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Eccentricity Analysis Of Connecting Rod Big End Needle Roller Bearing

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Abstract

In this study the eccentricity concept of connecting rod big end needle roller bearing are studied and effect of rotating shaft velocity, radial load acting on bearing and duration is studied. The experiment was carried out using methodology of design of experiment based on Taguchi approach and L9 orthogonal array. Regression analysis was carried out to find empirical relationship in the mathematical model used. In which the amount of eccentricity of connecting rod big end needle roller bearing in terms of RPM, radial load acting on bearing and time of one cycle used in investigation is developed by regression analysis, ANOVA and error in predicting eccentricity for connecting rod big end needle roller bearing is carried out. It is observed that for the range of cage pocket parallelism, Speed of shaft and radial load explored in this study. The paper mainly focus of the relationship between cage pocket parallelisms with respect to bearing eccentricity and effect of various geometrical parameter which affect bearing noise in 100cc engine connecting rod big end needle roller bearing.

Key words: *Eccentricity, Big end connecting rod needle roller bearing, cage pocket parallelism, predicted eccentricity.*

1.Introduction

The connecting rod big end needle roller bearing are considered to be vital component of automotive engines for two wheeler , three wheeler. needle roller bearings have a much smaller diameter-to-length ratio. By controlling circumferential clearance between rollers, or needles, rolling elements are kept parallel to the shaft axis. A needle roller bearing's capacity is higher than most single-row ball or roller bearings of comparable OD. The bearing permits use of a larger, stiffer shaft for a given OD, and provides a low-friction rolling bearing in about the same space as a plain bearing. bearing is used to support radial loads under high speed operating conditions. In a bearing, load , velocity & time is generated linear displacement called eccentricity due cage geometry.

Therefore it is essential to know the true or expected operating conditions of the bearings. These operating conditions can be studied both by experimental and mathematical means, for example in test rig experiments on eccentricity test machine with connecting rod big end bearing and by calculation. To study the operating variable of connecting rod big end bearings at varying load and speed conditions, a test rig is developed. With the help of test experiment; laboratory test with connecting rod big end bearing a concurrent relationship between eccentricity verses load, velocity and duration have been established.

1.1 Necessity The field of application for journal bearings is immense. The crankshaft and connecting rod bearings of an automotive engine must operate for thousands of miles at high temperatures and varying load conditions. The reliability expectations are increasing day by day. To fulfill the reliability expectations, it is required to understand the realistic influencing parameters of bearings under operating conditions. To understand the realistic influencing parameters of bearings under operating conditions, it is required to conduct different experimental trials that gives relationship of eccentricity , load and velocity. By studying this, the life of bearing can be evaluated. The main interest of this study is to understand the maximum eccentricity over number of revolutions of crankshaft and factors affecting the eccentricity. The connecting rod big end bearing test rig is required to carry out experimental work on the connecting rod big end bearing. This will help us to determine the values of different variables acting on the bearings, under the given conditions. These values are compared with the theoretical values and the graphs are plotted simultaneously.

1.2 Objectives

The main objective of the study is to determine the relationship between eccentricity mechanism and its key operating parameters like –

- Load acting on bearing.
- Sliding velocity of shaft.
- Time or duration.(no of revolutions)

Of connecting rod big end bearing.To execute the experimental trial, a bearing used for Hero Motocorp Ltd make, 100cc engine connecting rod big end bearing has been taken.This relationship will help to control the operating parameters to maintain bearing eccentricity within allowable limits for a particular life of bearing or to avoid noise in the engine due to bearing failure. This will also help in predicting the life of connecting rod big end bearing based on the study of key operating parameters.

1.3 Theme Theme of this project is to find out the mathematical relationship between load on connecting rod big end bearing, velocity of shaft and no of cycles (time) for the bearing used in investigation. Regression analysis is done to investigate the effect of individual factors varied on the performance parameter.

