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Quality Analysis of Connecting Rod for Axial Misalignment: Bend Generated while Machining

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Abstract – *This study aimed to identify the causes of axial misalignment generation between pin end bore and crank end bore of connecting rod. Validation of potential causes enlisted in cause and effect diagram has given the input independent parameters for Regression analysis. Linear regression analysis is performed to find out the parameters which impact on bend generation in connecting rod. The results of regression analysis showed that four independent parameters succeed to reject the null hypothesis. Customized full factorial design is employed to evaluate the output of regression. Based on the results of factorial design it is interpreted that only Big end bottom side ovality is responsible for generation and bend in connecting rod. Fault tree analysis is done to derive the likelihood of ovality generation. The FTA results suggest that locating fixture wear out, improper clamping pressure and clamping sequence, inadequate coolant supply, change in machining parameters and faulty semi-finished connecting rod are the main elements need to be validated.*

Key Words: Connecting rod, Axial misalignment, Bend, Regression analysis, Cause and effect diagram, Fault tree analysis.

1. INTRODUCTION

Connecting rod is the important part of internal combustion engine. The function of connecting rod is converting rotary motion of crankshaft into reciprocating motion of piston-cylinder. It has quite distinctive shape. It seems like rod joining two circles at its both ends. Small end denoted as pin end which is fitted in piston and Larger end called as Crank end is connected to crankshaft. During performance connecting rod deals with alternative tensile and compressive type stresses. Power stroke generates higher compressive stress. While suction stroke connecting rod is subjected to partial tensile stress. In compression stroke when piston goes from bottom dead centre to top dead centre connecting rod is exposed to partial compressive stress. This partial compressive stress increased to the high compressive stress in power stroke.

On forged semi-finish connecting rod, various machining operations are carried out to make it fit for use. Boring, facing, chamfering, grinding, milling and deburring are most common machining methods in current practise.

1.1 Axial and Angular misalignment of connecting rod

Axial and Angular misalignment of connecting rod is nothing but 'Bend' and 'Twist'. Pin bore axis and crank bore axis of connecting rod need to be perfectly parallel with each other. When there is misalignment between axis in same plane it is called as bend (Axial Misalignment). [1] If misalignment is by angle it is defined as twist (Angular Misalignment). For the sake of manufacturing, misalignment is tolerable up to allowable limit. Fig-1 shows the bend and twist of connecting rod.

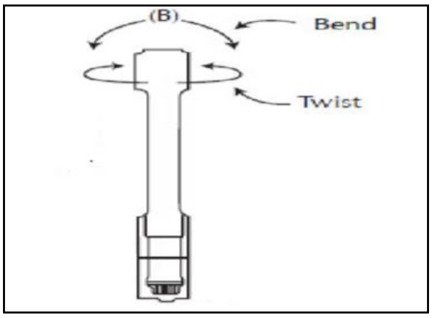

Fig -1: Bend and Twist

1.2 Impact of Bend

Presence of axial misalignment in connecting rod makes major impact

- Scoring of piston cylinder contact surface.
- Bearing failure due to uneven loading.
- Side thrust and irregular loading on piston.
- Premature failure of connecting rod.

When bend exists in the connecting rod, squeezing of oil hole clearance on one side of rod bearing will happen, and this will create the further tapered oil clearance problem. Which can ultimately lead to premature rod failure as unwanted forces acts on uneven manner.

Many methods are available for checking bend of connecting rod. Each method has its own benefits and drawback. CMM (Coordinate measuring machine) is one of the best method to measure bend. It gives accuracy to minute level. But it can't be used for 100% inspection as it incurs cost and time.

Generally, special purpose multigauge is used as inline inspection device for inspecting bend, twist, width, diameter, ovality, taper and other critical parameters. [8]

One can check bend by using two pins and v block. In this method, two pins with exactly same diameter of pin bore and crank bore are used. Length of pins should be longer than the width of connecting rod and both the pins should be of same length. Connecting rod is rested on v block. With the help of vernier height gauge height of extended length is measured. Deviation in height at various points need to zero. If it deviates from zero then there is bend present in the rod. Major drawback of this method is result accuracy, which depends on the operator skill.

2. Cause and Effect Diagram

To find out the possible causes of generation of bend in connecting rod the detailed study of machining process is done. Fig. 2 shows the cause and effect diagram.

