IJREAT International Journal of Research in Engineering & Advanced Technology, Volume 3, Issue 2, April-May, 2015
ISSN: 2320 – 8791 (Impact Factor: 2.317)
www.ijreat.org

Electrical And Mechanical Runot As A Problem In Manufacturing Industry

Darshan Jayaram[1], Dr. B.R. Narendra Babu[2], Dr. K. Chandrashekara[3]

[1]M.Tech , Department Of Mechanical Engineering, Vidya Vikas Institute Of Engineering And Technology, Mysore.
[2]Associate Professor, Department Of Mechanical Engineering, Vidya Vikas Institute Of Engineering And Technology, Mysore.
[3] Professor, Department Of Mechanical Engineering,, Sri Jayachamarajendra College Of Engineering, Mysore.

Abstract

This article explains what runout is, why it is important, and the root causes of runout in machinery shafts. It also outlines common methods for reducing runout to allowable levels and suggests best practices to observe during fabrication and machining to help avoid runout difficulties in the first place. Material electromagnetic anisotropy of revolution parts poses a potential hazard to the operation of rotary machine (such as rotor) and interferes the vibration monitoring. The maldistribution of electromagnetic property of material is detected by eddy current sensor as electrical runout, Mechanical Runout is a measure of the shaft's deviation from a perfectly uniform radius as its circumference is traversed.

Keywords: *Author Guide, Article, Camera-Ready Format, Paper Specifications, Paper Submission.*

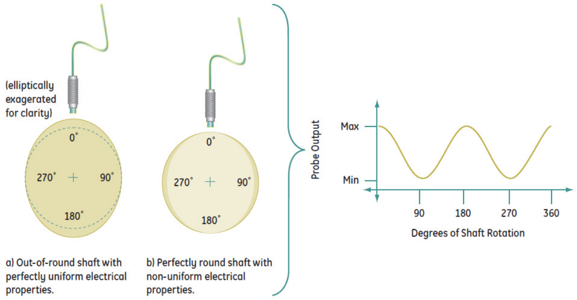
1. Introduction

The runout on a probe track is comprised of two components: mechanical and electrical. Mechanical runout can, in theory, be measured with a dial indicator as it represents dimensional imperfections. No matter how good a machine tool is, there will always be elements of error introduced. Shafts are not machined perfectly round. Nor are adjacent shaft surfaces perfectly concentric. For a typical installation where the proximity probe is located adjacent to the journal, and assuming no scratches or burrs on the shaft, there are three sources of mechanical error that will influence the slow-roll runout of a machine:

1. The journal diameter will not be perfectly round.
2. The proximity probe track diameter will not be perfectly round.
3. The journal and proximity probe track diameters will not be perfectly concentric.

The electrical component of runout, in contrast, is not dimensional and instead represents metallurgical variations around the circumference of the shaft. These metallurgical variations lead to variations in the electrical conductivity and magnetic permeability of the shaft, affecting the proximity probe signal. Once these variations are introduced in a forging, it is extremely difficult to change them. By breaking the slow-roll runout into its four components (three mechanical and one electrical), one can more readily identify which component is excessive and develop an appropriate strategy for reducing the slow-roll runout. This is extremely important because not knowing which component is the problem, or misdiagnosing the problem, can make the situation worse. For example, if one believes the problem is with the electrical component of runout when in fact the problem is an out-of-round proximity probe track, an action plan to fix the electrical component will be implemented when the electrical component is fully satisfactory. When this occurs, matters will almost always be made worse by trying to "fix"the non-existent problem.

2. Runout



a) Out-of-round shaft with perfectly uniform electrical properties.

b) Perfectly round shaft with non-uniform electrical properties.

Figure 1 – probe gap for a) an out-of-round shaft with uniform electrical properties and b) a perfectly round shaft with non-uniform electrical properties.

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. Thus, two different materials (for example, 4140 type steel and aluminum) can be positioned with the same physical gap from a proximity probe, yet will give different outputs due to their dissimilar electrical properties.