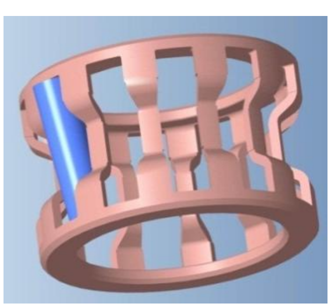

Figure 1: Cage of needle roller bearing

- **1.4 Cage:**Cage is a self-contained rolling bearing component. Cage is to hold rolling element in spacing, this helps in following ways: i) Ease of assembly & mounting in the unit. ii) Spacing between the rollers allows lubrication. Iii) Pocket guides needle rollers not to misalign during rotation, therefore running accurately with load carrying capacity.

1.7 Needle roller and cage assembly for big end

This assembly, subjected to a cranking motion with a simultaneous action of the rolling elements' rotation and revolution, must be light but have a high rigidity, and must have a precise dimension of the outer diameter of the cage so that the guiding system can keep an appropriate gap. The cage is made of high-tensile special steel with a surface hardening treatment. The guiding system employed is an outer diameter guiding system.The cage that may be subjected to poor lubrication can be protected with a surface treatment using a non-ferrous metal. For applications with a one-piece structure of crank shaft, the cage of split type is also available.

Table 1 :Assigning of Levels to the Variables as Applicable to experiment.

Level →	**Low**	**Medium**	**High**
Load, Kg	3	4	5
RPM	400	500	600
Time, Sec	1	1.5	2
Code	-1	0	+1

Table 2: Assigning of Levels to the Variables (Derived) as Applicable Practically for Hero Motocorp make 100cc engine crankshaft connecting rod big bearing.

Level →	**Low**	**Medium**	**High**
Load, N	29.43	39.24	49.05
Velocity , m/s	0.524	0.654	0.785
Time, second	1	1.5	2
Code	-1	0	+1

2.Calculations For the experimentation a machine designed for applying a load on bearing and correspondingly measuring velocity also measuring eccentricity after every trial. The diameter of shaft ground to 25 mm; the length of bush is 13.70 mm. Test parameter used with test rig are shown in table 3.2, while the parameters we usually used to calculate the eccentricity are given in table 3.3. The sample calculations for various parameters used for study are shown below.

For rolling Velocity:

$$V= (\pi \times d \times N) / (60 \times 1000)$$

Where, V=Sliding Velocity, m/sec;

D=Diameter of shaft, mm;

N=RPM motor shaft

For 400 rpm of shaft, V= (πx25x400) / (60x1000) = 0.524 m/s

For 500 rpm of shaft, V= (πx25x500) / (60x1000) = 0.654 m/s

For 600 rpm of shaft, V= (πx25x600) / (60x1000) = 0.785 m/s

Similarly other values are calculated and shown in above table.

Table 3: Model of Design of Experiment (DOE)

Trail No.	A	B	C	Y = E
1	-1	-1	-1	Y1
2	-1	0	0	Y2
3	-1	+1	+1	Y3
4	0	-1	0	Y4
5	0	0	+1	Y5
6	0	+1	-1	Y6
7	+1	-1	+1	Y7
8	+1	0	-1	Y8
9	+1	+1	0	Y9

2.1Postulation of Mathematical Model

The functional relationship between response (Eccentricity) and the investigated independent variables can be represented the equation is:

$$E = f(P, V, T) \text{ --------------------(I)}$$

Or we can write it as

$$E = K P^{m1} V^{m2} T^{m3} \text{ --------------(II)}$$

Where, E = Eccentricity mm

k = Characteristic constant

P=Bearing load, N

V=Velocity of shaft, m/s

T=Time, minutes (Duration)

Logarithmically equation 3.1 may be written as

$Log_{10}E= Log_{10}k+m_1 Log_{10} P +m_2 Log_{10}V+m_3 Log_{10} T$
The equation 3.2 of logarithm of depth of wear can be symbolically represented as

$$Y = m_0 + m_1X_1 + m_2X_2 + m_3X_3 \text{ ---------(III)}$$

Where, $Y = log_{10}E$

$m_0 = log_{10}K$

$X_1 = log_{10} P$

$X_2 = log_{10}V$

$X_3 = log_{10} T$

Equation 3.3 will be further used to determine the mathematical model for wear. Data was extracted from the observations made according to design of experiment. By using statistical techniques we can analyze the result to establish the relationship between variables.

