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Modelling and Analysis of The Effect of Plateau Honing Operation on Cylinder Liners

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Abstract

Honing is an abrasive procedure that removes material and creates grooves by employing three simultaneous motions of abrasive stones. Because honing is an abrasive operation, predicting the process outcome analytically is challenging. The steep peaks of a surface are eliminated during the plateau honing process, producing a reasonably plateau finish along with cross hatch pattern for retaining oil and increased bearing area. A cylinder liner is installed in an engine block to provide a cylindrical chamber where the piston may move extremely smooth. To obtain a honing pattern and good surface roughness, the machine setting plays an important role which includes many machine parameters like honing force, number of stokes, feed rate, processing time etc. So, in order to obtain an optimal machine set up, multiple trails on cylinder liners are done, which takes more time, and for each trail, one cylinder liner specimen is utilised, which results in the consumption of more cylinder liner solely for trail purposes. In this work, the key parameters effecting the surface roughness of cylinder liner are identified and optimal honing parameters (machine setup) are selected. FEA analysis is carried out to find the effect of pressure on the walls of cylinder liners. Based on the results of experiment, the optimal setting for honing machine is obtained for the selected surface roughness with less ovality and taper and also has less effect on cylinder liners.

Keywords: *plateau honing operation, surface roughness, honing machine, grid size of honing stick*

1.0 Introduction

Honing, a cutting process to enhance the surface of pre-machined liners. The finished surfaces are characterised by a cross hatch pattern. It is a superfinishing process for previously machined surfaces. Hone is a tool constructed of bonded abrasive stone in the form of a stick. The tool rotates around its axis and goes back and forth. The kind and size of abrasive used, as well as the pressure and speed applied, can all affect the quality of the surface finish generated by honing. To remove chips and keep temperatures down, a fluid is employed. Honing, if done incorrectly, can result in holes that are neither straight nor cylindrical, but rather bell mouthed, wavy, barrel-shaped, or tapered. For modelling the rough honing process, a neural network is developed using indirect model. This enables values to be defined for various process parameters as the function of necessary average roughness (Ra). From trial and error and Taguchi methods, best network configuration was determined [1]. An investigation on honing process utilized in the manufacture of liners at Kusalava International Ltd. was carried out to determine the impact of parameters on surface roughness of a cylinder liner. Taguchi optimization method was used to determine the optimized levels of parameters. From the plotted graphs and the Taguchi method, it was observed that the optimized levels of parameters are 125rpm cutting speed, 12kg/sq.cm load for finish and 10 strokes/piece no. of strokes [2]. An experimental investigation on surface quality of engine cylinder of grey cast iron material, machined in honing

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machine to determine the effect of honing parameters was carried out. For two different roughness parameters, the roughness models were also developed. To analyse the most affecting parameter on Ra and Rz, ANOVA method was carried and found that, Vp (Peripheral speed) and P2fh (finish honing pressure 2) [3]. The effect of various honing parameters on MRR and surface roughness was investigated. In particular, regression analysis yielded second order mathematical models for maximum peak to valley roughness, mean average roughness and MRR. In all experiments, CBN (Cubic Boron Nitride) abrasive was utilized. To generate, the mathematical models for MRR and roughness and to optimize the parameters response surface approach was utilized [4]. To determine the surface roughness of honing machines used in industries, a new method to translate the surface roughness values from the test honing machine was provided. By regression analysis of the roughness data of both machines, a quadratic model was developed and found that pressure and grain size are the most affecting parameters on surface roughness. This translation method was validated by using two more roughness parameters, core roughness depth (Rk) and maximum profile height (Rz) [5]. An examination on the effect of plateau honing patterns on liners with two ground surfaces and five types of honing marks was carried out for wear and frictional tests conducted with ISOVG68 oil at 40°C, 120 rpm speed and 100 N load. It was observed that, the amounts of wear volumes were larger in the deep grooved honing marks test, than in the shallow grooved honing marks test. This also reveals the wear behaviour was analogous form lubricated ball on flat contact test around the piston ring cylinder liners [6]. Dry cylinder liner for HinoX diesel engines was designed using Pro/Engineer and using ANSYS, thermal and structural analysis of cylinder liners with uncoated and coated was carried out. After comparing the results, thermal analysis and structural analysis of coated materials gives better results than uncoated materials used for dry cylinder liner. The alloying elements (coated materials) help to give the better performance of the dry cylinder liner [7]. The research on the cylinder liner plateau honing process indicated that the pressure of honing is a significant element of honing process. It also determines eventual depth of valley. The processing time is the second significant honing parameter [8]. Analysis on surface texture of plateau honed liner was carried out and found that the honed cylinder liner parameters can be predicted utilising statistical relationships between surface texture characteristics and honing profile parameters [9]. An investigation of wide variety of roughness characteristics was undertaken. The results show that, grit size has a substantial influence on the resulted topographical signature. Further, upon doubling the expansion speed, no noticeable effect on surface roughness parameters was detected, with the exception of isotropy str [10].

