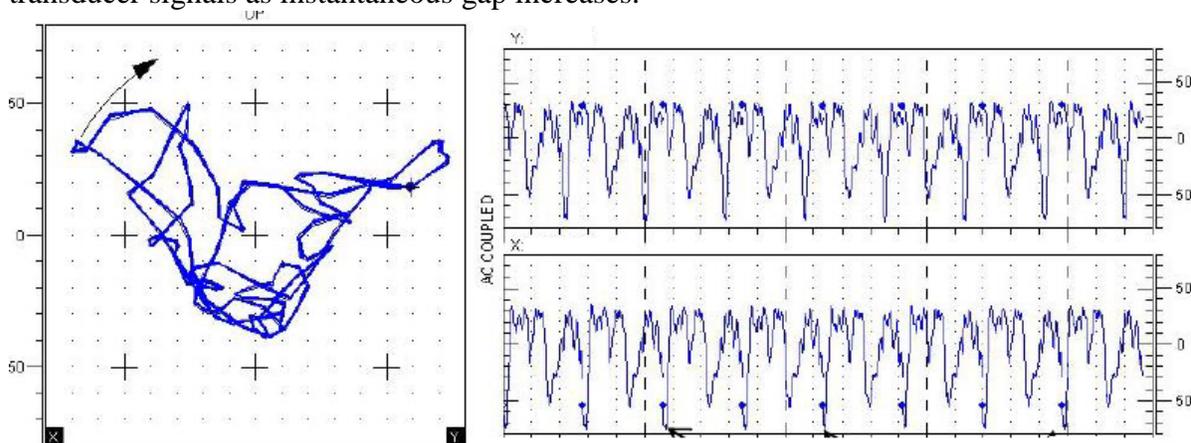


Fig -1 Unfiltered Orbit and slow speed time wave form of rotor with scratch

There are various sources of Mechanical Run out such as machining processes -

- If center-less grinding machines are used , then variations in shaft hardness can result in a non-circular geometry. This is known as Lobing of shaft.
- Improper feed rate, blunt tool and speed of cutting tools. Surface finish is strongly affected by cutting tool feeds and speeds and cause high mechanical run out.
- Defective or worn bearings on Lathe machine,

- Dents caused by mishandling and / or rust patches cause high mechanical run out.

Electrical run out in the probe track area is caused by:

- variations in conductivity and magnetic permeability of the steel
- sub surface defects in the steel
- variations in surface stress during heat-treating
- localized burnt areas due to grinding / residual stress concentration.
- generation of small magnetic fields such as those left by during MPI (magnetic particle inspection) without proper degaussing. As a rule of thumb, residual magnetism of 5 gauss can cause an electrical run out as much as 12.5 microns .

Synchronous and Asynchronous Shaft Run out Components

Some run out components such as shaft out-of-roundness will repeat at certain angular locations of the rotation; these are synchronous error motions. Other shaft run out components such as run out due to out-of-roundness of rolling elements in the bearing are cyclic but do not repeat at the same angular locations and are called asynchronous error motions. Slippage of rotor on V block also may give asynchronous error motions. So it is quite important that we identify and mitigate asynchronous error motions first before correcting synchronous error motions.

Vibration measurement affected by slow roll run out

The out of roundness of a shaft at both the 90° and 270° positions (oval shape) produces a time wave form which has a frequency of twice the rotational speed. In this case, if run out is not considered then it would appear as if we have a large 2x vibration when in fact there is none. An even more misleading situation would be if the run out were in anti-phase (180 degree) to the true vibration. In such a case it may appear as if there is little or no vibration when in fact there is a significant amount of vibration.

The slope of the curve, the linear range, and the DC output by a probe corresponding to a given gap will vary with changes in a target's geometric surface profile, its conductivity and permeability.

If a eddy-current probe and oscillator demodulator calibration for 4140 steel are used without recalibration on a material as such stainless steel or chrome , the curve shifts to the left, producing a higher-output voltage for a given gap than expected . Since the magnetic field of the probe penetrates the surface of the observed material, any repair which results in an interface between two materials (when the shaft is plated or metal sprayed, HVOF coated) may introduce distortion in the output signal measured by an eddy current displacement transducer. Porosity of spray coating on probe track area will also cause serious issues as the transducer shall read this as scratches on shaft probe track .Eddy-Current sensors are normally calibrated to a flat target. If the shaft diameter is less than 8-10 times the eddy-current probe diameter as a minimum we may have inaccurate measurements or possibility of sensor cross talk.

A scratch is the most common problem in rotor probe track which produces spikes on an unfiltered orbit that usually point away from the probes. A single scratch on the rotor will produce a 1X component and its harmonics in the vibration signal, but they will be visible in the spectrum over all speeds. If a shaft has multiple scratches, it is possible for two scratches to affect two probes simultaneously. When this happens, one spike will appear on the orbit that moves away from both probes (but not directly away from either), and two more will appear that move directly away from each probe. The three spikes will be spaced at 90° of rotation from each other. Direct orbit and full spectrum show the effect of a scratch on the shaft in the probe track area. As the shaft rotates, the scratch first passes under the X transducer, producing a sharp, and negative-going voltage spike in the orbit that points away from the X transducer. The scratch then passes under the Y transducer, producing another spike in the orbit that points away from the Y transducer. In the full spectrum, the 1X frequency consists of both the 1X rotor dynamic response and the once-per-turn scratch response. The scratch response persists to slow roll speed, and the sharpness of the scratch produces a rich, harmonic spectrum as shown in figure 2.

