Effect of Diameter, Pressure & Time on Maximum Free Rotation of a Needle Roller Bearing by ANOVA & Regression Analysis

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Abstract— In this study the Effect of bearing needle diameter, air pressure which is used for bearing auto rotation inspection and air blow time studied. Maximum free rotation counts of a needle roller bearing analysis done by using three factor factorial experiments by design of experiment approach and validate it by analysis tool by ANOVA and regression analysis software. Experiments were carried out using auto rotation testing machine. The result is useful to design engineer and automation development engineer in Research & Development department to optimize bearing life on the basis of maximum number free rotation of needle roller bearing during running inside the gear box or transmission under standard operating condition. This is the main aim of this study.

Key words: Needle Roller Bearing, Auto Rotation Testing Unit, DOE, ANOVA and Regression Analysis Software Etc

I. INTRODUCTION

The needle roller bearing need to check functionally for maximum free rotation test and it is carried out by shaft and housing on automatic testing machine where bearing fitted on shaft and housing with externally gear used . On the top side of the gear there is air pressure nozzle available with pulse counting sensor. Specific air blow carried out with specific time and air pressure on gear and hence due to pressure of air gear start to rotate and after free rotation it reach to stationary position. At the same time while gear rotate and sensor count rotation of bearing i.e. gear pulse count and PLC system shows the number of bearing rotation counts. On that pulse count basis machine decide bearing free rotation is OK or not ok. This is very important to show the bearing correct result when we check it by auto testing machine to avoid customer complaint and functional failure of needle roller bearing and as well as life of bearing. Auto machine based on air pressure, blow time of air pressure and needle diameter plays the major role hence it is necessary to study to fulfil the reliability expectations, it is required to understand the realistic influencing parameters auto rotation testing machine and bearing parameter

A. *Objectives*

To understand the realistic influencing parameters of bearings under operating conditions, it is required to conduct different experimental trials that give relationship of needle diameter, air pressure and air blow time. By studying this, the free rotation bearing can be evaluated. The main interest of this study is to understand the main effect of needle diameter, pressure and air blow time on maximum free rotation pulse count of needle roller bearing. Design of experiment approach used and validate it by ANOVA method and relationship by statistical mathematical model (Regression model). These values are compared with the theoretical values and the graphs are plotted simultaneously. Variety of parameter influences free rotation pulse count for the needle roller bearing are - Rotational Speed, Radial load, Lubricating oil used., Air pressure , Duration or time of air pressure blow, Needle diameter, Surface finish of roller, Temperature, Material of used for cage and rolling elements, Cage hardness and rolling element hardness. etc Based on the various needle roller bearing failure analysis report and literature survey we found that three most significant parameter which affect the maximum free rotation count of needle roller bearing are:-

1) Air pressure, P.
2) Time (Air blow time), T
3) Needle diameter, D

To execute the experimental trial, a needle roller bearing used tested on automatic free rotation testing machine. This relationship will help to control the operating parameters to maintain bearing result accurate and within allowable limits for a particular confirmation to avoid bearing failure during functional test. This will also help in predicting the life of needle roller bearing based on the study of key operating parameters.

B. *Theme*

Theme of this project is to find out the mathematical model between needle diameter, air pressures, blow time and needle diameter of bearing used in investigation. Regression model is to be developing by considering three factor factorial DOE approach. ANOVA and regression analysis is done to investigate the effect of individual factors varied on the performance parameter of bearing during free rotation testing.

C. *Research Gap*

By various research papers and failure analysis data of needle roller bearing we found following research gab:

1) Free rotation testing done by manual judgement.
2) Pressure to rotate bearing which cause to know free rotation bearing not clear.
3) How much time requires to blow the air pressure on gearing for testing on particular needle diameter were based on judgement for bearing testing.

D. *Earlier Work Done and Scope*

In earlier work and articles there is no more study done in the area to simulate maximum free rotation count of bearing concept automatic rotation bearing pulse count statistical mathematical model not established. In the view of the above there is scope for research to examine the effect of various parameter needle diameter, pressure and time to study the free rotation pulse count of needle roller bearing.

