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Full Length Research Paper

Longitudinal Honing Input Parameter Characterisation with Surface Finish and Energy Use during the Precision Machining of Motor Vehicle Cast Iron Cylinder Reliner Sleeves

N. Tayisepi* **and E. Mahopolo**

Department of Industrial and Manufacturing Engineering, Faculty of Engineering, National University of Science and Technology, Bulawayo, Zimbabwe.

ARTICLE DETAILS

Corresponding Author:
N. Tayisepi

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ABSTRACT

The reconditioning and refurbishment of internal combustion engines involves significant operations such as machining engine blocks, heads, bearing seats, cylinder relining sleeves, cam shafts, crank shafts, and connecting rod ends. The abrasive process of plateau honing is crucial for improving surface texture quality and enhancing cylinder liner oil retention capacity. The sleeve liners play a crucial role in reducing oil consumption and losses due to friction in the engine. Research estimates that up to 40% of friction losses in engines originate from friction between piston rings and cylinder liner. The honing process generates cross-hatch pattern sleeve liner surface finish standard, which is important in cylinder liners of internal combustion engines found in motor vehicles. This study experimentally examines the influence of honing parameters on machining energy use and surface finish quality. The research methodology involved iterative variation of three important honing parameters – spindle speed, tool rotational diameter, and depth of cut – while monitoring, assessing, and analyzing the response parameters – surface finish quality and energy use. The results showed significant impacts on the response parameters due to variations in input parameters, suggesting the subsistence of optimal operating points to minimize energy consumption and achieve desired smoother cross-hatch surface finish quality. Further studies are recommended to establish the optimum honing input operating parameters for turning cast iron cylinder relining sleeves.

1.0 Introduction

Honing is a versatile and intricate abrasive super finishing machining process which is usually employed to improve the surface smoothness of machining manufactured components such as internal combustion engine liner sleeves and hydraulic cylinders. Longitudinal honing is an abrading operation of fine machining the inner bores of cylindrical surfaces such as are

* Author can be contacted at: *Department of Industrial and Manufacturing Engineering, Faculty of Engineering, National University of Science and Technology, Bulawayo, Zimbabwe.*

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utilised in the manufacturing of motor vehicle combustion engine cylinder liners. The honing operation is intended to produce internal cylindrical surfaces of fine finish quality as well as top-notch geometrical accuracy (El-Hofy & Youssef, 2008; Edberg & Landqvist, 2015). It is intended to remove flaws on high smoothness requiring surface, such as out of effective cylindricity or roundness, indentations, bore tapering, lacerations, etc on precise mating surfaces in assembled components.

Honing is a low velocity abrasive process, involving the correlation of three concurrent movements of the abrading stones which will also be pressing against the cylinder liner bore walls to remove material and create grooves, (Goeldel, Voisin, Dumur, El-Mansori, & Frabolot, 2013) on the bore walls. The process generates the cross-hatched pattern surface finish quality in the honed bores from the influence of the combination of the simultaneous reciprocating linear movement and rotational movement of the honing tool head on which the grit impregnated abrasive stones are mounted. Figure 1 show the cross-hatch pattern in a section of a honed cylinder and a typical honing tool head showing the nature of movements in operation, graphically. The cross-hatched pattern surface finish standard desirable, for lubrication holding, on the internal journal surfaces of the cylindrical bores such as bearings, hydraulic cylinders and internal engine bores, is mainly resultant from honing finish operating processes, (Irene, Piotr, & Carmelo, 2023).

The cylinder forms a structural element, of the internal combustion engine block, which holds the working fluid and the detachable piston wall in a closed space. The cylinder liner constitute one of the most essential functional components which construct the interior of an engine. It is the cylindrical component which is fitted into the engine block, forming the inner bore surface of the engine block cylinder. The cylinder liner cylindrical bore space forms the cavity in which the piston reciprocates. The cylinder liner serves as the internal wall of the engine cylinder as well as providing the journal surfaces for the piston rings whilst simultaneously maintaining the lubricant within. Thus, functionally, the cylinder liner must possess excellent sliding surface and oil retention characteristics, (Buj-Corral , Sender , & Luis, 2023)

Surface finish quality as well as energy use efficiency form two of the major performance metrics requiring close consideration, (Duc & Trinh, 2022), during the grinding machining process such as the honing of engine block cylinder sleeve liners. Particularly, for mating parts which experience relative motion with respect to each other, surface quality is a crucial performance enabler during the service condition of the components, (Umesh, Shubham, & Varinder, 2017). The honing abrading operation involves utilisation of three simultaneous motions of the abrasive stones, during the grinding process, to remove material and creating grooves. These, concurrent reciprocation motion and rotating abrasive cutting stone movements, result in the generation cross-hatched lay pattern in the interior bore surfaces of the cylinders. The component excess material is ground off by the slowly reciprocating and rotating abrading sticks which will be hard pressed against the cylinder walls to be machined.