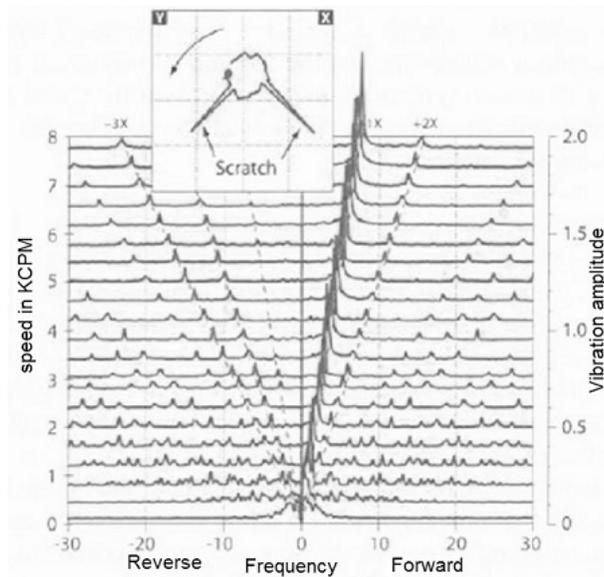


Fig 2 sharp 1x vibration due to scratch on probe sensing area

Effect of run out during rotor balancing -

Run out is the total linear displacement measured on the outside diameter of rotor when it is turned using a dial indicator. The run out is considered as static feature for balancing .Both the run out and mass unbalance are separate and independent quantities. For example, a noncircular part (cam) can be well balanced to run smoothly but it would measure a very large run out. On the other hand, a perfectly round disk (having zero run out) but having a heavy spot might have a serious unbalance .Since we measure the unbalance forces at shaft ends , the displacement probes measure unbalance response along with slow roll run out .

If the rotor is balanced on bearing pedestal and reaction forces on bearing are measured by a velocity transducer, then slow roll run out does not make considerable difference.

If the rotor is being balanced on bearing with X-Y probe then it is imperative to use a mode identification probe to see the displacement at centre span. It is often said that for exact balancing, a slow roll run out must be subtracted from the vibration proximity probe reading. Slow Roll Run out subtraction may be counterproductive or sometimes even dangerous when other dimensional deficiencies exist on the rotor (bow, coupling eccentricity, etc.). Slow roll subtraction could lead an inexperienced balancer to ignore bearing-pedestal vibration up to the point of damaging it while reducing shaft readings. So, when Slow Roll Run out is applied, it must be done with caution and understanding that rotor is free from a bow / bend.

One of plausible method to forego the slow roll run out is to consider Four-Run and Least-Squares Influence Coefficient method (some of computer programme have an optional feature to extract such data).

Measuring Mechanical Run out (MRO)

API 687 (Repair of Special Purpose Rotors) specifications recommend rotation intervals of no more than 20 degrees; but with truthfully , this is a relatively large gap between data points. As the rotor is moved, it may not settle into position repeatedly, leading to significant error. To help counteract this “stick slip” effect, smaller measurement intervals (10 degrees or less) are recommended. When measuring TIR, it is strongly recommended that the same probe series be used to eliminate possible sources of inconsistencies. Two types of devices can be used for measuring MRO.

1 Linear Variable Differential Transformers (LVDT) - LVDT are available with a resolution in the 0.01mil (.0003 mm) range and are particularly well-suited for accurate mechanical run out determination.

2 Dial Indicators-Use of a conventional needle type indicator that can be very difficult to read with the required resolution and for this reason are unsuitable for run out measurements. In addition, they do not allow for automated data acquisition. Dial indicators with a digital display should be used for the necessary resolution.

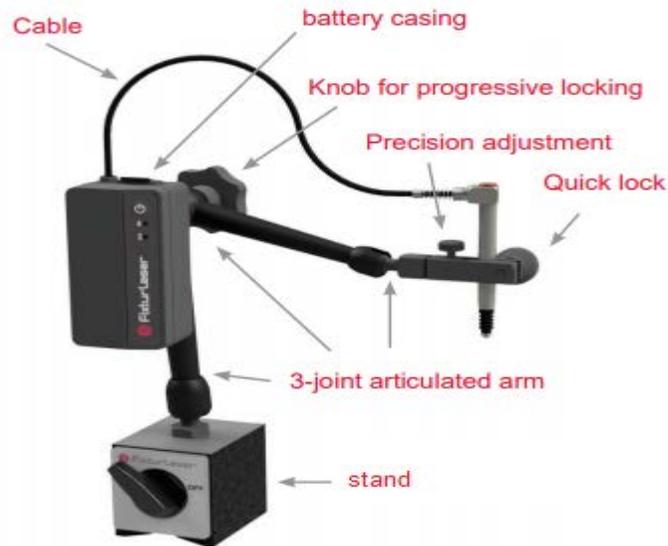


Fig-3 Device to measure mechanical runs out

Measuring Electrical Run out

The bottom probe in the Fig 4 uses an electronic dial indicator. The top one (the cylindrical one) is the electronic run out probe. The device under the shaft, very closely spaced is a large capacitor. The Run out Testing System is a measuring tool is used to check the run out of a rotor's measuring planes used for vibration monitoring. The measuring software takes the measuring data about the total and the mechanical run out to calculate the electrical run out and displays it depending on the angular position of the rotor. That information will then be used to arbitrarily change the actual run out for given limits. Run out is often being tested on lathes. However the rotor bearings of a lathe have limited accuracy if bearings are old and worn.

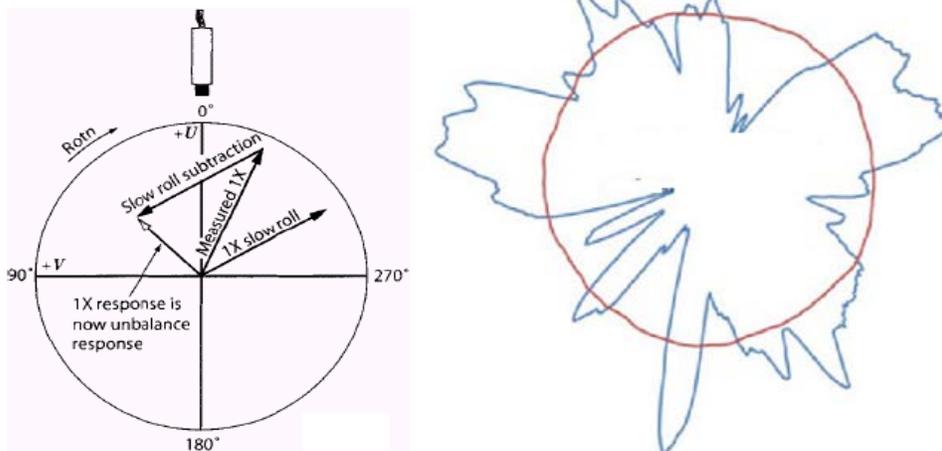


Fig 4 - Set up for Measuring electrical run out- courtesy Hoffmann

It is advised to measure slow roll characteristics of partially machined rotating machine shaft which is supported by hydrodynamic journal bearings. This shall enable to mitigate the issue which ingress in different process in early stage of manufacturing