II. PROPOSED EXPERIMENTAL STUDY

The participation in the initial stages of experiments in different areas of research leads to justify the experimental treatments whose effects to compare and to defend completed experiment. When experiments are repeated, the effect of experimental treatment varies from trial to trial. This introduces a degree of uncertainty into any conclusion. Essentially, this is a rule for a deciding from examination of the data whether Hypothesis that is true shall be rejected only very occasionally and the probability of rejection may be chosen by experimentation and Hypothesis that is false shall be rejected as often as possible.

A. Design of the Experiment

It is a methodology based on statistics and other disciplines for arriving at an efficient and effective planning of experiments with a view to obtain valid conclusions from the analysis of experimental data. Design of experiments determines the pattern of observations to be made with a minimum of experimental efforts. To be specific Design of Experiments (DOE) offers a systematic approach to study the effects of multiple variables / factors on product / process performance by providing a structural set of analysis in a design matrix. More specifically, the use of Orthogonal Arrays (OA) for DOE provides an efficient and effective method for determining the most significant factors and interactions in a given design problem

The free rotation test carried out on single bearing checked "Auto rotation Test Machine" as shown in following figure.

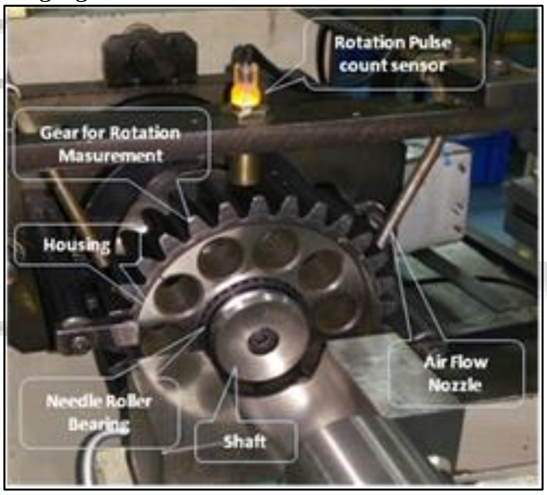


Fig. 1: Auto rotation testing machine set up

The basic function of this test machine is to test maximum free rotation of needle roller bearing by sensor mechanism . When bearing is come for testing, its free rotation is tested in terms of pulse count sensor mechanism. If free rotation is within range as we set benchmarking given range then bearing is accepted and if it beyond the range then bearing is rejected by auto machine.

III. MATHEMATICAL ANALYSIS (REGRESSION ANALYSIS)

The dictionary meaning of the term 'regression' is the act of returning or going back. Sir Francis Galton first used the term 'regression' in 1877 while studying the relationship between height of fathers and sons. He introduced this term in his paper "Regression towards mediocrity in hereditary stature". His study of height of about one thousand fathers and sons revealed a very interesting relation, i.e., tall fathers tend to have tall sons and short fathers, short sons. Galton called the line describing the tendency to regress or going back as 'Regression Line'. Now a day the estimating line instead of regression line is used. The term regression is defined in different contest as given below:

- Regression is the measure of the average relationship between two or more variables in terms of the original units of the data.
- According to Morris Hamburg, "Regression Analysis refers to the methods by which estimates are made of the values of a variable from knowledge of the values of one or more other variables and the measurement of the error involved in this estimation process.
- According to Ya-Lun Chou, "Regression Analysis attempts to establish the 'nature of the relationship' between variables- i.e., to study the functional relationship between the variables and thereby provide a mechanism for prediction, or forecasting".

Thus we may conclude Regression Analysis is a highly useful statistical technique for investigating and modeling the quantitative relationship between a dependent variable and one or more independent variables. The variable, which is used to predict the variable of interest, is called the predictor or repressor (independent) variable and the variable we are trying to predict is called the response variable. The predictor or regressor variable is denoted by X and the response (dependent) variable by Y.It utilizes experimental data on the pertinent variables to develop a numerical relationship showing the influence of independent variables on a dependent variable of the system. If nothing is known from theory about the relationship among the pertinent variables, a function may be assumed and fitted to experimental data on the system. Frequently, a linear function is assumed. In other cases where a linear function does not fit the experimental data properly, the engineer might try a polynomial or exponential function.

