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ANALYSIS OF IMBALANCE IN ROTOR OF UNIVERSAL MOTOR USING MINITAB

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Abstract: This paper is focused on calculating the imbalance in washing machine rotor of universal motor, using statistical tool, Minitab. Experiments has been carried out for finding the different practical reasons which can affect the balance of rotor and the percentage contribution for imbalance. There are number of reasons for imbalance of rotor, out of which the paper will cover the effect of run out on imbalance, outer diameter of shaft, performance of straight shaft in place of tapered shaft and knurling on straight shaft. Chart has been prepared for the different causes of imbalance on which more experiments can be performed. Finally, permissible imbalance value has been calculated for the specific values of rotor where procedure to find the Balance quality grade has also been disclosed.

Keywords: Rotor imbalance, Minitab, Knurling, Runout, Permissible Imbalance Value, Causes of Imbalance.

I INTRODUCTION

(A) Imbalance:

Imbalance is an inherent property for any rotating part(s). Factors responsible for imbalance in rotating parts are material properties (Density, porosity, voids), Fabrication properties (Misshapen casting, eccentric machining, poor assembly, tolerance, runout), Distortion properties (Rotational stresses, temp. changes), Rotor Design properties (Inherent which cannot be avoided) and Periodic properties (Corrosion, wear, distortion, deposit) etc. In universal motor, the rotor winding connected to external circuit by a commutator. It is responsible for delivering the mechanical power and for the transmission of torque. It is forced to rotate due to the interaction between winding and magnetic field. Thickness of lamination depends upon frequency at which armature is designed to work. Shaft must be stiff enough to control any out of balance forces. The length of the shaft is selected based on speed, bearing placed, and pulley requirement so as to minimize the harmonic distribution.Shaft material will be harder than stack and outer diameter of shaft will be more than the inner diameter of stack, for interference fit. Most of the problem is associated with rotor only, since it is the moving part and hence causes imbalance which will result in vibration and other kind of machine part failure. For this reason its balancing is required.

(B) Minitab:

Minitab is a statistic tool which gives us a very effective way to input statistical data, manipulation of data, identifies trends and patterns, and then extrapolate answer. It has boxplots, scatterplots, and histograms, and provides the ability to calculate "descriptive statistics". Minitab is a software which is vital to find the real underlying cause of problems within a process and makes problem-solving a much faster and easier process. The decision-making process for a hypothesis test is based on the p-value, which indicates the probability of falsely rejecting the null hypothesis when it is really true.If the p-value is less than or equal to a predetermined significance level (denoted by α or alpha), then you reject the null hypothesis and claim support for the alternative hypothesis and if the p-value is greater than α, then you fail to reject the null hypothesis and cannot claim support for the alternative hypothesis. With α equal to 0.05, the p-value (0.000) in the Analysis of Variance table provides enough evidence to conclude that there is a significantly different in the given data. The Tukey 95% confidence interval plot is the best graph to use to determine the likely ranges for the differences and to assess the practical significance of those differences.

(C)Knurling of Shaft :

The operation is performed for producing indentations on a part of a workpiece. Knurling allows hands or fingers to get a better grip on the knurled object than would be provided by the originally smooth metal surface. Occasionally, the knurled pattern is a series of straight ridges or a helix of "straight" ridges rather than the more-usual crisscross pattern. In case of shaft and stack (hole), knurls are provided to maintain the grip between them, so that slippage may not occur when torque and rotational force are induced.

(D) Runout :

Runout is how much one given reference feature or features vary with respect to another datum when the part is rotated 360° around the datum axis. It is essentially a control of a circular feature, and how much variation it has with the rotational axis. Runout can be called out on any feature that is rotated about an axis. It is essentially how much wobble occurs in the one part feature when referenced to another. In case of this paper, effect of change in runout value has been observed.

(E) Permissible Imbalance Value :

Any rotating body faces inherent balancing problem even if it will be in small quantity. There is no machine which while rotating does not have any imbalance value. Therefore International Standards Organization (ISO), American National Standards Institute (ANSI), Military Standards (MIL-STD), American Petroleum Institute (API) had made some acceptable value for imbalance under which a machine or a motor can run safely. This acceptable value is known as Permissible Imbalance value.