Removing run out from a vibration signal

Some types of tracking filter enable run out vectors to be automatically removed from the incoming signal, so that the true vibration vector is displaced immediately. This facility can also be programmed into data logging equipment. The nulling is also carried out between critical speeds when producing a Bode plot, to obtain information about phase for use in balancing. It is always preferable to utilize hot shutdown data than to use cold startup data for establishing the correct, actual, operating condition slow roll values. Rotor axial thermal growth at times is significant, which could result in a different observed shaft run out surface cold vs. hot. The figure 5 is the example of removing the slow roll vector from 1x displacement data. The figure shows the high participation of ERO shown in blue as compared to MRO data almost circular in shape.



Figs 5 (Left) Slow roll compensation, Right - comparison of MRO and ERO

Slow Roll Waveform Compensation

Slow roll waveform compensation provides the capability to digitally “memorize” an unfiltered (direct) slow roll waveform and then digitally subtract it from dynamic waveforms at different machine speeds and operating conditions.

Each unfiltered time base waveform consists of a sequence of digitally sampled values. Once a suitable slow roll waveform has been selected, the digitally stored slow roll sample values can be subtracted from the corresponding digital sample values in the unfiltered time base waveforms at different machine speeds and operating conditions.

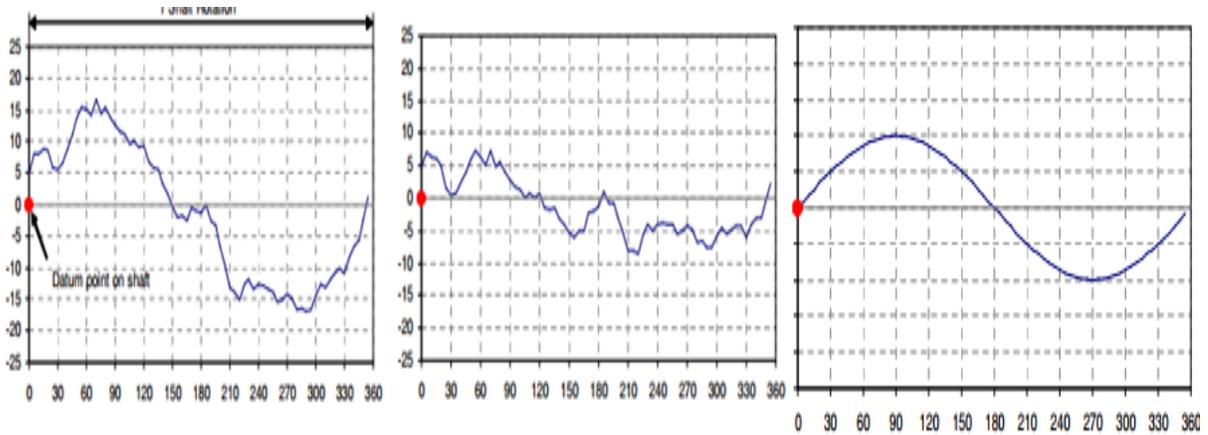


Fig 6 -Left -Unfiltered wave form, middle - Slow roll run out, Right -compensated waveform

Slow roll waveform compensation has the advantage of removing 90% of the total slow roll signal. Slow roll waveform compensation will remove both sub synchronous and super synchronous frequencies, including signal errors due to surface defects, imperfections, scratches, etc.

Waveform compensation can be applied to unfiltered time wave form, orbit plots and spectrum plotted as orders of running speed. This is quite helpful to find actual synchronous amplification factor (SAF) for machinery analysis and diagnosis.

Commentary on API standards -

A detailed study of relevant clauses / mandates as made in various API standards -

API 670 11th edition clause 9.3.3.1 states – shafts shall be machined and finished throughout their length so that TIR is not more than 25/ 40um .This requirement is based on flexible fit and component fit on shaft .

The standard mandates that probe areas shall be properly demagnetized and combined total electrical and mechanical run out shall not exceed 25% of the maximum allowed peak-to-peak vibration amplitude or 6 micrometers (0.25 mil), whichever is less.

API 541 and API 546 define limits for the maximum probe track run out. In simple terms, these run out limits are 25% of the unfiltered vibration limits, or 0.45 mils (thousandths of an inch) for most induction machines and 0.5 mils for most synchronous machines. These correspond to 11.4and 12.7 um respectively.

API 616 5th edition define limits for the maximum probe track run-out as 15 um peak-peak

The surface finish of sensing areas shall have a maximum 0.8um average roughness and area shall not have a residual magnetism more than 2 gauss with a variance not more than 1 gauss at two different places of probe track.

API 616 adds a note as “rotor run out determined by V block placed at journal centres may not be reproduced when the rotor is installed with hydrodynamic bearings. API 670 further mandates that surface areas shall not be plated or metalized whereas API 610 adds a note that use of metalized aluminium of 1mm thickness have been successful. We find this as contradiction to one another.

Difference between slow roll run out and rotor bow

During startup of a turbo machine equipped with hydrodynamic bearing, at the beginning it is difficult to separate slow roll run out and rotor bow up to 70% of its 1st critical speed.