For a rotating shaft, physical out-of-roundness results in a change in gap. This is shown in Figure 1a. 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. This is shown in Figure 1b. In this example, both shafts give identical probe outputs even though they have different physical shapes. In practice, mechanical runout can indeed be somewhat sinusoidal as shown in the example. However, electrical runout is rarely – if ever – sinusoidal and is generally characterized by a noisy waveform with numerous spikes. It is represented as a sinusoid in this example merely for illustrative purposes. Notice also that these signals have nothing to do with the dynamic motion or vibration of the shaft. They are inherent properties of the shaft that will be observed regardless of whether it is stationary or rotating at high speed. These signals are known as runout. For convenience, we divide runout into two primary categories as follows:

2.1 Mechanical Runout

Mechanical Runout is a measure of the shaft's deviation from a perfectly uniform radius as its circumference is traversed. This type of runout can be measured by a dial indicator.

2.2 Electrical Runout

Electrical runout is a measure of a shaft's electrical property variations as its circumference is traversed. This type of runout cannot be measured by a dial indicator. Because a proximity probe senses both types of runout, it is customary to speak of Total Indicated Runout (TIR) which is simply the sum of mechanical runout and electrical runout. In most cases, when runout is discussed in conjunction with proximity probes, it is understood to mean TIR.

3 Sources of Mechanical Runout

3.1 Machining Processes

3.1.1 Lobing" of the shaft is particularly problematic when centerless grinding machines are used because variations in shaft hardness can result in a non-circular geometry. Grinding on centers provides a reference for the wheel to work against and is less prone to runout.

3.1.2 Tool chatter. Selection of the correct tool and holder, as well as adjustment, is critical for all machining processes. Make certain tools are not dull.

3.1.3 Improper feed rate and speed of cutting tools. Surface finish is strongly affected by cutting tool feeds and speeds.

3.2 Dents From Handling

3.3 Rust Patches

3.4 Rotor Bow Due To Thermal Effects, Gravity, Or Other Influences/Loads

3.5 Defective Or Worn Bearings In The Machine Or Lathe Supports

4 Sources of Electrical Runout

4.1 Metallurgy

The material chemical composition is fundamental to its electrical and magnetic properties. As well, the material's purity can affect runout. In general, non-ferrous materials such as copper and aluminum exhibit the fewest electrical runout problems, since they are devoid of any significant magnetic effects.

Conversely, the worst materials in terms of electrical runout are precipitation-hardened steels. Precipitation hardening is a process where clumps of different crystal states are formed in the matrix of the parent metal. The probe observes these clumps as they pass by while the shaft rotates, producing the unwanted runout signal. 17-4 PH can be particularly troublesome in this regard

In general, the vacuum arc remelt (VAR) or double vacuum arc remelt (DVAR) materials possess the best homogeneity and exhibit the fewest number of problems with electrical runout. It is recognized that the choice of shaft materials is rarely as simple as merely considering the material's runout properties. Instead, designers are faced with multiple criteria and inevitable tradeoffs. Pumps are a good example of machines that must often employ more exotic materials due to the corrosive nature of the process fluid that will be handled, whether seawater, liquefied sulfur, acids, or others. Motors are another machine type that commonly use materials other than 4140 type steels. , when a designer requires certain shaft metallurgies, yet the material exhibits intractable runout characteristics, one approach is to attach a collar or coating of a different material to the shaft.

4.2 Forging

The forging process involves forming an ingot into the rough shape of the shaft using enormous hydraulic hammers and presses. During the forging process, the material flows into the shape of the shaft and gains a grain structure that is present throughout the cross section of the material. This grain structure defines a set of large scale boundaries that contain the smaller scale crystal boundaries. A non-uniform grain structure can result in electrical runout.