II METHODOLOGY

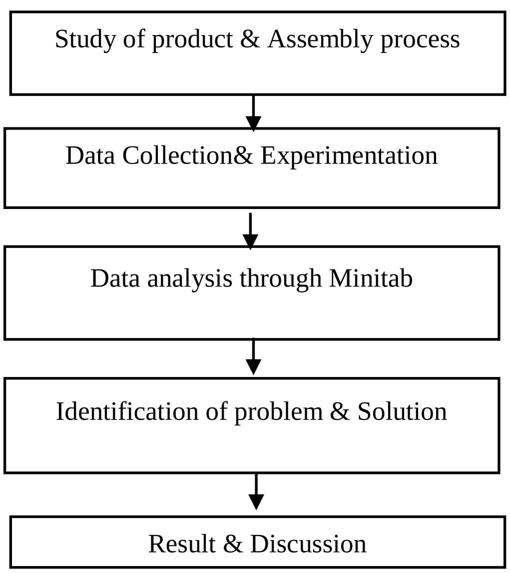


Figure 1: Methodology

III EXPERIMENTATIONS AND ANALYSIS WITH MINITAB

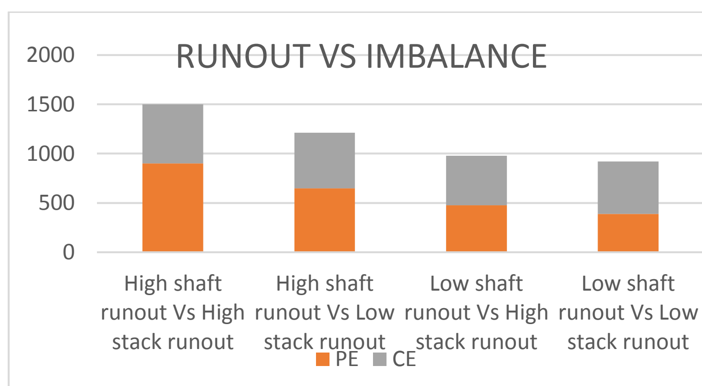
Nomenclature:
OD – Outer Diameter
CE& PE - Commutator End &Pulley End
P-Value- Probability that measures the evidence against the null hypothesis
T-Value- Measure size of difference relative to variation in sample data.
CI- Confidence Interval
DF- Degrees of Freedom
B Pr. – Before Pressing
A Pr. – After Pressing

(i) Effect of runout on imbalance:

The first consideration is Shaft and Stack Runout. For this, 25 samples of Shaft and 25 samples of random stack (hole) sized 40mm are taken and measured its runout at the center of stack seating area.
Later, it was dividedinto 4 categories (For each above conditions):
HSHSR **->**High Shaft & High stack Runout
HSLSR **->** High Shaft & Low stack Runout
LSHSR **->** Low Shaft & High stack Runout
LSLSR **->** Low Shaft & Low stack Runout

LEVELS	Mean PE	Mean CE	RANK
High shaft runout Vs High stack runout	903	597	4
High shaft runout Vs Low stack runout	647	564	3
Low shaft runout Vs High stack runout	476	503	2
Low shaft runout Vs Low stack runout	388	534	1

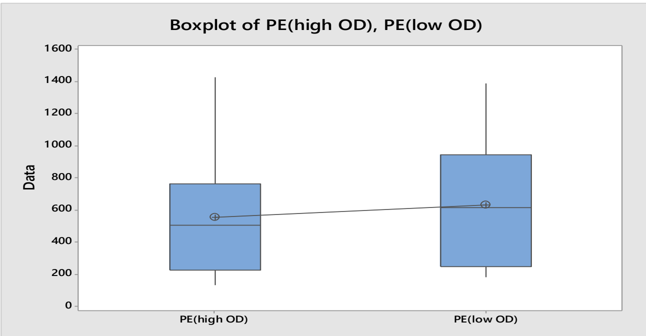
Table 2: Mean value for imbalance



Graph 1: Runout Vs imbalance

(ii) Effect of outer diameter of shaft:

In this experiment effect of outer diameter (OD) of shaft on imbalance must be calculated. For this condition 25 samples of shaft and arranged into two categories of High OD and Low OD and will examine the effect of imbalance after shaft and stack pressing.