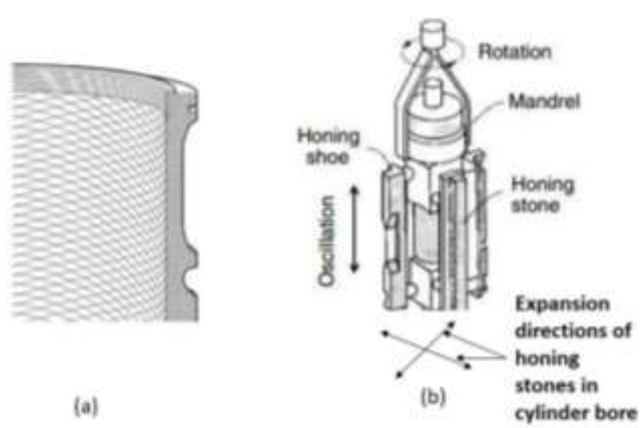

Figure 1. (a) View of the cross-hatch pattern on cylinder liner section, and (b) Simultaneous movement directions depicted on the honing head. (Edberg, Landqvist, 2015)

Studies estimate that as much as 40% of the frictional losses in internal combustion engines are attributable to friction experienced between the piston rings and the cylinder liners, (Sadeghi & Bolander, 2007). This elevates the prominence of the need for defined smoothness in the cylinder liners wall as a critical component in the engine with regard to moderating oil consumption as well as mitigating frictional losses, (Edberg, Landqvist, 2015). Thus, the sleeve liner surface should promote the cylinder wall ability to retain sufficient lubricating oil amounts in the crosshatch valleys as well as allowing the smooth gliding of the piston across the smooth cylinder inner wall crosshatch plateaus, (Umesh, Shubham, & Varinder, 2017). Establishing the trend of honing parameters effect on the generation of good crosshatched surface quality energy efficiently would provide vital aid to the machining industry of internal combustion engine sleeve liners.

Correlation of the associated reciprocating linear and rotational movement speeds, of the honing tool, determine the desirability of the generated crosshatch surface pattern, with appropriate angles, in the cylinder liner inner bore. Equation 1 describes the relationship of the of the movement velocities in order to determine the crosshatch angle value:

$$a_h = \tan^{-1}\left({}^{v_a}/_{v_r}\right) \qquad (1)$$

Where, v_r is the honing stone tangential velocity, v_a refers to the reciprocation speed and a_h is the half the angle of the crosshatch pattern.

Minimising manufacturing cost, time, resources and energy use combined with performance improvement is the main goal of production enterprises, (Neugebauer, Drossel, Wertheim, Hochmuth, & Dix, 2012). The research further dispelled the notion of attaining higher manufacturing efficiency predicated on utilising highest cutting conditions. In the practical reality of machining operations, cutting strategy determination is an essential aspect of the process optimisation consideration. Variable cutting parameters are set by the manufacturing operatives as necessitated by the requirements of workpiece component material and the condition of the machine tool (Chen, et al., 2021). The appropriate selection of honing variable parameters can effectively produce good quality surface finish and minimise cutting energy consumption, thus enhancing the machining process efficiency, (Umesh, Shubham, & Varinder, 2017).

This empirical experimental study aimed to enhance understanding of the honing operation process in the automobile cylinder liner sleeves machining process, as well as establishing the main influence trends of the three cutting parameters (spindle speed, tool path diameter and depth of cut) on the machining energy consumption and surface quality. Appropriate determination and selection of cutting conditions ensures the subsistence of efficient cutting action by the self-dressing process of the abrasive sticks, which action helps to avoid honing tool glazing. Information empowerment could assist machining manufacturers to improve their operation efficiency.