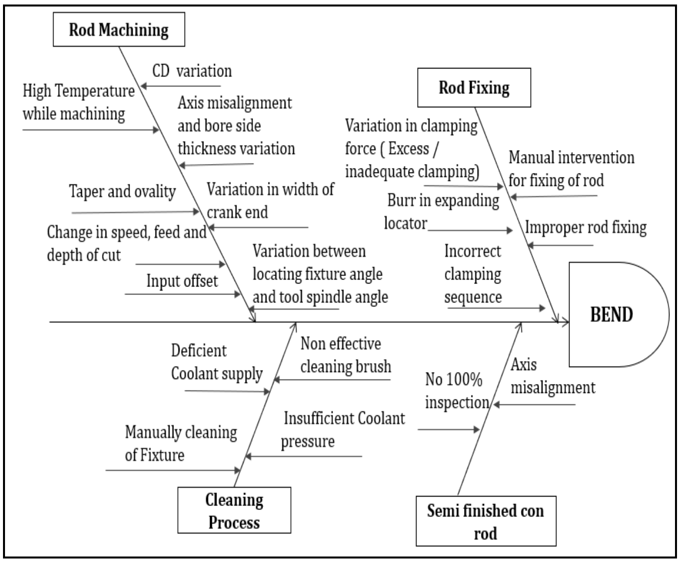

Fig -2: Cause and effect diagram

Validation of possible causes is done after plotting cause and effect diagram. One lot of Semi – finished forged rods is checked to ensure that input is free from bend. After that cleaning cycle study is taken out. Concerntration of cleaning solution, spraying pressure and position of cleaning solution, coolant supply, condition and performance of cleaning brush these major things validated and assured timely preventive maintainance. Burr is found on the locating fixture, because of that component did not rested on pad properly. For that pneumatic pipe connections are given so that there will not be any burr/chips on component resting pad. Generally crank end and pin end boring is carried out on Horizontal machining centre. At input stage, connecting rod is loaded on machine in horizontal condition. After resting, locating fixture rotates through right angle. The varition between this angle with respect to spindle, results in axial misalignment.

After validation and fixing of inputs from cause and effect diagram. Ten parameters are considered for Regression analysis. The regression analysis methodology is based on the equation 'y = a + bx'. Where x is independent variable and y is dependent variable.

3. Regression Analysis

Regression analysis method is used to find out that independent parameters which impacts on dependent parameter.[9] In this study, bend is treated as dependent paramter, is also called as response variable. And other eight independent parameters are predictor variables. The analysis is done by using MINITAB software. As number of input parameters is 8. For getting accuracy in interpretation of results around 100 components are considered for study. MINITAB's multiple regression analysis tool is used in this case.

Centre distance between two bores, top and bottom side ovality of BE and SE (Big end and small end), X side taper of BE and SE and width of big end are eight input parameters taken fot study.

Analysis is carried out in three iterations. In first iteration the continuous data is considered for study. For second iteration only second shift data is taken. Third iteration included third shift data. After analyzation, values of R Square, Adjusted R Square and standard error are checked for selection of better model to interpret the results.

Table:1 Output summary of iterations

Iteration's Summary output			
Iteration	**R Square**	**Adjusted R Square**	**Standard Error**
Continuous Data	56.35%	52.47%	0.0234318
Second shift Data	54.17%	50.26%	0.0242376
Third shift Data	53.48%	49.39%	0.0220936

Table 1 shows that the R Squre value is maximum for first iteration. More the value of R Square, better the model to interpret the accurate results. Hence, considered first model for interpretation of regression analysis. From the coefficient table generated in result it is seen that 4 parameters are having P- value <0.05, they succeed to reject null hypothesis. Null hypothesis says that there is no significant relation between dependent and independent parameter. As shown in fig. 3 ovality of big end bottom side, taper of big end x side, ovality of small end bottom side and width are the parameters which were highly impacting on generation of bend in connecting rod.

From table it is observed that the value of coefficient for width is negative. Negative coefficient concluded that there is negative correlation between bend and crank end width.

When one parameter increases as other decreases, it shows negative correlation.

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	-151.2	94.2	-1.61	0.112	
CD	0.445	0.241	1.85	0.068	3.90
ovality BE top	1.28	2.02	0.63	0.528	2.09
ovality BE bottom	6.73	1.32	5.10	0.000	1.32
BE taper_x	5.94	2.52	2.35	0.021	1.75
ovality SE top	2.81	2.85	0.99	0.327	2.74
Ovality SE bottom	7.67	2.81	2.73	0.008	1.20
SE taper_X	3.33	4.24	0.78	0.435	2.00
width	-0.307	0.121	-2.54	0.013	1.63

Fig -3: Result coefficients

VIF (Variance inflation factor) is criteria for multicollinearity. When VIF factor > 5, it indicate that predictors parameters highly correlates with each other. In this case VIFs are in accepatable range and the considered data is suitable to predict the correct results and model is reliable.