In real world, a rotor shall always have a certain amount of residual unbalance, eccentricity and slow roll run out. Eccentricity is the measurement of Rotor Bow at rotor slow roll which may be caused by any or a combination of: -

- Fixed mechanical bow,
- Gravity bow (sag) and
- Temporary thermal bow.

When the run out is subtracted vectorially, an error is introduced by subtracting rotor bow also. At rotor 1st resonant speed the run out may have a slight rise in peak vibration at that point but effect of rotor bow at resonant speed has a profound effect as this is termed as eccentricity at rotor mid-span. Consider a Jeffcott rotor with all three imperfections listed above as real world example. Due to these imperfections the total response vector δ at vibration sensing area shall be –

$\delta = \delta_o + \delta_r + \delta_x$ where is δ_o response vector due run out, δ_x unbalance and δ_r due to bow .The below pictures of bode plots depicts the difference between rotor run out without bow and rotor bow without run out.

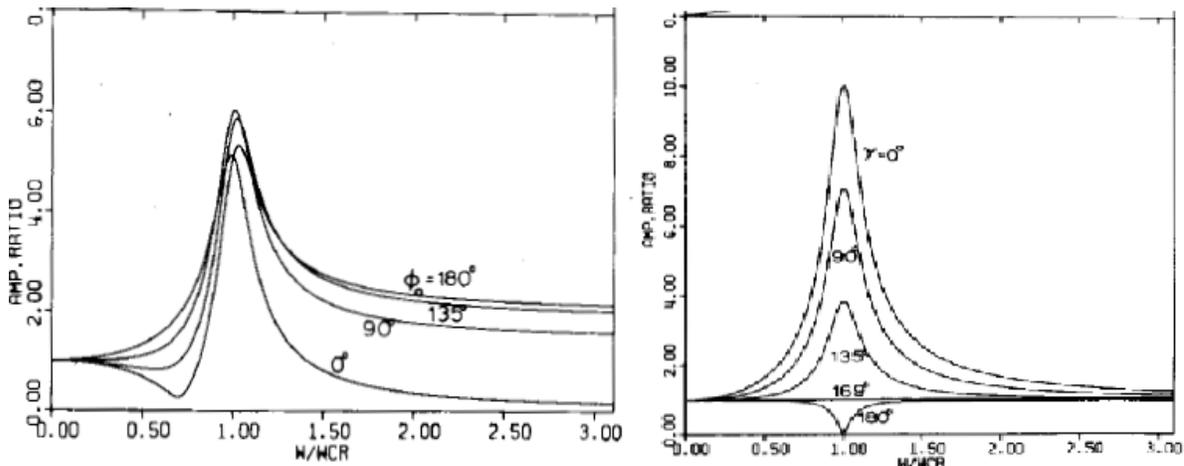


Fig -7-Left - Response with only run out no rotor bow Right - Only Rotor bow no run out

Where γ is angle between bow vector and mass unbalance vector, ϕ is rotor run out vector and timing mark.

Based on the above plots, the test can be done at the time of commissioning and hot restart of machine very carefully with trip limits lowered.

In a full speed range bode plot the slow roll and shaft bend can be differentiated by comparison of phase and amplitude at certain RPM which have fixed relation with 1st resonant speed.

A rotor with a transient bow may continuously change its phase and after repetitive start up the extent shall be considerably decreased where slow roll data remains almost same.

Sample Case study -

One of four Effluent Water Transfer Pumps (API 610 Horizontal, between bearing design) showed high readings at 45 RPM after tripping multiple times even after all possible reasons were eliminated .It was found that probe track area of NDE side had partly affected by corrosion . Before dismantling, slow roll was measured & recorded. High residual magnetism observed in the shaft probe track area at NDE side. NDE side slow roll displacement has reduced from 50 microns pk-pk to 21 microns pk-pk after demagnetization of the track probe location.DE side slow roll displacement maintains around 25 microns pk-pk before and after demagnetization of the track probe location. TIR on both track probes are within 0.02 mm as checked with dial gauge indicator .Bearings were inspected and found to be OK .Rotor mechanical run out checked and found 0.02mm at probe area due to suspected corrosion. (Reduced to 0.005mm after grinding).on both DE & NDE probe track. After that HVOF spray coating was applied to probe track area. Electric run out was found to be higher which was lowered by burnishing. The run out was taken in V-Blocks to meet acceptance criteria mandated by API 610. Once the rotor was fixed and started the pump NDE was showing high slow roll run out. Similar activity was carried out with no tangible benefit. It was suspected that due to porosity in coating, high electric run out was causing high slow roll run out. However any other electrical run-out (other than TIR and magnetic run out) is not possible to be corrected. The observed run-out has no detrimental effect on machine vibration although it affects as cascade effect on 1x vibration and subsequently overall vibration.

EWP	2989 RPM	900 RPM	750 RPM	600 RPM	500 RPM	350 RPM	270 RPM	97 RPM
PUMP DE	$\mu\text{m pk-pk}$	41	27	27	26	26	25	24
	$\mu\text{m pk-pk}$	45	28	27	27	27	26	25
PUMP NDE	$\mu\text{m pk-pk}$	37	36	36	36	36	36	35
	$\mu\text{m pk-pk}$	36	37	36	36	36	36	35

Table 1 - Slow roll run out readings.

Overall vibration was well below alarm limit (75 μ m). End user reluctantly accepted the pump for operation with an understanding the rotor stator gap is 2 times higher than maximum measured vibration although actual vibration was quite low .The delay in repetitive , unproductive corrective actions was due to lacunae of understanding (which slow roll run out reading should be onerous) .

Considerations for an acceptance criteria

These are important deliberations to be exercised for a rotating machine installed at site during dynamic acceptance testing .The first consideration to take in account is that bearings lubrication, which is by oil ring, will start to work properly at 500-600 RPM, so before that running speed , the oil film that sustain the shaft is not yet fully created. The second consideration is that at low speed the hydraulic sustainment of a pump rotor is not yet archived since the pressure inside the pump casing is not yet built. It is to be noted that when the rotor is coupled with a drive some of other parasitic effect may not give the desired reading as mandated in API standards.