2.0 Working of Honing Machine

The honing procedure consists of a stroke and rotating movement of an expanding honing tool with embedded honing stones or diamond tips, as shown in the Fig.1. Honing creates a surface topography with a cross hatch pattern. The plateau honing process is timed by quickly cutting the peaks of the pre-machined bore face. This quickly results in surface smoothing.

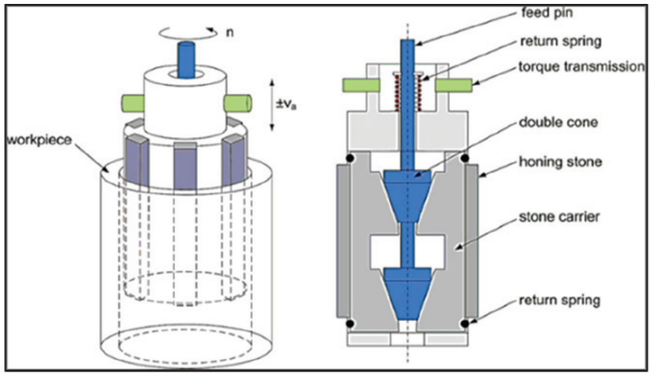

Figure 1: Working principle of honing operation

3.0 Problems of Honing Operations

1. Increased number of strokes lead to increase in the processing time and improper plateau honing pattern, uneven metal removal.
2. High pressure applied on the inside wall of cylinder liner leads to deformation in cylindricity.
3. Increased feed rates give rougher finishes, remove material faster, use up abrasives faster, generate more heat and make fine tolerances more difficult to obtain.

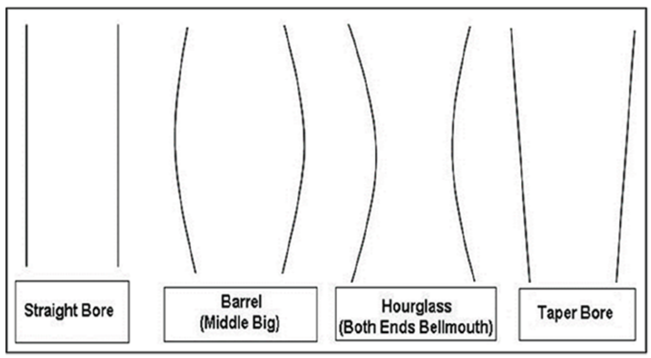

Figure 2: Cylinder liner defects

4. Stones typically overtravel the bore ends by one-third of their length. Too little over-travel creates a tight spot at the end. Too much over-travel creates a bell mouth bore. If the stones are so long that they do not reach the centre of the hole, the bore will be barrel-shaped, as shown in the Fig 2.
5. Increasing rpm will give rougher surface finish, slow cutting ability, decrease crosshatch angle and decrease geometric accuracy if increased too much.