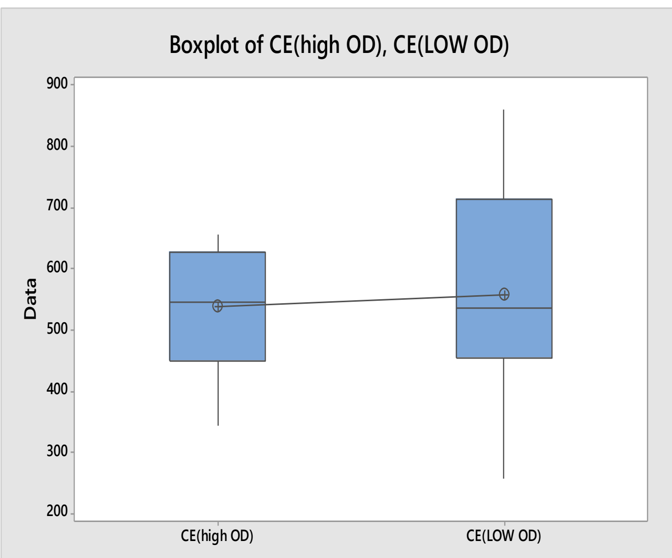


Testing of Hypothesis for the given data:

Two-sample T for PE (high OD) vs PE (low OD)

T-Test of difference = 0 (vs ≠): T-Value = -0.49 P-Value = 0.629 DF = 22

Analysis inference: From the P-Value of 2 sample t test (0.629 > 0.05), it is confirmed that there is no significant difference between the output of Low OD shaft and High OD shaft with the give data range.



Boxplot for low and high OD on PE side

Testing of Hypothesis for the given data:

Two-sample T for CE(high OD) vs CE(LOW OD)

T-Test of difference = 0 (vs ≠): T-Value = -0.36 P-Value = 0.720 DF = 19

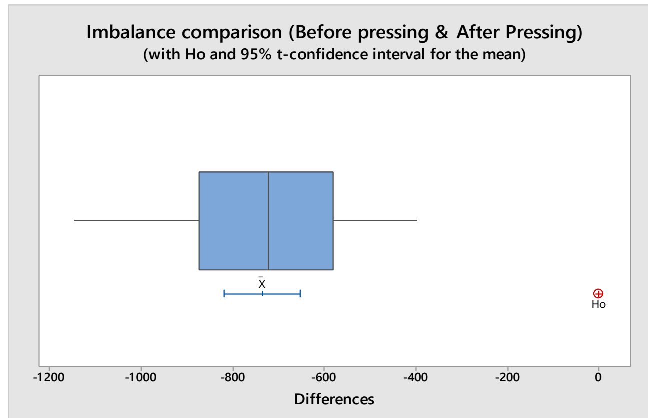
Analysis inference:

From the P-Value of 2 sample t test (0.720 > 0.05), it is confirmed that there is no significant difference between the output of Less OD shaft and High OD shaft with the give data range.

Boxplot for low and high OD on CE side

(iii) Effect of straight shaft replacement of taper shaft:

To reduce imbalance of rotor one of the alteration tried is to convert tapered shaft, 19.02mm to 19.09mm with tolerance of 30microns into straight shaft of 19.00mm diameter with tolerance of 20 microns.25 samples of straight shaft with four stack on each has been considered.



Paired T-Test and CI: Before and after pressing in PE side

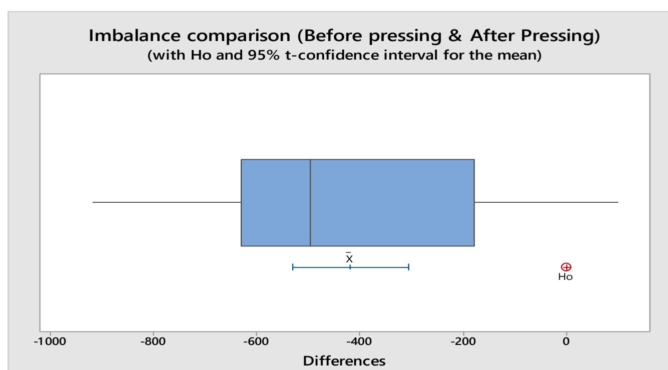
T-Test of mean difference = 0 (vs ≠ 0): T-Value = -18.28 P-Value = 0.000

Analysis inference:

From the P-Value of paired t test (0.000< 0.05), it is confirmed that there is a significant difference between the imbalance before and after pressing of shaft within the give data range.