4.3 Heat Treatment

The purpose of heat treatment is to modify the crystal structure of a material to tailor the material mechanical properties (toughness, ductility, etc.) to the application. The magnetic properties of ferrous materials are a function of the crystal structure, so it follows that heat treatment is a factor in the resulting electrical uniformity of the shaft.
Many large shafts are quenched as part of the heat treatment process by lowering into tanks of salt water or other liquids. Most commonly, the shaft is horizontal when lowered into the quench tank, which results in an asymmetrical quench profile. It is recommended to lower the shaft vertically into the quench tank if possible to improve the radial homogeneity of the quench.

4.4 Grinding

Grinding the bearing journals to final dimensions and finish is generally the last step in the shaft manufacturing process. The grinding process generates significant heat that is localized at the point where the grinding wheel touches the shaft. It is important to have maximum coolant flow on the work piece and to start and stop the grinding process slowly. Avoid sudden increases or decreases in feed rate when grinding. It is also recommended to keep the wheel freshly dressed to limit heat build up. Because grinding results are highly dependent on the operator, it is recommended that this step be closely monitored if runout problems are occurring.

4.5 Magnetism

Residual magnetic fields in the shaft can cause significant variation in the output of the proximity probe system.

4.6 Stress Effects

Stress affects the crystal structure and magnetic properties of materials. Occasionally, a shaft with runout problems can be traced back to an event that caused the probe area to undergo significant mechanical stress. It is best practice to support shafts in slings in such a way that they are not subject to significant bending stresses during installation and handling. Bead blasting or other impact-based cleaning processes create compressive stress in the surface of the shaft and can induce runout.

4.7 Handling

In addition to the stress effects mentioned above, it is possible to 'bruise' metal by hitting or dropping the shaft on the probe tracks during intermediate steps of manufacture. The external damage is erased by subsequent steps such as machining, but the damage to the crystal structure may go quite deep into the material. Thus, it is important to handle the shaft carefully at all steps in the process.

4.8 Plating

Occasionally, a rotor is refurbished by plating the bearing journal area to replace worn material. Sometimes, this surface will be intentionally "roughed up" to allow the chrome plating to adhere better. However, the probe will "see through" the plating to the rough surface underneath, resulting in runout. Also, chrome plating has very different electrical properties than typical shaft materials and strongly affects proximity probe output. In general, plating in the area of proximity probes is not recommended. However, when this is not an option, plating thickness should be at least 20 mils to prevent the "see through" effect mentioned above, and the Proximitor® sensor should be calibrated to the plating material rather than the substrate shaft metallurgy.

5 Measuring Mechanical Runout

5.1 Linear Variable Differential Transformers (LVDT)

LVDTs operate on the principle of a transformer with a movable core. As the core moves, the gain of the transformer changes and the displacement is inferred from that signal. Units are available with a resolution in the 0.01 mil (.0003 mm) range and are particularly well-suited for highly accurate mechanical runout determination.

5.2 Dial Indicators

While inexpensive, reliable, and found in most every machinist's tool box, mechanical dial indicators are generally limited to increments no finer than a tenth of a mil. Analog versions use a conventional needletype indicator that can be very difficult to read with the required resolution, and for this reason are unsuitable for runout measurements. In addition, they do not allow for automated data acquisition. Dial indicators with a digital display are also available, and are generally capable of providing thenecessary resolution. In addition, some of the more advanced versions feature an electrical output in addition to the display, making them suitable for automatic data acquisition.

5.3 Form Measuring Equipment

These are specialized devices that evaluate components in terms of geometric dimensioning and tolerancing definitions. The machine typically holds the component vertically on a turntable and measures the form of the surface using a stylus. Output is the radial deviation from absolute roundness along with values describing the concentricity, eccentricity, and roundness as defined by Geometrical Dimensioning and Tolerancing (GDT) standards. Unfortunately, such equipment is of only academic interest for most rotating machinery because it cannot handle components larger than 60 kg.