4.0 Experimentation

The cylinder liner of inner diameter 155 mm and length 330 mm is selected as specimens (Fig.3). This cylinder liners are majority used in generators, HMV etc. The VH 800mm honing machine was used for the test as shown in Fig.4. The specifications are shown in the Table 1. From the Literature survey and by continuous trial of honing machine, it was found that the honing machine parameters that plays an important role in obtaining required surface roughness and good plateau hone pattern are spindle speed, pressure applied on inner wall of cylinder, stoke length, number of stokes, grit size of honing stone etc. [2]. The number of strokes was varied in 3 levels, 10, 20 and 30. Honing stick, made of Cork are built of simple eco and human-friendly abrasives found naturally that are powerfully bonded by the unique bonding to help scrape away microscopic materials that are still adhering to the cylinders and bearings. The advantages of using Cork stick were to reduce Ra and Rz values to good levels and also has no metal removal affects which extends engine life, improving fuel efficiency, and decreasing noise. The honing stick is made of Cork and Resin and is 203.2 mm (8 inches) in sength, 4 mm in width, and 4 mm in height is shown in Fig.5. The 3 levels of spindle speed i.e., 70, 80 and 90 rpm was selected. Continuous trial was carried out on the cylinder liner to know the optimal pressure to be applied inside cylinder. The pressure applied on the cylinder was varied and observed that at 3 MPa the MRR was very less and at 4 MPa and 4.5 MPa the MRR was too high than the required. So, pressure of 3.5 MPa was found to be the effective pressure. The number of strokes, grit size of honing stone and spindle speed were varied. The roughness parameters like R_t (maximum height of the profile), R_{3z} (base roughness), MR_2 (valley depth), R_a (mean roughness) values were measured using roughness tester and the ovality and taper are measured using inner ovality gauge, tabulated in Table 4. The cylinder liner is 3D modeled using CATIA V5 software is shown in the Fig.6. The CATIA Model was

Table 1: Specifications of Honing Machine

Honing Machine Model	VH800mm
Stoke Length of the Cylinder	800 mm
Max Honing Length	450 mm
Max Honing	Ø180 mm
Min Honing Capacity	Ø100 mm
Rotation Speed of Spindle	30 to 130 RPM
Clamping	By Hydraulic
Electronic Touch Screen	Yes

Table 2: Pressure variation for 30 steps during analysis

Steps	Time [s]	Pressure [MPa]
1	0.	0.
	1.	1.
2	2.	0.625
3	3.	0.75
4	4.	0.875
5	5.	1.
6	6.	1.125
7	7.	1.25
8	8.	1.31
9	9.	1.375
10	10.	1.5
11	11.	1.7
12	12.	1.9
13	13.	2.1
14	14.	2.3
15	15.	2.5
16	16.	2.7
17	17.	2.9
18	18.	3.1
19	19.	3.3
20	20.	3.5
21	21.	1.5
22	22.	1.44
23	23.	1.39
24	24.	1.34
25	25.	1.29
26	26.	1.24
27	27.	1.19
28	28.	1.14
29	29.	1.09
30	30.	1.

Table 3: Material Data

Material of liner	Structural Steel
Volume	1.6351 e^{+6} mm^3
Density	7.85 e^{-6} kg mm^{-3}
Mass	12.835 kg
Specific heat	4.34 e^{+5} m J/kg C
Thermal conductivity	6.05 e^{-2} W/mm C
Coefficient of thermal expansion	1.2 e^{-5} C^{-1}
Resistivity	1.7 e^{-4} ohm mm
Compressive yield strength	250 N/mm^2
Poisson ratio	0.3

Figure 3: Cylinder liner Specimen

Figure 4: VM 800mm vertical honing machine

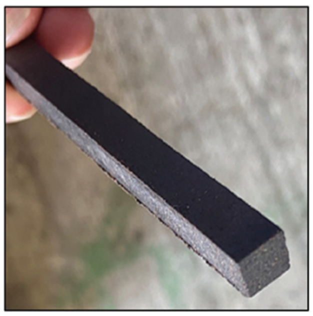

Figure 5: Honing Stick prepared

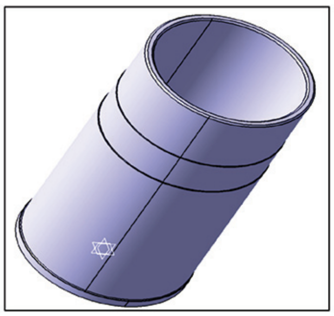

Figure 6: 3D CATIA model of cylinder liner

directly imported to ANSYS. The material data is mentioned in Table 3. The global coordinate system was selected and the state of coordinate system was fully defined. The model was meshed with mesh size of 3 mm and used Hexahedron element. The meshed model is shown in Fig.7. For the fineness, mapped face meshing was used. The pressure is