The value of m1, m2 and m3 can be calculated by the formula

$$m_i = \frac{\sum_{i=1}^{3}\sum_{j=1}^{9}(X_{ij}Y_j)}{\sum_{i=1}^{3}\sum_{j=1}^{9}(X_{ij})^2} \text{ ----------------(IV)}$$

Where i = 1, 2, 3 & j = 1, 2…9.

Simplifying the above expression, we can find value of m_1 as

$$m_1 = \frac{\left\{\begin{matrix}(X_{1,1}Y_1)+(X_{1,2}Y_2)+(X_{1,3}Y_3)+(X_{1,4}Y_4)+(X_{1,5}Y_5)+\\(X_{1,6}Y_6)+(X_{1,7}Y_7)+(X_{1,8}Y_8)+(X_{1,9}Y_9)\end{matrix}\right\}}{\left\{\begin{matrix}(X_{1,1})^2+(X_{1,2})^2+(X_{1,3})^2+(X_{1,4})^2+(X_{1,5})^2+\\(X_{1,6})^2+(X_{1,7})^2+(X_{1,8})^2+(X_{1,9})^2\end{matrix}\right\}} \text{ -------------(V)}$$

Using above equation we can find out the values of constants m_1, m_2 and m_3 used in equation (II). We can find out the value of characteristics constant 'k' for all 9 treatments and taking the average we get mean value of K. This value can then be used for generalized equation of eccentricity.

3. Experimentation by eccentricity test machine The eccentricity test carried out on single bearing checked "Eccentricity Test Machine" as shown in figure. The basic function of test machine is to note radial displacement of bearing in clockwise and anti clockwise direction of needle roller bearing. When bearing is come for testing, its displacement of weight rings from laser sensor. If displacement is within range as we set benchmarking given then bearing is OK and if it is beyond given range then bearing is not OK.

Figure 2 : Big end needle roller bearing

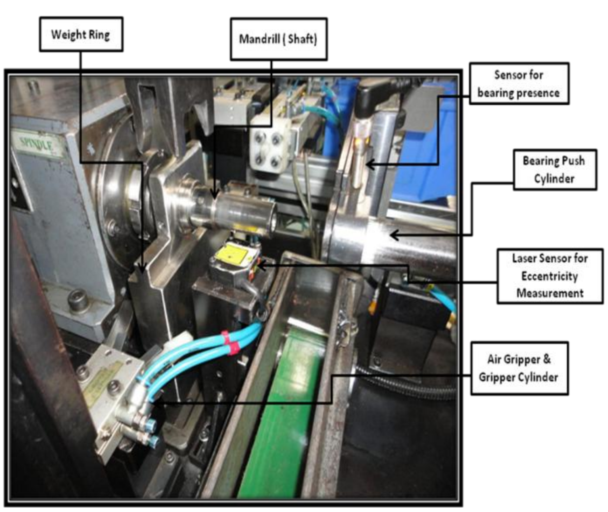

Figure 3: Eccentricity(Displacement) test machine

Bearing Eccentricity Analysis:
The effect of variable parameters (i.e. bearing load, velocity of shaft and time) on bearing eccentricity have been conducted in two ways-
1) Through test rig experiment.
2)Through endurance test with engine on engine testing dynamometer.

Table 4: Summary of test rig data for connecting rod big end bearing of 100cc Hero Motocorp engine

Trail	P (Load) in N	V (Velocity) in m/s	T (Time) in min	Eccentricity (mm)
1	29.43	0.523	1	2.7
2	29.43	0.654	1.5	4.0
3	29.43	0.785	2	5.1
4	39.24	0.523	1.5	4.2
5	39.24	0.654	2	4.6
6	39.24	0.785	1	3.7
7	49.05	0.523	2	4.4
8	49.05	0.654	1	3.3
9	49.05	0.785	1.5	4.5

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Table 5: Design of experiment for test rig data for Hero Motocorp 100cc engine Connecting rod big end bearing. (Bearing having avg. pocket parallelism is 0.03 mm)

Trial	P (load on bearing) in N	V (Velocity of shaft in m/s	T (Time) in min	E (Eccentricity) in mm	Log_{10} (Eccentricity)
1	-1	-1	-1	2.7	0.431364
2	-1	0	0	4.0	0.602060
3	-1	1	1	5.1	0.707570
4	0	-1	0	4.2	0.623249
5	0	0	1	4.6	0.662758
6	0	1	-1	3.7	0.568202
7	1	-1	1	4.4	0.643453
8	1	0	-1	3.3	0.518514
9	1	1	0	4.5	0.653213