6 Correcting the Electric Run-out

6.1 Burnishing

Electrical run-out is measured and corrected by using a process called burnishing (Figure.2). Burnishing is the rolling of a blunt tool against the surface of a work piece – with a force being applied by the tool. As soon as the yield point of the material is exceeded, plastic deformation occurs which leads up to a smoother surface profile. At the same time, compressive stresses (Figure.3) are introduced in the surface layer. Compressive residual stresses in the surface layer of a component are beneficial because it leads to the increase of the component's fatigue resistance under dynamic loading (formation and propagation of fatigue cracks at the surface of the component is reduced

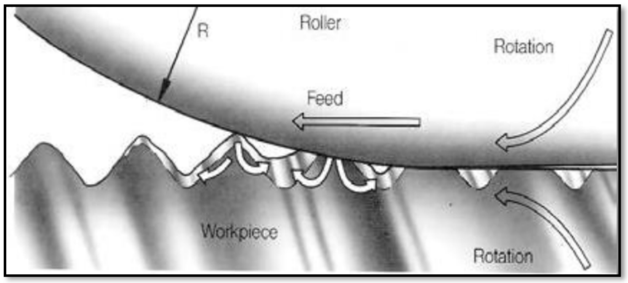


Figure.2. - Schematic illustration of the burnishing process

Metallurgically, burnishing is a cold working process that improves the surface characteristics of components. A burnished surface is actually smoother than an abrasively finished surface of the same profilometer reading. A machined surface has microscopic "peaks" that are forced to cold flow into the "valleys" during burnishing. The sharpness of the surface profile is reduced or eliminated in the contact plane causing a burnished surface to resist wear better (Figure.3).

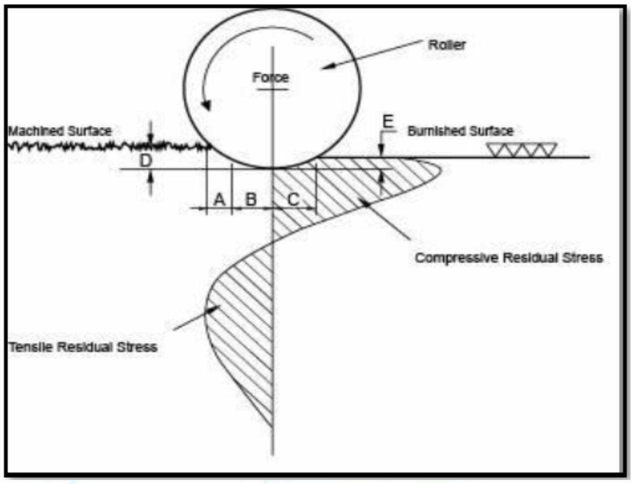
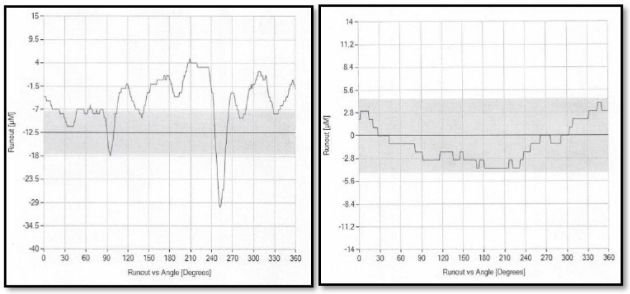


Figure.3. - Plastic deformation of the surface asperities during burnishing

Electrical run-out can then be measured using an electrical run-out indicator apparatus on a lathe or inspection bench, after the burnishing process. Electrical run-out is measured every 1° through 360° and plotted on graphs using specialized, calibrated equipment and applicable software (Figure.4).



Before burnishing **After burnishing**

Figure.4. – Typical electrical run-out report

6.2 Degaussing (Demagnetizing)

One method of checking residual magnetic field strength is by using a small, hand-held field indicator, available in digital and analog versions from manufacturers such as Magnaflux®. Even a relatively small amount of localized residual magnetism can contribute to runout. For example, a localized concentration of 5 gauss on a rotating shaft can give electrical runout on the order of 0.5 mil. Therefore, it is always good practice to check the shaft with a field indicator and, if required, degauss in the area of the probe tracks. A degausser emits an AC pulse of decreasing strength. The magnetic field generated "scrambles" the domains in the material to reduce the residual magnetism. While special degaussing apparatus is available, a very common field practice is to use an arc welder set to AC with the cables shorted together. The cables are waved over the area to be degaussed, or sometimes wrapped around the shaft. The current in the cables sets up a large enough magnetic field to effectively degauss the shaft.