Boxplot for B Pr. & A Pr. in PE side

Testing of Hypothesis for the given data:



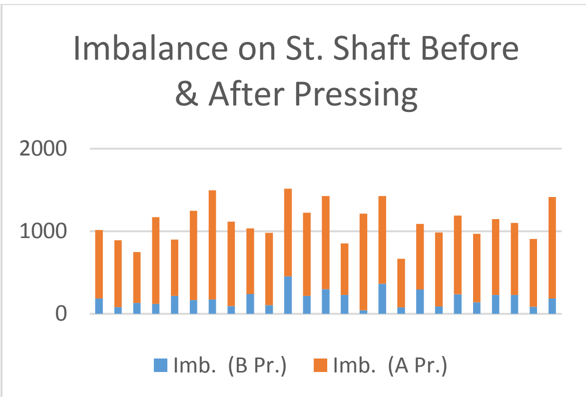
Paired T-Test and CI: Before and after pressing in CE side

T-Test of mean difference = 0 (vs ≠ 0): T-Value = -7.66 P-Value = 0.000

Analysis inference:

From the P-Value of Paired t test (0.000< 0.05), it is confirmed that there is a significant difference between the imbalance before and after pressing of shaft with the give data range.

Boxplot for B Pr. & A Pr. on CE side

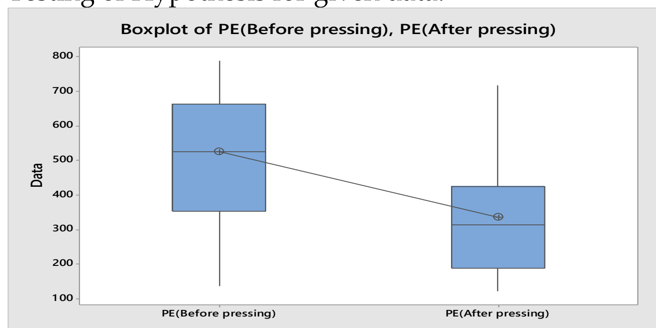


Graph 2: Graphical Presentation of Straight shaft

(iv)Effect on imbalance with knurling of shaft:

One of the consideration taken is straight shaft of diameter $19.01^{+0.01}$ with knurl of 42mm length, in the stack seating area. Change in shaft pattern is done to reduce the interference between shaft and stack. Insertion force will be reduce when the type of contact between the shaft and stack will be line contact instead of surface contact. Tapered form of shaft are having the possibility of reduced abrasion of the assembled surfaces; less pressure is required during assembling; and parts are more readily separated if required. But the taper fit on the other side is considered to be less reliable, because if it loosens, the entire fit is free with but little axial movement.

Testing of Hypothesis for given data:



Two-Sample T-Test and CI: PE (Before pressing), PE (After pressing)

T-Test of difference = 0 (vs ≠): T-Value = 3.10 P-Value = 0.004 DF = 31

Analysis inference: From the P-Value of 2 Sample T test (0.004> 0.05), it is confirmed that there is significant difference between, imbalance before and after pressing of shaft within the give data range.

Boxplot for B Pr. & A Pr. in PE side

(IV) Overview for the causes of imbalance, Table 3: Causes of Imbalance

S.No.	**Problems with imbalance**	**Examples**
1	Material Problems	Density, porosity, Voids, Blow Holes
2	Fabrication Problem	Misshapen casting, eccentric machining, poor assembly, tolerance
3	Distortion Problem	Rotational stresses, temp. changes
4	Rotor Design Problem	Inherent which cannot be avoided
5	Periodic Problem	Corrosion, wear, distortion, deposit
	Causes of imbalance	**Observational Signs**
1	Component eccentric on Shaft	Detectable runout on slow rotation
2	Dimensional Inaccuracy	Measurable lack of Symmetry
3	Eccentric Machining	Detectable runout
4	Oblique angled Component	Detectable angular runout, measured with dial gauge on knife edge
5	Bend shaft; Distorted assembly; stress relaxation with time	Detectable runout on slow rotation, often heavy vibration during rotation
6	Eccentric accumulation of process dirt on blade	Bearing vibration
7	Differential thermal expansion	Shaft bend & throws C.G. out; Source of heavy vibration
8	Non homogeneous component structure; subsurface voids in casting	Rotor machined concentric; C.G. runs to bottom on knife edges
9	Loose Parts or component slip	Vibration reappears after balancing; Vibration magnitude and phase changes