A. Uses of regression analysis

Applications of regression are numerous and occur in almost every field, including engineering, the physical and chemical sciences, and the social sciences. In fact, regression analysis may be the most widely used statistical technique.

The regression analysis attempts to accomplish the following:

1) It provides estimates of the values of the dependent variables from the values of independent variables. The device used to accomplish this estimation procedure is regression line. The regression line describes the average relationship between X's and Y variables. The equation of this line, known as the regression equation, provides estimates of the dependent variables when the values of independent variables are inserted into the equation.
2) A second goal of regression analysis is to obtain a measure of error involved in using the regression line as the basis for estimation. For this purpose the standard error of estimate is calculated. This is a measure of the scatter or spread of the observed values of Y around the corresponding values estimated from the regression line. If there is little scatter of the observations around the regression line, good estimates can be made of the Y variable.
3) With the help of regression coefficients we can calculate the correlation coefficient. The square of

correlation coefficient, called coefficient of determination (R^2), measures the degree of association of correlation that exists between the variables. The value of (R^2) is the important criteria to decide the validity of regression model. In general, greater the value of R^2 better is the fit, and more useful the regression equation is as a predictive device. If this value is 0.85 or more, then the relationship established by regression model is acceptable.

B. Assumptions of linear multiple regression analysis

1) The dependent variable is a random variable whereas the independent variable need not be random variable
2) The relationship between the several independent variables and the one dependent variable is linear.
3) The experimental error (residue) is randomly distributed with the constant variance and errors are normally distributed.

The limitation of the regression analysis is that, it cannot be used for extrapolation. This means that the values of independent variables must lie within upper and lower limits, those are set at the time of testing. This model gives the predicted value with some error, which cannot be exact. The error in the prediction is estimated by the coefficient of determination (R^2).The value of R is termed as regression coefficient. This value is calculated for all parameters of a given sample. To know the behavior of population-based sample, adjusted (R^2) value gives the level of validity, to use the regression model for population. Standard error gives the error in the predicted value of Y, the output or response.There is difference between predicted and actual value of the response or the same set of independent variables. It is possible to attribute this difference to a set of independent variable and the difference due to random or experimental errors. The technique of analysis of variance (ANOVA) work.

C. Analysis of Variance (ANOVA)

Analysis of variance is a standard statistical technique to interpret experimental results. It is extensively used to detect differences in average performance of groups of items under investigation. It breaks down the variation in the experimental result into accountable sources and thus find the parameters whose contribution to total variation is significant. Thus analysis of variance is used to study the relative influences of multiple variables, and their significance. The importance of ANOVA is:

1) To determine two estimates of population variance viz., one based on between samples variance and the other based on within samples variance. Then the said two estimates of population variance are compared with F-test.

$$F = \frac{\text{Between-Samples Variance}}{\text{Within-Samples Variance}}$$

2) Compare the calculated value of F with the table value of F for the degrees of freedom at a certain level of significance. If the calculated value of F is equal to or greater than the table value at pre-determined level of significance, the null hypothesis is rejected, otherwise accepted.

For this ANOVA table is prepared. In this ANOVA table, the sum of squares (SS) due to independent variable (this is also collectively due to regression) and the sum of squares due to error (residual) is separately given. Degree of freedom (df) is the number of way one can select the components for a set up under restriction. In the case of analysis, there is loss of one degree in sum of squares due to regression. Mean sum of squares (MSS) are obtained by dividing the SS by df, each for regression and error. The MSS related to error is called as variance. Now computer software is also available for doing all statistical calculation and preparing regression analysis and ANOVA based on the experimental design selection. All that we have to do is to mechanically enter the data in the manner prescribed by the software. Such software save engineers from spending time on statistical calculations and allow them to concentrate more on an experimental designs and experiment itself. One such software is Microsoft's Office. Microsoft Excel is a part of Microsoft Office. Excel is a powerful spreadsheet program that helps you to collect and to manage and analyze the data. Excel is a collection of worksheets.