Using the formula for calculating m_1, m_2 and m_3,We get,

$$m1 = 0.012$$
$$m2 = 0.038$$
$$m3 = 0.083$$

Therefore the eccentricity of bearing equation (II) becomes,

$$E = K\, P^{0.012}\, V^{0.038}\, T^{0.083} \text{-------------------(VI)}$$

Now K is found by substituting actual values of variables in the above equation for all 9 treatments and average was calculated.

Average K = 3.815

Thus generalized eccentricity equation for connecting rod big end bearing for 100cc engine is given as

$$E = (3.815)\, P^{0.012}\, V^{0.038}\, T^{0.083} \text{----------(VII)}$$

Table 6: Regression Statistics for Test Rig Experiment Data

Regression Statistics	
Multiple R	0.94488643
R Square	0.892810365
Adjusted R Square	0.828496584
Standard Error	0.034911061
Observations	9

By observing the regression statistics table it is seen that the value of R^2 is more than 0.85 so, the relationship established is acceptable

Table 7: ANOVA for Test Rig Experiment Data

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.601153545	0.01163702	51.65871766	5.13859E-08	0.571239632	0.631067458	0.571239632	0.631067458
X Variable 1	0.0123642	0.014252381	0.867518194	0.425326315	-0.024272712	0.049001111	-0.024272712	0.049001111
X Variable 2	0.038486447	0.014252381	2.700352126	0.042766066	0.001849536	0.075123359	0.001849536	0.075123359
X Variable 3	0.082616876	0.014252381	5.79670698	0.002152851	0.045979965	0.119253788	0.045979965	0.119253788

By observing the ANOVA table it is seen that the values obtained for X variables are same as that obtained by the mathematical calculations.

3.1Error in Predicting Amount of Eccentricity. In this work, numbers of tests were carried out to develop a mathematical model for eccentricity for 100cc engine connecting rod big end bearing by controlling the load, rotating velocity and rotation time. The developed mathematical model predicts the value of eccentricity at various conditions. The error in predicting eccentricity i.e displacement of bearing from its mean position is calculated for needle roller connecting rod big end bearing investigated and is given below.

3.2 Error in predicting eccentricity for connecting rod big end bearing of Hero Motocorp 100cc engine:

The generalized eccentricity equation for Sample bearing is

$$\mathbf{E = (3.815)\ P^{0.012}\ V^{0.038}\ T^{0.083}} \text{---------(VIII)}$$

The developed mathematical model predicts the value of amount of eccentricity in mm at various conditions. The measured value and predicted value of eccentricity are given in abovetable.

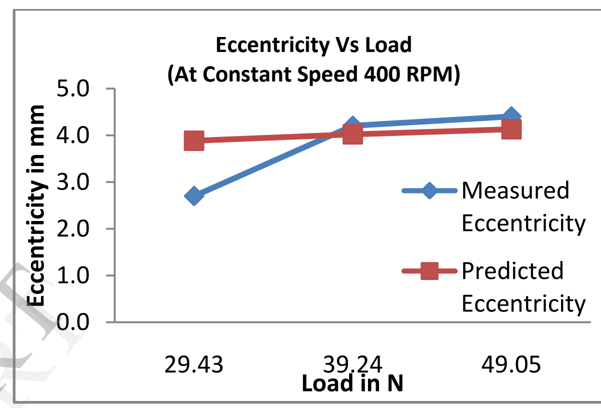
Table 8:Comparison Table of Measured E and Predicted E_p of bearing.