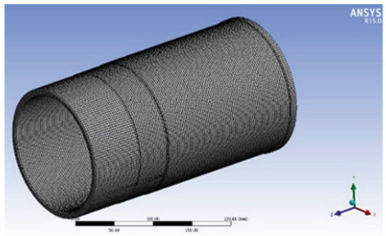

Figure 7: Meshed model

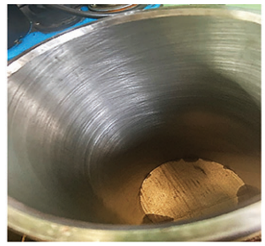

Figure 8: The final cross hatch pattern obtained

defined with respect to time. During analysis 30 steps are defined with having time value of 1 second i.e., 30 seconds in total. The tressure variation on liner's inner wall for 30 steps is shown in Table 2. The maximum pressure of 3.5 MPa was observed at 20th step.

5. Results and Discussion

For the experimentation, number of strokes, grit size, spindle speed was selected as major parameters. From the results, it is observed that increase in the number of strokes resulted in lesser Ra. The honing stick grit size variation showed a significant improvement in surface roughness. From the variation of spindle speed in 3 levels there was better surface roughness with good MRR. The final cross hatch pattern obtained is shown in Fig.8. The results for the surface roughness parameters like Rt, R3z, MR2, Ra with ovality, taper for different spindle speed, no. of strokes, and honing stick grit size is shown in Table 6. The required mean surface roughness (Ra) is 1.2 microns with less ovality and taper. So, for the honing stone of 120 grit size along with the spindle speed of 80 rpm and 30 number of stokes, achieved the mean surface roughness (Ra) of 1.2 microns and ovality and taper of 0.01 microns. The final maximum and minimum result from ANSYS software are shown in Table 7. The Time dependent analysis results at each step for total deformation, equivalent