Alternative measurement devices

Other than widely used Eddy-current sensors which employs in a magnetic field to determine the distance to the target; capacitive sensors use changes in capacitance.

Capacitive sensors assume that changes in capacitance between the sensor and the target are a result of a change in distance between them. Another factor that affects capacitance is the dielectric constant (ϵ) of the material in the gap between the target and sensor. The dielectric constant of air is slightly greater than one. If another material, with a different dielectric constant, enters into the sensor/target gap, the capacitance will increase, and the sensor will erroneously indicate that the target has moved closer to the sensor. Due to the sensitivity to the dielectric constant of the material between the sensor and the target, capacitive displacement sensors must be used in a clean and steady environment when measuring a target position. Eddy-current displacement sensors work in wet, dirty environments and can be mounted further away from the shaft .Capacitive sensors are not affected by material thickness and subsurface irregularities but need a closer view of target material.

Factor	Capacitive	Eddy-Current
Dirty Environments	—	••
Small Targets	••	•
Large Range	•	••
Thin Materials	••	•
Material Versatility	••	•
Multiple Probes	••	•
Probe Mounting Ease	••	•
Resolution	••	•
Bandwidth	•	••
Cost	•	••

Table 2 - Comparison between sensors two dots - best , one dot less compatible

The capacitive sensors measure all conductive materials the same. Once a capacitive sensor is calibrated, it can be used with any conductive target with no degradation in performance. Since the electric field of a capacitive sensor does not penetrate the material, variations within the material do not affect the measurement. Capacitive sensors do not exhibit the electrical run out and can be used with rotating targets of any conductive material without additional error. Capacitive sensors, once calibrated, can be used with any conductive material with no material related errors and they work well with rotating targets. Because of differences in the shape and reactive nature of the sensing fields of capacitive and eddy-current sensors, they have different probe mounting requirements.

The electric fields of capacitive probes are only emitted from the front surface of the probe. The field has a slightly conical shape resulting in a spot size about 30% larger than the sensing area diameter.

Inductive sensors are not as sensitive as the eddy current sensors and it is advantageous. However, there are disadvantages with inductive sensors: (a) There are very few variety of inductive sensors available in the market as it is very costly, (b) The shaft target ring has to be made from laminated silicon steel.

Laser Triangulation Method

Laser triangulation sensors determine the position of a target by measuring the reflected light from the target surface. High resolution lasers are generally utilized in position and displacement monitoring applications but they require stability (much rigid casing), high precision and low temperature drift.

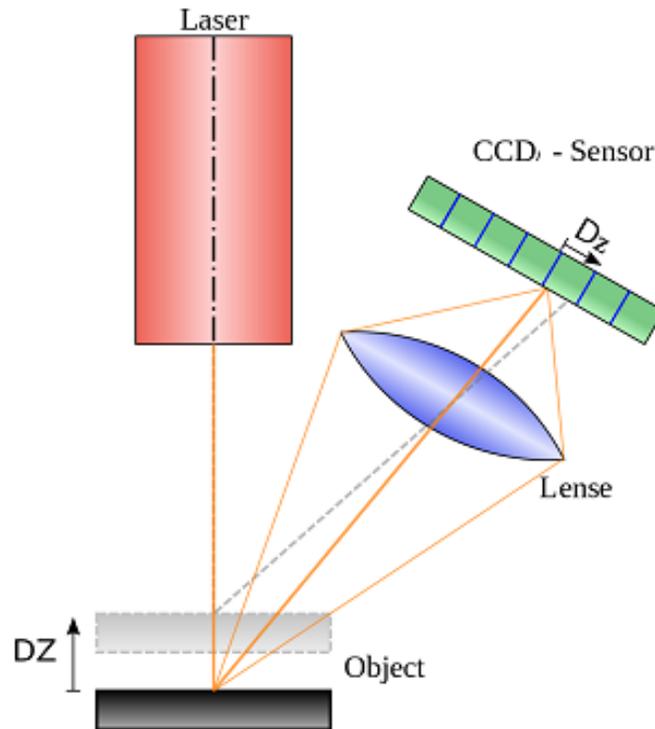


Fig 8 - Laser Triangulation Measuring

Proximity type laser triangulation sensors are also less expensive when compared to other high performance technologies. Laser triangulation sensors include a CMOS/CCD detector and a solid-state laser light source. They operate on the basic principle wherein a laser beam is projected on the target under measurement and a part of this beam is then reflected via focusing optics onto a detector. As and when the target shifts, the laser beam moves on the detector. The detector sends a signal which is utilized to measure the relative distance to the object or target. This data is usually available through a digital (binary) interface, an analog output, or a digital display for processing. Since laser heads have electronic components that are highly sensitive, their operating temperature is somewhat restricted.

Remedial actions to mitigate high slow roll

To remove mechanical run out the shaft must be re-machined; if the shaft is bent it must be straightened prior to re-machining. Once shaft is machined, honing and grinding activities shall be taken up. Electrical run out is present when, around the shaft circumference, there are variations in the permeability of the shaft material to the electrical field set up by the transducer. Residual magnetic fields can be removed by degaussing, if residual magnetism is not the cause of the electrical run out then special treatments such as diamond burnishing, micro peening, or electroplating with non-magnetic material may be necessary. As we can see all these activities to remove electrical run out are time consuming, repetitive and costly.