Trail No.	E	P	V	T	$P^{0.012}$	$V^{0.038}$	$T^{0.083}$	Ep	Ep - E	% Error
1	2.7	29.43	0.523	1	1.041	0.976	1.000	3.88	1.18	30.35
2	4.0	29.43	0.654	1.5	1.041	0.984	1.034	4.04	0.04	1.07
3	5.1	29.43	0.785	2	1.041	0.991	1.059	4.17	-0.93	22.31
4	4.2	39.24	0.523	1.5	1.045	0.976	1.034	4.02	-0.18	4.4
5	4.6	39.24	0.654	2	1.045	0.984	1.059	4.16	-0.44	10.7
6	3.7	39.24	0.785	1	1.045	0.991	1.000	3.95	0.25	6.33
7	4.4	49.05	0.523	2	1.048	0.976	1.059	4.13	-0.27	6.51
8	3.3	49.05	0.654	1	1.048	0.984	1.000	3.93	0.63	16.1
9	4.5	49.05	0.785	1.5	1.048	0.991	1.034	4.10	-0.40	9.85
% Average Error =					11.96%					

By comparing the measured E and predicted Ep for connecting rod big end bearing of Hero Motocorp 100cc engine, it is seen that average error is 11.96%.

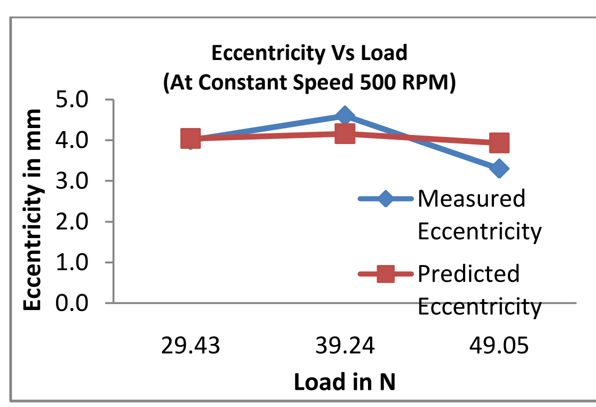
4. Result Analysis: The results obtained from the experimentation have been expressed in the form of tables and graphs shown in below.

Graph 1: Eccentricity of bearing (measured and predicted) Vs load at constant speed 400 RPM



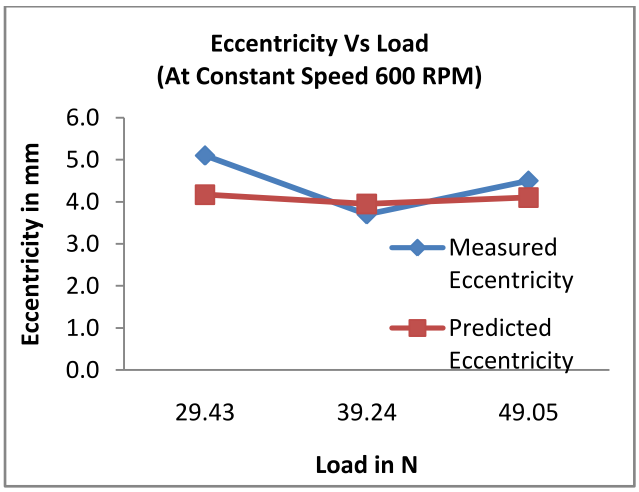
Graph shows - 1) Measured and predicted wear trend with respect to load at constant speed 400 RPM.2) The eccentricity of connecting rod big end bearing increases with respect to load. 3) Relative error between measured wear and predicted wear by regression analysis.

Graph 2:Eccentricity of bearing (measured and predicted) Vs load at constant speed 500 RPM



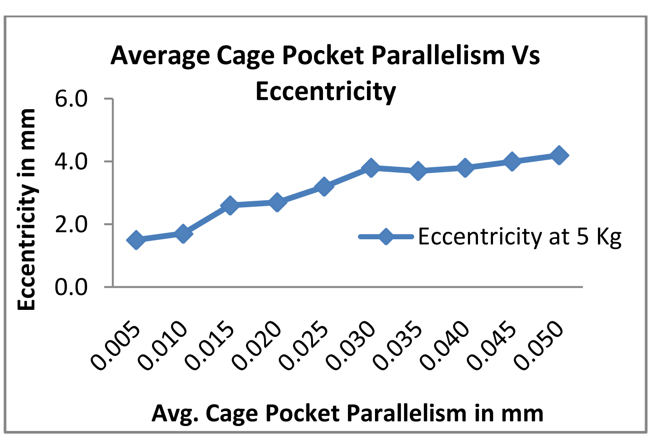
Graph shows - 1) Measured and predicted wear trend with respect to load at constant speed 500 RPM.2) The eccentricity of connecting rod big end bearing increases with respect to load.3) Relative error between measured wear and predicted wear by regression analysis.