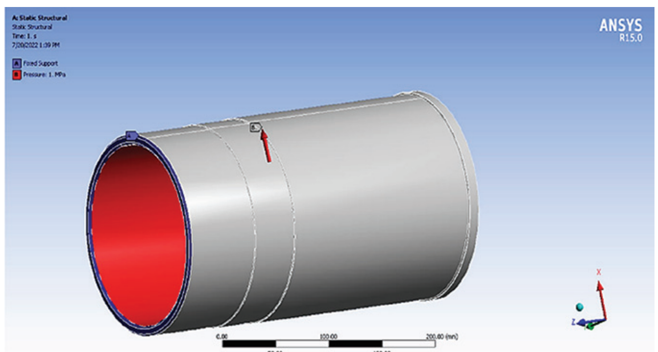

Figure 9: Load conditions

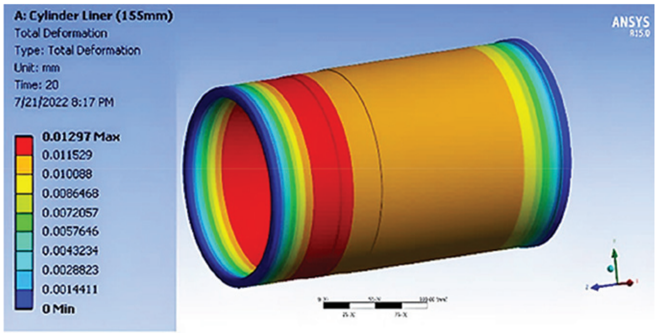

Figure 10: Contour plot for Total deformation

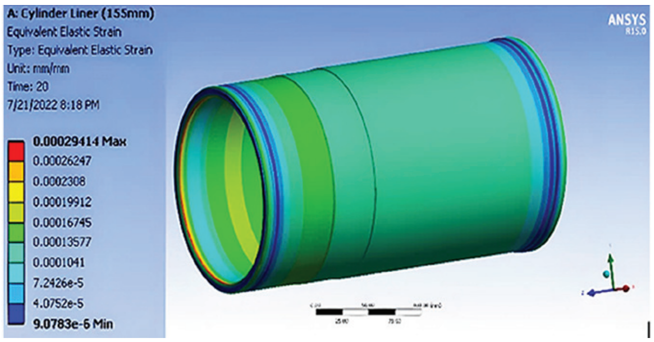

Figure 11: Contour plot for Equivalent Elastic Strain

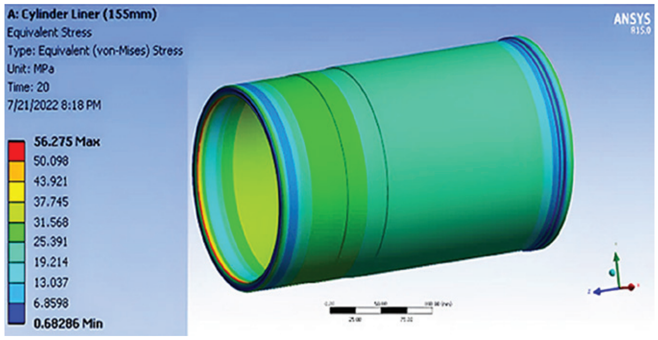

Figure 12: Contour plot for Equivalent (von mises) Stress

elastic strain, equivalent (von-mises) stress are shown in Table 8. It is observed that there is no major deformation due to the honing pressure applied on inner wall of cylinder. The maximum deformation of 0.012971 mm was found at 20th step. Therefore, there was no major deformation found, which is depicted in Fig.10. It is observed that the strain on cylinder liner was minimum, which is represented in Fig.11. The contour plot of equivalent (von-mises) stress displayed in Fig.12, shows that the stress on liner was also minimum when the pressure was maximum. From FEA analysis results, it was observed that there was no significant effect on the cylinder liners geometry due to honing pressure during the honing operation on cylinder liner.

Table 4: Measured data for surface roughness, ovality and taper

80 Honing Stick Grit Size							
Spindle Speed (RPM)	No of Stroke	Rt (μm)	R3z (μm)	MR2 (%)	Ra (μm)	Ovality (μm)	Taper (μm)
70	10	7.16	2.19	30.4	1.25	0.07	0.09
	20	5.83	3.58	40.4	1.24	0.05	0.06
	30	7.65	2.89	39.8	1.20	0.01	0.01
80	10	6.64	3.72	42.3	1.15	0.06	0.05
	20	5.63	2.75	41.2	1.14	0.03	0.04
	30	7.58	3.67	37.3	1.10	0.01	0.01
90	10	6.87	3.67	43.2	1.05	0.03	0.03
	20	6.73	3.85	41.1	1	0.02	0.02
	30	6.53	3.66	47.7	1	0.01	0.01

120 Honing Stick Grit Size							
Spindle Speed (RPM)	No Of Stroke	Rt (µm)	R3z (µm)	MR2 (%)	Ra (µm)	Ovality (µm)	Taper (µm)
70	10	7.3	4.12	63.2	1.35	0.08	0.01
	20	7.2	4.35	65.7	1.28	0.08	0.01
	30	7.8	4.9	69.3	1.21	0.07	0.01
80	10	7.74	4.32	64.7	1.22	0.05	0.02
	20	8.21	4.12	65.8	1.23	0.04	0.03
	30	8.71	3.7	68.7	1.2	0.01	0.01
90	10	8.12	3.32	65.8	1.12	0.05	0.05
	20	8.31	3.82	69.2	1.1	0.04	0.04
	30	8.91	4.52	68.4	1.21	0.03	0.01
140 Honing Stick Grit Size							
Spindle Speed (RPM)	No Of Stroke	Rt (µm)	R3z (µm)	MR2 (%)	Ra(µm)	Ovality (µm)	Taper (µm)
70	10	9.15	4.19	80.4	1.1	0.03	0.02
	20	10.4	3.69	79.7	0.91	0.04	0.01
	30	13.1	5.82	79.8	0.7	0.04	0.04
80	10	7.63	4.37	76.9	0.92	0.07	0.06
	20	10.2	4.24	80.6	0.91	0.01	0.01
	30	10.1	5.48	75.7	1.0	0.02	0.01
90	10	7.42	4.52	82.4	1.11	0.08	0.07
	20	8.55	4.24	80.4	1.1	0.05	0.04
	30	8.12	4.63	80.4	1.1	0.01	0.01