D. Experiment Result

Nos of Factor = 3 and Nos of Level = 2
Factor A: Rotation Checking Air Pressure
3bar or 4bar (Low level -1 or High level +1)
Factor B: Time- Air Blow
0.2sec or 0.4sec (Low level -1 or High level +1)
Factor C: Diameter of Needle
2.497mm or 2.499mm (Low level -1 or High level +1)
Response: Y = Maximum Free Rotation Count

1) We test Hypothesis:-

H0: b1 = b2 = b3……….= bk = 0 (No explanatory variable is significant)
Ha: at least one bj ≠ 0 (At least one explanatory variable affect Y linearity)
In this case , Null hypothesis,
H0: P = T = D = 0 (Effect of air pressure , time of air blow and needle diameter has no significant effect on maximum free rotation count of needle roller bearing.)
Alternative hypothesis,
H1 : P ≠ 0 or T ≠ 0 or D ≠ 0 (At least one explanatory variable has significant effect on maximum free rotation count of needle roller bearing.)

Soruce of order	Air Pressure, P	Time-Air Blow, T	Diameter of Needle, D	Max. Free Rotation Count, Y
1	Low (-1)	Low (-1)	Low (-1)	10
2	High (+1)	Low (-1)	Low (-1)	115
3	Low (-1)	High (+1)	Low (-1)	16
4	High (+1)	High (+1)	Low (-1)	170
5	Low (-1)	Low (-1)	High	7
6	High (+1)	Low (-1)	High	114
7	Low (-1)	High (+1)	High	10
8	High (+1)	High (+1)	High	136

Table 3.4.1: Design of Experiment Method.

Exp.Order	Actual Exp. Order	Air Pressure P(Bar)	Time-Air Blow, T(Sec)	Dia. of Needle, D(mm)	Max. Free Rotation Count, Y(Nos)
1	6	3	0.2	2.497	10
2	8	4	0.2	2.497	115
3	2	3	0.4	2.497	16
4	3	4	0.4	2.497	170
5	4	3	0.2	2.499	7
6	7	4	0.2	2.499	114
7	5	3	0.4	2.499	10
8	2	4	0.4	2.499	136

Table 3.4.2: Three Factorial Design of Experiment.

Regression Statistics	
Multiple R	0.985416583
R Square	0.971045842
Adjusted R Square	0.949330223
Standard Error	15.30522787
Observations	8

Table 3.4.3: Regression Analysis Summary output

Source of Variation	*df*	*SS*	*MS*	*F*	*Significance F*
Regression	3	31424.5	10474.8333	44.71647	0.001556639
Residual or Error	4	937	234.25		
Total	7	32361.5			

Source of Variation	*Coefficients*	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	13348.50	13517.28	0.9875	0.379	-24181.48	50878.48	-24181.48	50878.48
Air Pressure	123.00	10.82	11.365	0.000	92.95	153.05	92.95	153.05
Time- Air Blow	107.50	54.11	1.9866	0.118	-42.74	257.74	-42.74	257.74
Diameter of Needle	-5500.00	5411.22	-1.016	0.367	-20523.94	9523.94	-20523.94	9523.94

Table 3.4.4: ANOVA Analysis

Observation	Predicted Free Rotation Count	Residuals
1	5.5	4.5
2	128.5	-13.5
3	27	-11
4	150	20
5	-5.5	12.5
6	117.5	-3.5
7	16	-6
8	139	-3

Table 3.4.5: Residual Output

Percentile	Free Rotation Count
6.25	7
18.75	10
31.25	10
43.75	16
56.25	114
68.75	115
81.25	136
93.75	170

Table no. 3.4.6: Probability Output

R^2 & adjusted R^2 is nearly 1 Thus model seems to be good.