Graph 3:Eccentricity of bearing (measured and predicted) Vs load at constant speed 600 RPM



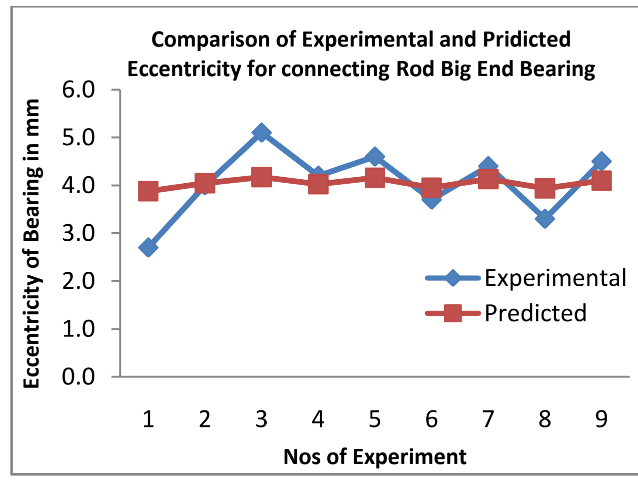
Graph shows -1) Measured and predicted wear trend with respect to load at constant speed 600 RPM.2) The eccentricity of connecting rod big end bearing increases at beginning and at certain load it just decrease and then increase with respect to load.3) Relative error between measured wear and predicted wear by regression analysis.

Graph 4: Relationship between average cage pocket parallelism Vs eccentricity of connecting rod big end bearing.



Graph shows - 1) Measured eccentricity trend with average cage pocket parallelism keeping load 5 kg, velocity 600 RPM and time 2 second. 2) The result shows that if average cage pocket parallelism increases then bearing linear displacement i.e. eccentricity also increases.

Graph 5:Comparison of measured & predicted eccentricity of connecting rod big end bearing for test rig trials.



Graph shows -1) Actual eccentricity of connecting rod big end bearing pattern with respect to the experiment trials.2) The eccentricity of bearing pattern by regression analysis with respect to the experiment trials.3) Relative error between actual eccentricity of connecting rod big end bearing and eccentricity derived by regression analysis.

5. Conclusions The test rig is indigenously designed for measurement of influence of variable parameters on eccentricity of Hero Motocorp ltd.make 100cc Engine connecting rod big end bearing.The experiments were conducted by varying controlled parameters such as load, speed and duration (time).

The Bearing is tested to practical level by keeping geometrical parameters *i.e.* diameter of bearing, width of bearing, thickness of bearing, surface finish, as per engine standard. The experimentation has been carried out on special type eccentricity checking test machine and confirmed the test results derived by rig test experiment.

The work generated a generalized eccentricity equation from both the experimentations for eccentricity with load, speed and time. Based on above experimentations and mathematical analysis following conclusions are drawn.

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1. The equations derived shows that the eccentricity of big end bearing is function of load, speed and time.
2. The equations derived from the graphs of eccentricity verses number of revolutions, the experiments shows that is having higher eccentricity at high shaft speed.
3. By increasing the bearing clearance, (varying c/d ratio of bearing *i.e.* bearing clearance to bearing dia.) the eccentricity of bearing also increases.
4. 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.
5. The average cage pocket parallelism should be less than 30 micron to control the noise in the 100cc Heromotocorp make engine, big end connecting ro bearing. Hence the benchmarking for eccentricity for this big end bearing is 4.195 mm maximum.

5.1 Applications The above results obtained from both the experimentations are useful for analysis of -

1. The rate of connecting rod big end bearing eccentricity atthe operating variables; load, velocity of shaft and no of shaft revolutions as a useful input for the designer while bearing design and new engine design and development.
2. It is possible implement eccentricity measurement with respect to control of cage pocket parallelism for other types of needle roller bearings. i.e. horizontal deployment..
3. Useful to modify and develop the punching tool to control pocket parallelism at process stage because pocket parallelism directly affect to eccentricity of connecting rod bearing indirectly reduces the factor which create noise in engine.

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