Table 5: Results from ANSYS software

	Total Deformation	Equivalent (von-Mises) Stress	Equivalent Elastic Strain
Results			
Minimum	0. mm	0.1951 MPa	2.5938e-006 mm/mm
Maximum	3.7058e-003 mm	16.079 MPa	8.4041e-005 mm/mm
Maximum Value Over Time			
Minimum	2.3161e-003 mm	10.049 MPa	5.2526e-005 mm/mm
Maximum	1.297e-002 mm	56.275 MPa	2.9414e-004 mm/mm
Minimum Value Over Time			
Minimum	0. mm	0.12194 MPa	1.6211e-006 mm/mm
Maximum	0. mm	0.68286 MPa	9.0783e-006 mm/mm

Table 6: ANSYS results for total deformation, equivalent stress, equivalent strain at each step

Total Deformation			Equivalent Stress			Equivalent Strain		
Time [s]	Minimum [mm]	Maximum [mm]	Time [s]	Minimum [MPa]	Maximum [MPa]	Time [s]	Minimum [mm/mm]	Maximum [mm/mm]
1	0	3.71E-03	1	0.1951	16.079	1	2.59E-06	8.40E-05
2		2.32E-03	2	0.1219	10.049	2	1.62E-06	5.25E-05
3		2.78E-03	3	0.1463	12.059	3	1.95E-06	6.30E-05
4		3.24E-03	4	0.1707	14.069	4	2.27E-06	7.35E-05
5		3.71E-03	5	0.1951	16.079	5	2.59E-06	8.40E-05
6		4.17E-03	6	0.2195	18.089	6	2.92E-06	9.45E-05
7		4.63E-03	7	0.2439	20.098	7	3.24E-06	1.05E-04
8		4.85E-03	8	0.2556	21.063	8	3.40E-06	1.10E-04
9		5.10E-03	9	0.2683	22.108	9	3.57E-06	1.16E-04
10		5.56E-03	10	0.2927	24.118	10	3.89E-06	1.26E-04
11		6.30E-03	11	0.3317	27.334	11	4.41E-06	1.43E-04
12		7.04E-03	12	0.3707	30.549	12	4.93E-06	1.60E-04
13		7.78E-03	13	0.4097	33.765	13	5.45E-06	1.76E-04
14		8.52E-03	14	0.4487	36.981	14	5.97E-06	1.93E-04
15		9.26E-03	15	0.4878	40.197	15	6.48E-06	2.10E-04
16		1.00E-02	16	0.5268	43.412	16	7.00E-06	2.27E-04
17		1.07E-02	17	0.5658	46.628	17	7.52E-06	2.44E-04
18		1.15E-02	18	0.6048	49.844	18	8.04E-06	2.61E-04
19		1.22E-02	19	0.6438	53.06	19	8.56E-06	2.77E-04
20		1.30E-02	20	0.6829	56.275	20	9.08E-06	2.94E-04
21		5.56E-03	21	0.2927	24.118	21	3.89E-06	1.26E-04
22		5.34E-03	22	0.281	23.153	22	3.74E-06	1.21E-04
23		5.15E-03	23	0.2712	22.349	23	3.61E-06	1.17E-04
24		4.97E-03	24	0.2614	21.545	24	3.48E-06	1.13E-04
25		4.78E-03	25	0.2517	20.741	25	3.35E-06	1.08E-04
26		4.60E-03	26	0.2419	19.938	26	3.22E-06	1.04E-04
27		4.41E-03	27	0.2322	19.134	27	3.09E-06	1.00E-04
28		4.22E-03	28	0.2224	18.33	28	2.96E-06	9.58E-05
29		4.04E-03	29	0.2127	17.526	29	2.83E-06	9.16E-05
30		3.71E-03	30	0.1951	16.079	30	2.59E-06	8.40E-05

6. Conclusions

1. The major honing parameters i.e., number of strokes, spindle speed, grit size played an important role in obtaining a required surface roughness.
2. The required mean surface roughness of 1.2 microns was achieved with honing stone of 120 grit size along with the spindle speed of 80 rpm and 30 number of stokes. These are concluded as the optimal honing machine settings for obtaining Ra of 1.2 microns.
3. The number of stokes decides the total processing time.
4. The FEA analysis depicted that the load condition i.e., honing pressure had no significant influence on the liner geometry and also that the stress in the cylinder liner was found to be minimal.

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