	Reason for Imbalance	Reduction/Elimination Process
1	Assembly Error	Accuracy in fixture
2	Eccentricity	Amplitude varies with load, runout
3	Wear	Regular checking of Life cycle
4	Corrosion	Avoiding moisture
5	Thermal distortion	Thermal Resistor/TOP
6	Mechanical distortion	Check speed/handling/keeping/assembling
7	Misalignment	Self-Alignment bearing
8	Loose rotating parts	Internal assembly between base and structure
9	Resonance	Natural frequency=operatingfrequency(Avoiding this condition)
10	Runout	Surface machining error, irregularities due to damage, scratches in rotor surface.
11	Unsymmetrical Design	Balanced properly with minimum sudden change in cross section
12	Mass unbalance	Even Distribution of Mass about rotating geometric center

V PERMISSIBLE IMBALANCE VALUE FOR UNIVERSAL MOTOR

Procedure for finding permissible imbalance value:

- For finding balance quality for rigid rotor go through ISO 1940/1, Article 6.2.3
- Determine Balance quality grade (G) according to requirement from the table given.
- Experimental Method

  Total residual accepted unbalance, U (gm.mm) = $\frac{9550 \times M \times G}{N}$

  Accepted unbalance per plane = U/2

  Acceptable unbalance in each plane = $\frac{U/2}{D/2}$ gm

  Balancing formula requirements:
- Unbalance of rotor (U) = Unbalance Mass (gm) × Distance from Unbalance Mass to rotor Centerline (mm).
- Quality Grade(G) relates Maximum Service Speed (rpm) and Permissible Specific /residual Unbalance(u) whose value will come in **mm/sec**
- N is Maximum Service Speed (rpm)
- For this paper:

  Quality Grade: Electric motor of at least 80 mm shaft height of maximum rated speed above 950 rpm will fall in G 2.5

  D= 71 mm or D/2 = 35.5 mm

  Conditions:

Table 4: Rotor parameters

S. No.	Size of rotor in mm	Speed in rpm (N)	Weight of rotor in Kg (M)
1	35	12000	1.47
2	40	15140	1.63
3	52	15276	1.95

Therefore,

Permissible Imbalance Value = U (gm.mm) = $\frac{9550 \times M \times G}{N}$ for different size of rotor are:

U (35) = (9550*1.47*2.5)/12000 = 2.925 gm.mm

Acceptable unbalance in each plane =2.925/35.5= 0.0824gm = 82.4 mg

U (40) = (9550*1.63*2.5)/15140 = 2.57 gm.mm

Acceptable unbalance in each plane = 2.57/35.5 = 0.0724 gm = 72.4 mg

U (52) = (9550*1.95*2.5)/15276 = 3.047 gm.mm

Acceptable unbalance in each plane = 3.047/35.5 = 0.0858 gm = 85.8 mg

VI RESULT AND DISCUSSION FOR EXPERIMENTAL TESTINGS

•In the first experiment, samples are arranged in decreasing order of combined runout for shaft and stack in which it has been confirmed that runout is directly proportional to imbalance of rotor.

•In the second experiment effect of outer diameter of shaft on imbalance has been checked, for which shaft was grouped in two categories (higher &lower OD), it is confirmed that there is no significant difference between Less OD shaft and High OD shaft.

•In the third experiment, straight shaft replaced tapered shaft, which has drastically increased the imbalance value, hence it is not recommended for reduction of imbalance.

•In fourth experiment, when straight shaft with knurling of 42mm length on the stack seating area is used, the imbalance value approaches the permissible range of imbalance. In this case interference is less with less runout, and hence the insertion force is also measured.

•Different problem, causes and reasons has been tabulated for the convenience and as a check out list for further consideration of imbalance.

•Permissible imbalance value formula with some examples has been discussed for Quality Grade, G2.5having property of electric motor of at least 80 mm shaft height of maximum rated speed above 950 rpm.

VII CONCLUSION

It is concluded that imbalance is more whenever the runout is more than the assigned value. The main cause of imbalance is runout and the interference between shaft and stack. Graph shows the decline in imbalance when straight shaft of diameter $19.01^{+0.01}$ with knurl of 42mm length, in the stack seating area is used. All the imbalance are under permissible value in this condition. More experiments can be performed based on list of imbalance and similar permissible imbalance can be calculated for knowing the allowable value of imbalance for any rotating machinery.

VIII FUTURE SCOPE

Alteration on the shaft and stack assembly process can be tried for best results. Winding pattern and windings wire tension on stack can also play the role in imbalance. Since imbalance is not the individual phenomenon, this may be due to combinations of different factors as described in the introduction of this paper.

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