Regression Equation

Bend = -151.2 + 0.445 CD + 1.28 ovality BE top + 6.73 ovality BE bottom + 5.94 BE taper_x + 2.81 ovality SE top + 7.67 Ovality SE bottom + 3.33 SE taper_X - 0.307 width

Fig -4: Regression equation

Regression equation is shown in fig. 4. It is algrebric representation of regression line. It dectates coefficient value with their relation with dependent variable. The regression equation with more than 1 independent parameters follow following form :

$$y = a + b_1x_1 + b_2x_2 + b_3x_3 + \cdots\cdots + b_rx_r$$

Fig -5: Multiple linear regression equation form

The form used of regression equation is as given in fig. 5. From the equation 'y' is used to denote the response variable. 'a' is constant. 'b_1, b_2, ..., b_r are the coefficients. And x_1, x_2, ..., x_r are the predictor terms.

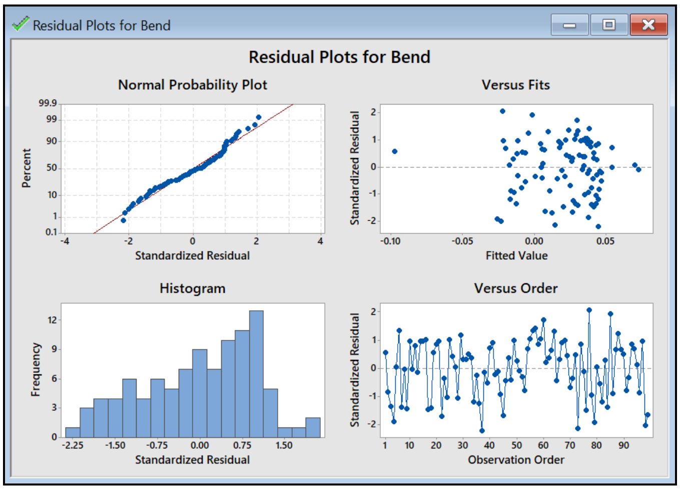

Fig -6: Residual plots

Histogram of residual plot shows distribution of residuals. It is mainly used to verify the data for outliers and skewness. In this case, it is observed that no skewness is present as there is no any long tail in one direction. No gap presents between the bars hence the data is free from outliers. From normal probability plot is is seen that distribution is normal, as residuals followed apporoximately the straight line. In versus fit plot, points fell on both the side of 0. Pattern of versus order is also evenly distributed about the centre line. The graph of versus fits and versus order ensured that model is fit for use.

4. Factorial analysis

To reach towards the exact impacting parameter, 2k factorial design is carried out for the 4 output parameters of regression. Output parameters are measurands. Because of that setting the levels and taking trials for analysis was not possible. For the analysis purpose customized design model is created by converting input data values into quanlitative type. For converting the statical values into qualitative type mean value is considered as basic criteria. Two levels defined as 'greater' and 'less'. The value which is more than that of mean value is treated as greater. When value is lower than respected mean is considered as less. The customized design matrix generated in minitab is as shown in fig. 7. Full factorial design matrix is formed. In this case, design is formed for 16 con rod as 4 factors with 2 levels are taken for study.

	C1-T	C2-T	C3-T	C4-T
	ovality BE bottom	BE taper_x	Ovality SE bottom	width
1	less	less	less	greater
2	greater	greater	greater	less
3	less	greater	greater	less
4	less	greater	greater	less
5	less	greater	greater	less
6	greater	less	greater	greater
7	less	less	greater	less
8	less	less	less	greater
9	less	less	less	less
10	greater	greater	less	less
11	greater	less	greater	less
12	greater	greater	less	less
13	greater	greater	greater	less
14	greater	less	less	less
15	greater	less	less	less
16	greater	less	greater	greater

Fig -7: Customized design matrix

For analyzation purpose, value of bend respected to that con rod is taken. Analysis id carried out by considering different terms.

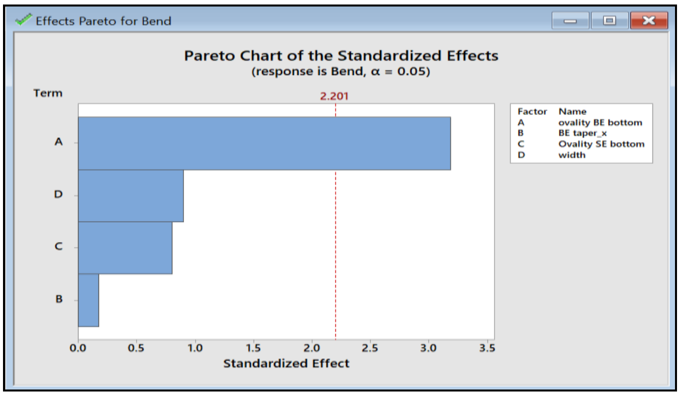

Fig -8: Pareto chart of main parameters

When analysis is carried out only by considering main parameters without consideing any interaction between them, result showed that only big end bottom side ovality is made impact on bend generation in connecting rod. The pareto chart from in fig. 8 clearly indicted that only BE bottom side ovality made significant impact by crossing the standardized effect line.