6.3 Probe Gap

A simple first attempt at reducing electrical runout is to gap the probes closer to the shaft. Sometimes this can change the runout measurement. However, be certain that the probes are not gapped so close that they take the probes outside their linear region or allow the probes to contact the shaft during periods of high vibration.

6.4Alternate probe track material

6.4.1 Collars

Collars can be very effective, provided they are attached to the shaft in such a way that they cannot come loose or induce additional loads or stresses on the machine. Additionally, the collar must be ground after it is shrunk onto the shaft to ensure that it is suitably concentric. However, some shaft geometries cannot accommodate a collar. In other situations, the shaft geometry may allow for a collar, but significant thermal gradients due to differential expansion problems may make use of a collar unwise.

6.4.2 Coatings

Depositing a layer of less runout-prone material onto a shaft can be employed successfully, and there are several technologies for this. The idea is similar to that of plating (already discussed) and many of the same considerations apply. Primary concerns are to choose a material that is nonferrous and applies with sufficient density that inclusions do not generate a runout signal of their own. The material must also be applied in a thick enough layer to prevent the probe from seeing through to the substrate.

7 Why Be Concerned About Runout?

Even if a target material has non-uniform physical or electrical properties, it does not create a problem for probes observing the same location on the target at all times – such as an axial position measurement using the end of a shaft. However, proximity probes are often used for radial vibration measurements where the "track" observed by the probe is constantly changing (repeating itself every 360 degrees) as the shaft rotates. This results in a proximity probe signal composed of both actual vibration and runout. Because the runout signal is not related to actual shaft vibration, it can lead to erroneous vibration readings and machinery diagnostic conclusions. To avoid this problem, the amount of TIR must be kept to allowable levels, generally 25% or less of expected vibration amplitudes.

7 Sources of Error and Non-Repeatability

API 687 (Repair of Special Purpose Rotors) provides a very detailed description of how to measure runout. API specifications, in general, require that:

1. The shaft be supported in v-blocks;
2. The probe be perpendicular to one face of the v-block;
3. Runout be measured in terms of peak-to-peak probe output. One of the primary reasons that v-blocks are recommended is that the runout measurement should be made in apparatus separate from that in which the machining was actually performed. For example, if a lathe has bearing wear that produces an elliptical shaft cross-section, the shaft will appear perfectly round as long as it is in that particular lathe. By moving the shaft to a separate measuring environment (i.e., v-blocks or a balancing machine), the error introduced by the lathe will not be masked. However, while the use of v-blocks represents recognized good practice, it is not immune from its own sources of errors as detailed below.

7.1 Failure to mount the probe perpendicular to one face of the v-block

This is a common error made in the field and results in incorrect mechanical runout readings. It affects only the mechanical runout measurement (not the electrical). The maximum mechanical runout error introduced is the sine of the probe's angular deviation from block face perpendicularity.

7.2 Lobing Effects

lobing is a common artifact of centerless grinding operations. When measuring the shaft profile in a lathe or other device where the shaft is rotated about its axial centerline, the user is measuring radial (rather than diametral) variations. As a result, there is no ambiguity in the profile measurement. In contrast, v-blocks cause the user to measure diametral variation, and can result in ambiguity regarding the shaft profile. This is easiest to visualize by way of examples, as shown in Figures 5 and 6. Notice that the dial indicator in Figure 5 gives exactly the same output shape (dark blue line) for both shafts and that it reflects the change in diameter (not radius) as the shafts are rotated. The user may incorrectly conclude that the one-lobed shaft had a two-lobed profile, and efforts to correct this through grinding would only exacerbate the problem. In Figure 6, notice that the three-lobed shaft provides a dial indicator output suggesting perfect roundness, when, in fact, it has three lobes. Only by examining the motion of the center of the inscribed circle for all three shafts does the user obtain the true profile. This ambiguity can be removed by making the mechanical runout measurement with a fixture that rotates the shaft about its centreline (such as a balancing machine). As previously mentioned, it is not recommended that the measurement be made on the same lathe in which the shaft is being machined, as the runout measured becomes the combined effect of the shaft and the lathe bearings, and the two can offset one another.