We observe that p-value (Significance F) in ANOVA table is 0.001556 which is much smaller than 0.05

Therefore we reject the null hypothesis and conclude that at least one explanatory variable is significant. F-test used to overall validity of Regression model or test if any of the explanatory variable having linear relationship with response variable.

Suppose response variable Y (Free rotation count) depends on k explanatory variable (pressure, time & diameter) denoted as X,

$$Y = a+b1X1+b2X2+b3X3+\dots\dots\dots.+bkXk+Error$$

It called as Multiple Linear Regression Model.

In model, a is a interceptor or constant terms and b1, b2,…..bk are called regression slopes or regression coefficients. Fitted Regression Model is

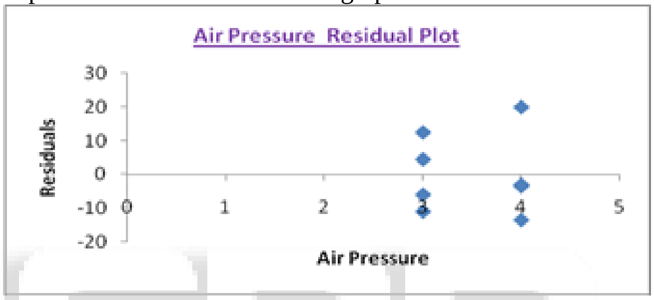
Max. nos of free rotation of bearing = 13348.5+123(Air Pressure)+107.5(Time-Air blow)-5500(Dia. Of needle)

$$Y = 13348.5 + 123(P) + 107.5(T) – 5500(D)$$

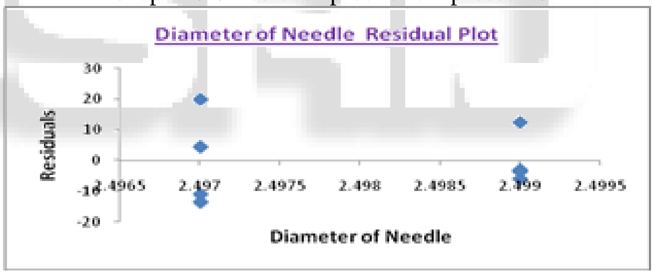
Hence this is the mathematical model or regression model for the auto rotation testing machine for needle roller bearing.

IV. RESULT AND DISCUSSIONS OF TEST EXPERIMENT TRAIL FOR NEEDLE ROLLER BEARING

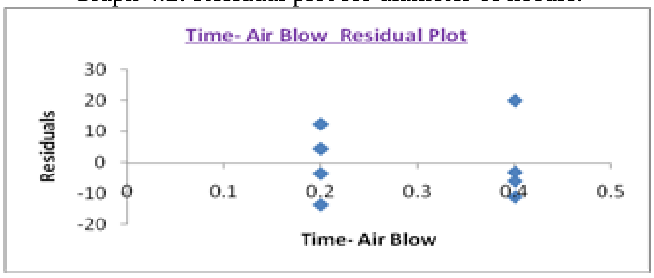
The results obtained from the experimentation have been expressed in the form of below graphs:-



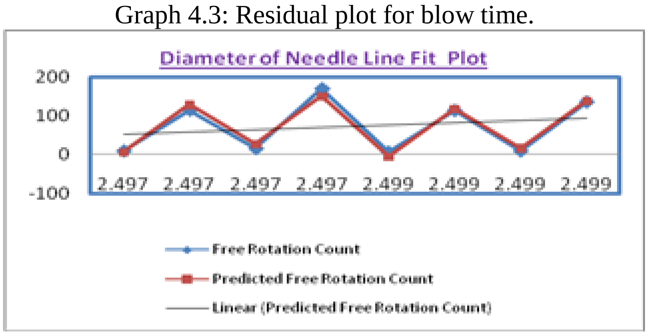
Graph 4.1: Residual plot for air pressure.