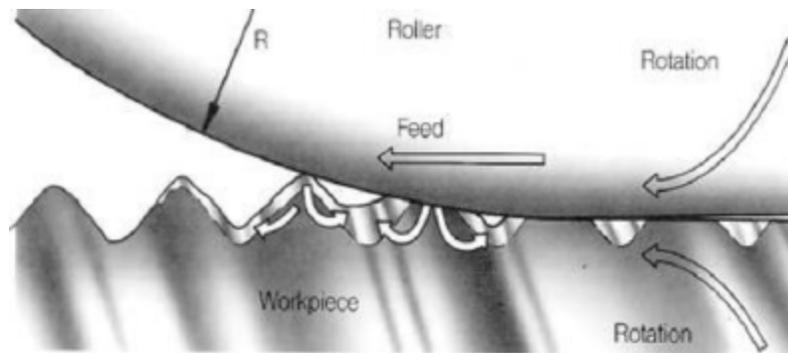


Fig 9- Rotor burnishing

Alternate treatment of probe track area to mitigate slow roll run out

Sleeve - Non- magnetic sleeve properly fit with a radial thickness of 1 mm can be mounted on probe track area. It is to be ensured that interference is not lost due to circumferential stress during high speed operation.

Coatings-Depositing a layer of less run out-prone material onto a shaft can be employed successfully, and there are several technologies for this. The material should not generate a run out signal by their own. The material must also be applied in a thick enough layer to prevent the probe from seeing through to the substrate.

When and how to live with high slow roll run out -

The slow-roll test of rotor is one of the last items to be tested on a machine in factory before machine is assembled in casing . If the machine fails to meet the slow-roll run out requirement, significant rework may be required in order to perform the necessary remedial work. For example, the machine may have to be disassembled and the rotor to be mounted on lathe again. This can cause significant delays in shipping the machine on time, resulting in project delays for the purchaser. Even with diamond burnishing of the rotor shaft, run out levels this low value may be very difficult for machinery manufacturers to achieve. The end result is that this error is costly for both manufacturer and purchaser. It is known that a “true” shaft vibration creates alternating stress and causing shaft fibres being stretched and contracted whereas a high slow roll run out is not a true vibration hence machinery reliability and integrity is not a concern .

Considering the value of highest amplification factor after a slow roll compensation and RCV as 60% instead of 75% as mandated in API we can live with a higher slow roll run out . The numerous data analysed from rotor-dynamic calculation by author shows that in 99% of cases it is achievable .

Use of electrically insulated coupling to mitigate residual magnetism and ERO - On specific demand , some manufacturers can offer an insulated spacer between the coupling ends, The insulation is provided by a fibre disk that, through small lips, also provides piloting between the two halves of the spacer. bushings and washers insulate the bolts. With proper design, the insulated connection can be left intact for the life of the machine.

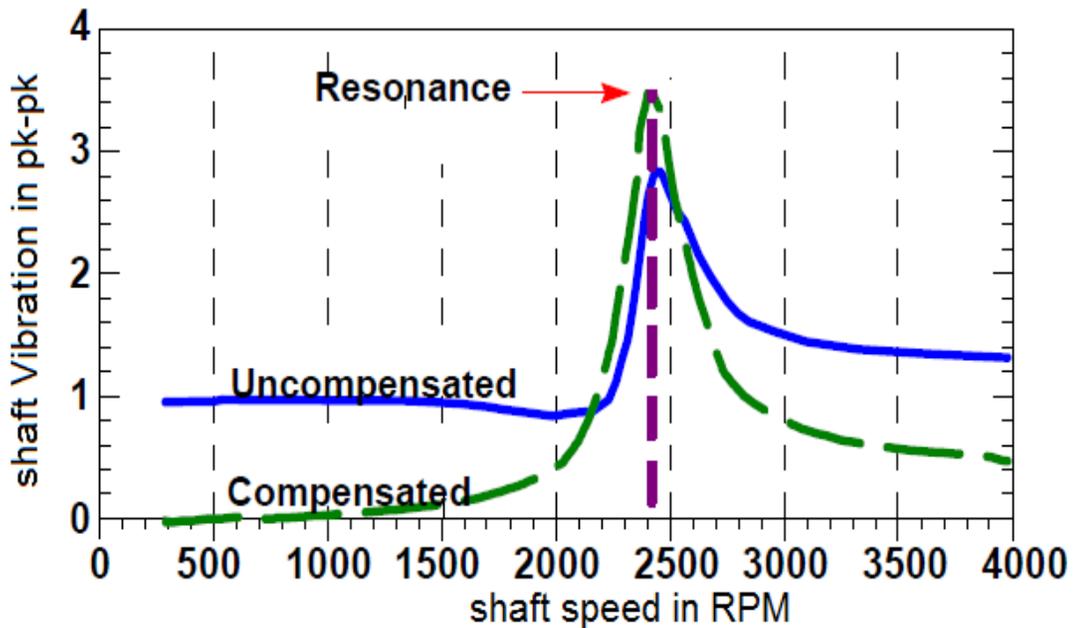


Fig 10 - Effect of slow roll compensation on Bode plot

If the rotor is using antifriction bearings, all vibratory stresses are passed on casing / bearing housing and is a true indication of rotor vibration. With rotor using antifriction bearings, slow roll run out has no meaning . But in case, the rotor is supported by hydrodynamic journal bearing true vibration cannot be extracted at casing / bearing housing due to damping of vibration oil film which enforces us to measure shaft vibration using proximity probes. As it is impractical to mount transducers at mid span on the rotor where displacement would be the highest the transducer(s) are mounted near bearing housing. As slow roll run out is not being measured in antifriction bearing as it has no effect on rotor vibration same can be held true theoretically in perspective of reaction forces on bearings.

If we find that rotor to stator clearances are much higher than alarm / trip limits then we can live with a higher slow roll run out such as 16 um pk-pk at site condition . This value can be further adjusted by OEM for onsite operation of a machinery train.

It is feasible to check if vibration is genuine due to machinery anomaly or benign due to slow roll run out. With consent of OEM expert vibration analyst, we can use the mask or envelope alarm where 1x, 2x and 3x values shall be used as individual alarm set up before triggering a trip. With a high slow roll run out we shall get a 1x and 2 x components higher in spectra which shall increase overall vibration level. The height of other components than unbalance and misalignment response should be kept as baseline as slow roll run out. The alarm should be set based on bearing clearance and rotor to stator clearance so that machinery damage is avoided. With a maximum limit set point, minimum limit set point for 1x and 2x component must be implemented so that possible nulling of actual vibration is also addressed. .