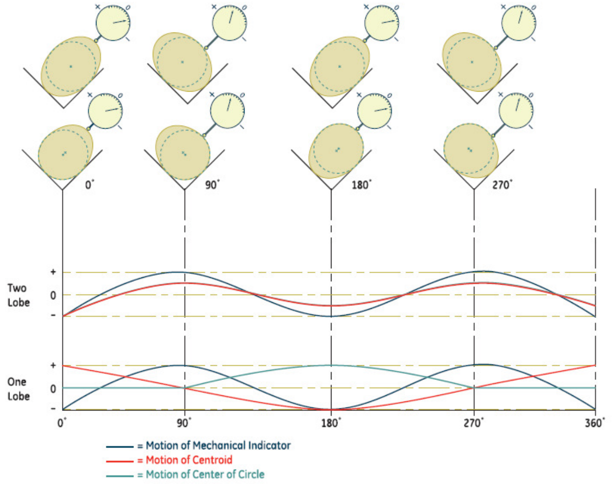


Fig 5 When mounted in v-blocks and measured with a dial indicator

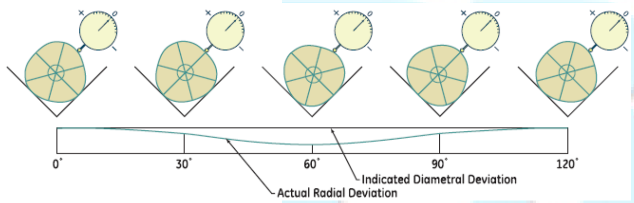


Fig 6 This 3-lobed shaft appears to be perfectly round when mounted in v-blocks and measured with a dial indicator.

7.3 Stick slip

V-block measurements will sometimes use an apparatus (such as a drive belt) that slowly rotates the shaft. However, manual barring of the shaft is most common. While API specifications recommend rotation intervals of no more than 20 degrees, this is a relatively large gap between data points. As the rotor is moved, it may not settle into position repeatably, leading to significant error. To help counteract this "stick slip" effect, smaller measurement intervals (10 degrees or less) are recommended.

7.4 Bow/sag

If a shaft has a bow or sag from gravity (and all shafts exhibit some level of this), it is possible that this will show up as runout as the shaft flexes during rotation. Anisotropic stiffness (unequal with respect to direction) will definitely cause irregularity in the runout reading due to rotor sag. To minimize this effect, make the runout measurements as close as possible to the shaft supports (e.g., v-blocks).

7.5 Inconsistent Transducer Models

When measuring TIR, it is not necessary to use the same probe in the shop as the installed probes in the field, as this is rarely practical. However, it is strongly recommended that the same probe *series* be used to eliminate possible sources of inconsistencies. For example, if the machine will be permanently monitored with Bently Nevada 3300 XL 8mm proximity probes, it is advisable to use this type of transducer system for the bench runout measurements as well. While the differences between transducer series are generally small, runout measurements are typically trying to resolve dimensions of 0.25 mils or less. As such, even the smallest sources of variation can affect the results.

8 Conclusions

As we have shown, many factors can influence the amount of runout present in a shaft. The best approach is to prevent runout – rather than mitigate it after the fact – through appropriate diligence at all stages of the manufacturing process. However, mitigation will still sometimes be necessary and this article has discussed several methods that can be employed with good success, ranging from degaussing and burnishing to the use of alternate materials for the probe tracks.

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