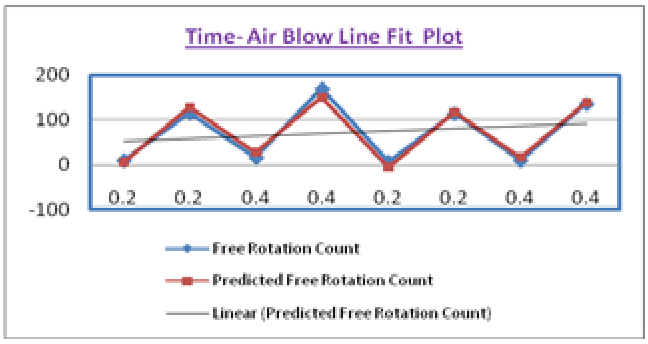
Graph 4.2: Residual plot for diameter of needle.



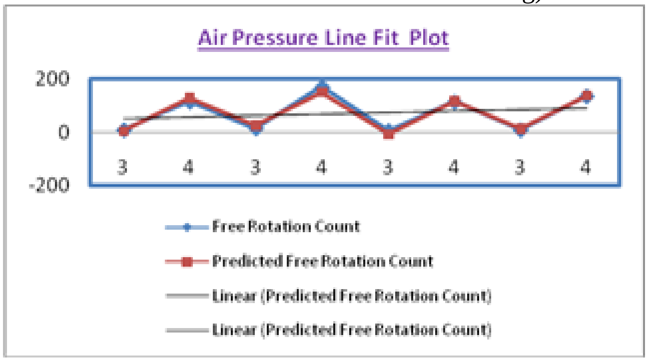
Graph 4.3: Residual plot for blow time.



Graph 4.4: Regression line fit plot (Needle diameter Vs Maximum free rotation count of bearing)



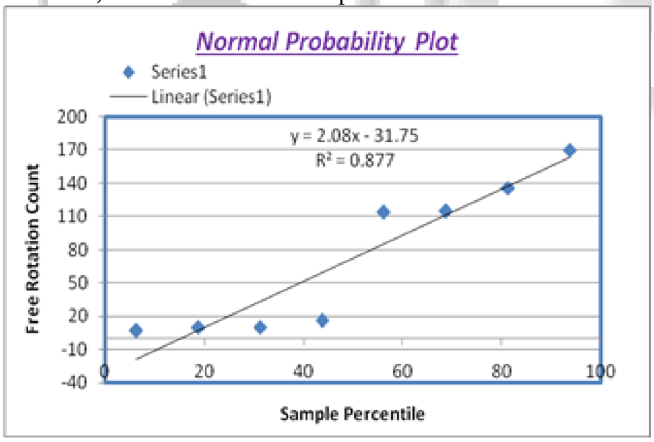
Graph 4.5: Regression line fit plot (Air blow Time Vs Maximum free rotation count of bearing)



Graph 4.6: Regression line fit plot (Air pressure Vs Maximum free rotation count of bearing)

Above all graph shows measured and predicted relative error.

Graph 4.4 to 4.6 Shows that maximum auto rotation counts of bearing result affect due to needle diameter, air blow time and air pressure.



Graph 4.7: Normal probability plot. (Sample percentile Vs Maximum free rotation count of bearing)

Graph shows correlation factor $R^2 = 0.88 > 0.85$. Hence regression model is acceptable and there is linear relationship between sample percentile and free rotation counts of needle roller bearing.

V. CONCLUSIONS

Based on above experimentations and mathematical analysis. Following conclusions are drawn:-

1) The equations derived shows that the number of free rotation counts of needle roller bearing is function of pressure, time and needle diameter. Hence generalize regression model for this experiment become,

   $$Y = 13348.5 + 123(P) + 107.5(T) – 5500(D)$$

2) The equations derived from the graphs shows correlation factor 0.89 which is more than 0.85 Hence regression model is acceptable and there is linear relationship between sample percentile and free rotation counts of needle roller bearing.
3) The equations derived by two types of experiments are accepted and error is minimum which is a cause of instrumental error, random error and fixed errors.

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