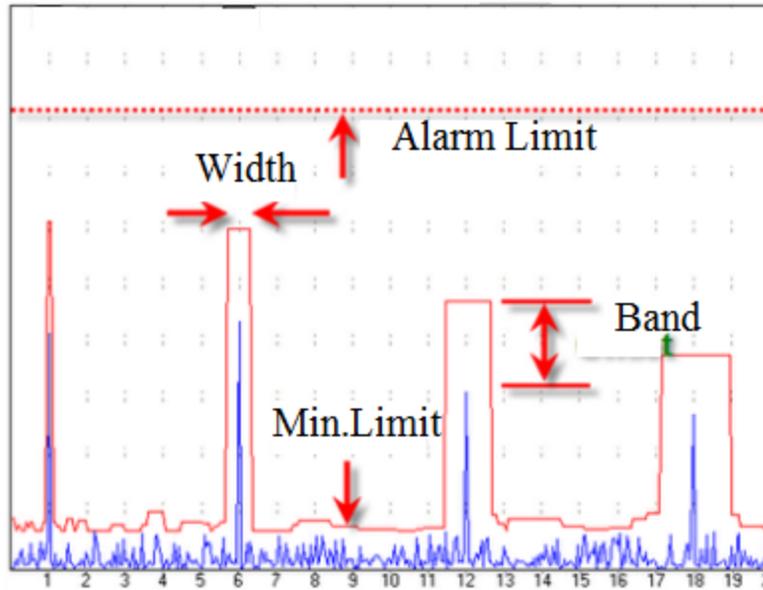


Fig 11 - Masked alarm

Statistical data based mask alarm configuration is further refined way to avoid unnecessary concerns of high vibration.

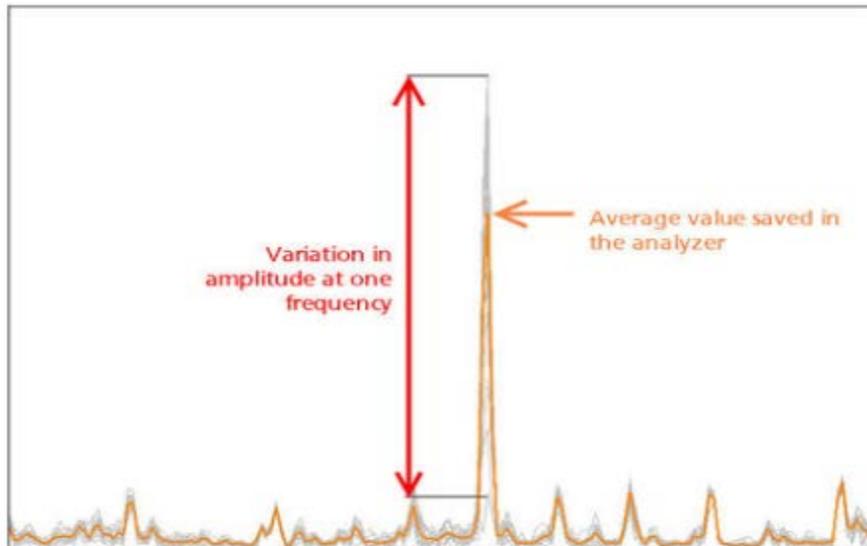


Fig 12 - Statistical data based alarm for a particular frequency

We can explore to create rule based logic to generate alarm to see the true vibration. This can be formulated by using shape identification algorithm in diagnostic system based on reference data captured by initial slow roll measurement and vibration spectrum by a Laser Doppler and eddy current probe as well at OEM works during test. The algorithm shall remember the difference as base data and same shall be applied to see 1 x and 2x vibrations.

By suggesting the above actions with consent of OEM, it should not be construed that OEM should be lenient on requirement of slow roll run out. OEM should ensure that mechanical run out is at minimum extent, free of scratches and required surface finish as mandated in API. The above suggestions are explicitly to avoid spurious trips and concerns due to electrical run out.

In a slow roll run out measurement, capacitive and Eddy current probes were alternately paired with the LVDT probe to observe the motion of the rotor shaft. The probes are set up to measure the mechanical and electrical run out on a lathe at slow speed (7-10 RPM) so that readings are not affected by lathe machine's bearing condition. Under similar conditions, one set of measurements was taken for the Eddy current probe in conjunction with the LVDT probe and one set of measurements is taken for the capacitive probe in conjunction with the same LVDT probe.