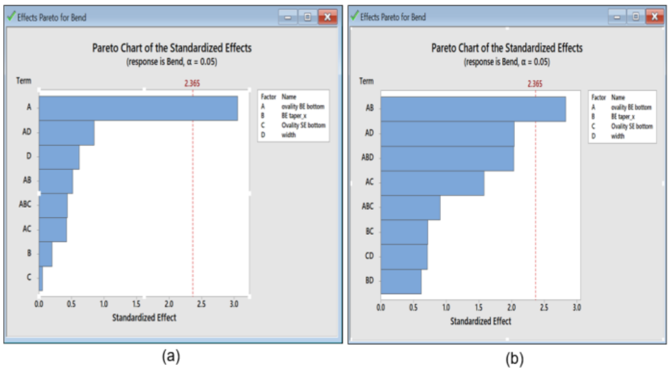

Fig -9: Pareto chart of interacting terms

Further analysis is done for the interactions between main terms to examine the impact of parameters interactions. As shown in fig. 9 it is concluded that no in between interaction terms are impacted on bend value.

5. Result and discussion

Factorial analysis implied that only reason of bend generation is ovality of big end bottom side. Fault tress analysis is constructed for ovality problem.

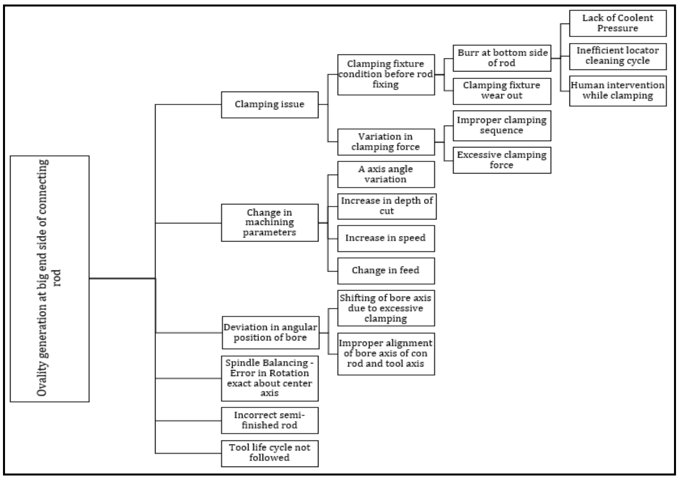

Fig -10: FTA of ovality

Fault tree analysis is plotted by process study, conducting brainstorming sessions on respected station. The first input from FTA is regarding clamping of connecting rod. If clamping is done irrespective to presence of burr/metal chips under the rod; there will be generation of ovality while machining. Clamping force variation and wrong clamping sequence may help to build ovality in connecting rod. Fig. 10 given detailed description of various elements. Change in machining parameter is main concern. When depth of cut increased irrelevant to speed and feed, ovality will take place. With respect to that if changes are carried out in speed and feed irrespective with depth of cut, ovality will build up. Balancing of rotating spindle is another important element need to be consider. If there is runout it will automatically generate ovality.

6. CONCLUSION

In this study analysis of connecting rod for axial misalignment (bend) is performed. In first part of analysis detailed process study is carried out and on the base of that cause and effect diagram is formed. After validation of cause and effect diagram, the points which are excluded invalidation are considered as input independent parameters for regression analysis. Multiple regression analysis is given the parameters which made bend generation in connecting rod. For further study of output of regression analysis 2k factorial analysis is performed. Factorial analysis cleared that only ovality of big end bottom side is responsible for bend generation in connecting rod.

To explain the reason of ovality generation, Fault tree analysis is formed. Fault tree analysis has given the parameters for validation as below:

- Locating fixture's condition
- Cleaning cycle efficiency, cleaning brush condition and coolant concentration
- Clamping sequence and clamping pressure
- Machining parameters
- Spindle balancing/ runout
- Tool life
- Semi-finished rod
- Inspection gauge

Above points validation will help to reduce ovality generation in connecting rod. When rod will free from ovality, there will be less chances of axial misalignment generation in connecting rod.

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