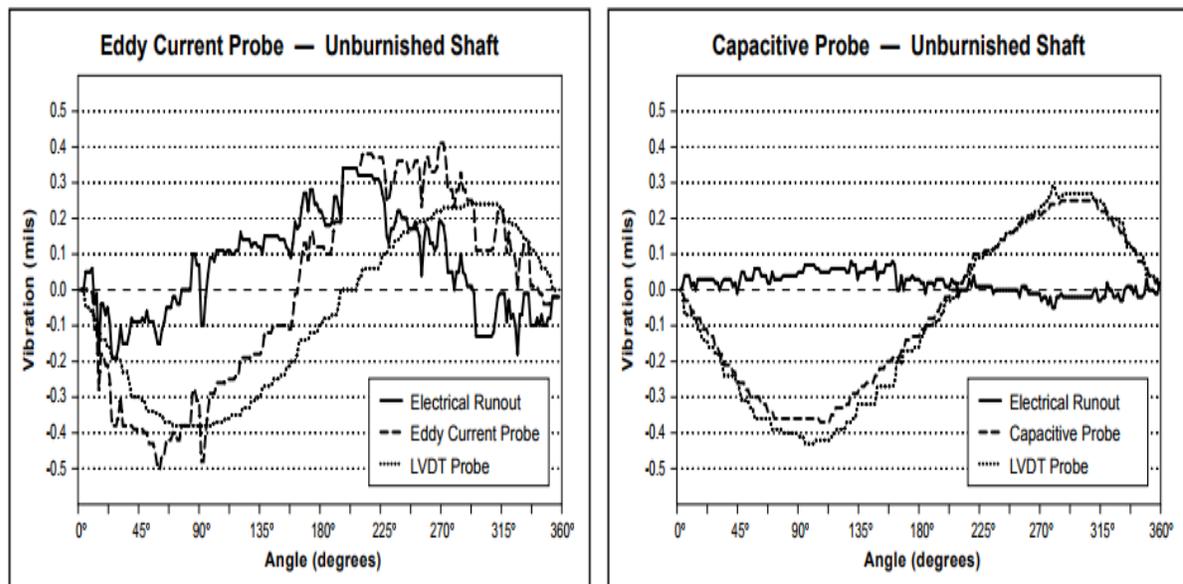


Fig13 - Comparison of readings of ERO by various sensors with LVDT probe

The most remarkable aspect of the capacitive proximity probe measurement is that the probe exhibits a peak-to-peak level of low level of electrical run out (roughly one-quarter of the Eddy current reading). This would pass run out specifications (in particular API-670) without the need for diamond-burnishing. Thus, false readings and their expensive consequences can be avoided.

Prospect of future research

A) Prospect of using capacitive transducer -

Considering the capacitive probe's competitive pricing, it should now be considered a superior replacement for Eddy current probes for almost all noncontact vibration measurement applications. The scope of research lies on reducing its size. The capacitive

probe can be interfaced into the same rack via a signal conditioning device to provide the standard 200mV/mil sensitivity required by the existing VMS rack instrumentation

b) Prospect of using Micro electro-mechanical systems (MEMS) - Now a days use of MEMS is highly encouraged for critical equipment installed in remote area .There is a good scope of exploration of using in shaft vibration monitoring (OSVM) in conjunction with on bearing vibration monitoring (OBVM).

c) Prospect of using Laser telemetry - As known to us that shaft centreline plot displays the shaft centre DC position changes within a bearing clearance range. An orbit plot represents the shaft centre AC dynamic motion. If the shaft true centreline is identified in both DE and NDE end and bearing details are kept in data base, it is possible to have real time data in form of orbit plot, shaft displacement and shaft polar and centreline plots. This is same principle on which shaft laser alignment tool works.

References -

- [1]Rotor Glitch - An article by GE MCS
- [2]Littrell, N. "Understanding and Mitigating Shaft Run out," ORBIT Magazine, Vol. 25 No. 3, 2005, pp. 5-17.
- [3]DeBlock, M., McDonnell, J.W., Wood, B. "Predicting Proximity Probe Track Run-out on API Motors and Generators," ORBIT Magazine, Vol. 27 No. 2, 2007, pp. 36-4
- [4]GE Bently Nevada System 1 Tips Tricks Vol3 Issue 4 Apr 2012 Collect Slow Roll Data
- [5] Comparison of unbalance response of a Jeffcott rotor with shaft bow and/or run-out by Dr.EJ Gunter , Flack et al ASME Paper 81-DET -47
- [6]Understanding Vector, Gap, and Waveform Data Compensation- Richard Thomas Machinery Diagnostic Services SETPOINT™ Vibration
- [7]Slow roll runout measurement for hydropower - Koncar electrical engineering institute
- [8]Development of Electrical Runout Online Measurement System Based on Eddy Current Technique and Laser Triangulation- Wang Yifeng et al -School of Mechanical and Automotive Engineering, Zhejiang University of Science and Technology, Hangzhou, 310023, China
- [9]Accu Scan 2-Probe Run-out Inspection System with ERO- Technical sheet by Paris Mountain Consulting, LLC.
- [10]Mechanical and Electrical Run-Out Removal on a Precision Rotor-Vibration Research Spindle- G. A. Horattas, M. L. Adams and F. Dimofte Journal of Vibration and Acoustics
- [11]Predicting, measuring and correcting for electrical run-out using a burnishing and degaussing process- Tech notes by Thermaspray (PTY) Ltd Olifantsfontein South Africa
- [12]Shaft Run-out Measurement With Noncontact Displacement Sensors General Sensing Application Note LA05-0022 - Lion Precision instrument notes
- [13]Comparing Capacitive and Eddy-Current Sensors General Sensor Tech Note LT05-0011

- [14]Non-contact displacement sensors technology -a review by Chris Jones Power in motion 2008
- [15]Method and apparatus for programming and reducing run out in rotating shaft vibration signal detection - US Patent 4135244 by Robert R Davis .
- [16]Identification of critical speed of rotating machines using on shaft wireless vibration measurement - ME Elandy , Jyoti Sinha et al University of Manchester UK
- [17]Rotor-dynamic measurement techniques - Tech notes by Agilent Technologies
- [18]A multi-model approach for anomaly detection and diagnosis using vibration signals - Victor Valencia et al . Conference on PHM 2013
- [19]Electrical And Mechanical Run-out As A Problem In Manufacturing Industry - Darshan Jayaram et al - Mysore India
- [20]Electrical Run-out using an eddy current sensor for roundness measurement - Byron Knapp et al Minnesota, USA
- [21]Electrical & Mechanical Run-out Inspection- Tech notes by Watson grinding system Houston, TX

Bibliography -

- [1]Rotating machinery vibration - from analysis to troubleshooting - Maurice Adams
- [2]Rotor and Structural Dynamics of Turbo-machinery A Practical Guide for Engineers and Scientists.: By Subbiah, Raj, Littleton, Jeremy Eli
- [3]Rotor Systems: Analysis and Identification - Rajiv Tiwari IIT Guwahati India CRC Press, Taylor & Francis 2017.
- [4]Practical Machinery Vibration Analysis and Predictive Maintenance-by Cornelius Scheffer and Paresh Girdhar
- [5] API 670 Machinery Protection Systems. Fifth edition
- [6]API Recommended Practice 687 - Rotor Repair