2.0 Experimental Process, Materials and Equipment

Understanding the behaviour of a manufacturing process influences the ability of stakeholders to continuously improve its operating efficiency and effectiveness. According to Edberg & Landqvist (2015), practical modelling is required to provide clear understanding of the machining process and estimate the nature of its output. This experimental study is intended to generate information which fosters understanding of how the honing process input variables (spindle speed, depth of cut and radius of rotation) affect the output performance outcomes of process energy consumption and surface quality, by respectively characterising them. It was deemed essential to establish the extent to which input process parameters influence the response parameters and in what way they do so.

The honing experiment runs design plan, in this study, were created utilising the Taguchi design of experiments (DOE) L16 orthogonal array, on Minitab 19 software which also was utilised in analysing the gathered primary data. The process involved varying three input parameters as the output responses, energy use and surface roughness quality of the lining sleeves, was being monitored and recorded. Table 1 show the parameters set and the setting levels considered.

Table 1. Parameter level settings

Process parameter	Levels			
	1	2	3	4
Spindle speed (rpm)	125	170	230	310
Tool path diameter	87.6	88.4	100.85	107.3
Depth of Cut (mm)	0.05	0.025	0.075	0.1

The honing tool used for the purposes of this study is a finishing stone number EHU 525-FY. The dry cylinder liners material used in the experiment was close grained pearlitic cast iron alloyed with chromium, molybdenum and vanadium. The graphite content available in the cast iron helps with lubrication whilst the alloying elements helps with corrosion resistance and wear resistance improvement at elevated temperatures, (Kumar, Rao, & Nara, 2015). The sleeve liner inner surface was heat treated in order to achieve smooth and hardened and surface. Castrol Honilo 981 honing oil was used as the coolant.
The experiment operation was carried out on the 310 rpm maximum spindle speed Sunnen CV-616E Cylinder King vertical honing machine shown in Figure 2.

Figure 2. Sunnen CV-616 Cylinder King vertical honing machine

The honing stone used was #580 grit silicon carbide vitrified abrasive. General sleeve liner dimension details, which conformed with the IS: 6750 – 1985 (Kumar, Rao, & Nara, 2015), were bore size 96.00 mm and length 86.41 mm. Surface quality measurement were conducted using the internal bore measuring hommel etamic perthometer – calibrated in accordance with the ISO 12179 standard - and electrical power measurements were recorded using the three phase digital Lutron 3 Power Analyser/meter. The surface measurement tool used had a 2 μm diameter diamond stylus in conformity with the IS0 3274:1996(E) standard. The tool have a resolution of, respectively, 0.5 μm in length and 7 nm in height. Measurements were done at a speed of 0.5 mms^{-1} accordingly in line with the standard, (Umesh, Shubham, & Varinder, 2017). The ISO 4288 standard was applied in guiding the measurement process. Accordingly, the measurement length was 5.6 mm whilst the evaluation length was 4 mm. An average of five (5) surface texture measurements was recorded for each parameters setting after which the settings would be adjusted for the next experiment. The average surface roughness parameter (R_a) was measured as the surface quality attribute in this research.

3.0 Results and Discussions

Summary of the experiment results is shown in Table 2 wherein data of the input variable parameters and response outcomes is presented.

Table 2. Summary of Experiment results

Run	Spindle Speed(rpm)	Depth of cut(mm)	Tool radius of Rotation(mm)	Ra (µm)	Electrical Power (kW)	Run Time(Sec)	Energy (x10-3kWh)
1	125	0.025	87.6	0.933	2.681	3.73	2.78
2	125	0.05	88.4	0.947	2.626	7.6	5.54
3	125	0.075	100.85	1.158	2.981	16.41	13.59
4	125	0.1	107.3	1.268	3.311	21.88	20.13
5	170	0.025	88.4	1.132	2.638	3.73	2.73
6	170	0.05	87.6	1.118	2.571	7.46	.33
7	170	0.075	107.3	1.453	3.122	16.41	14.23
8	170	0.1	100.85	1.343	2.975	21.88	18.08
9	230	0.025	100.85	1.59	2.981	5.47	4.53
10	230	0.05	107.3	1.7	3.318	10.94	10.08
11	230	0.075	87.6	1.365	2.632	11.19	8.18
12	230	0.1	88.4	1.378	2.669	14.92	11.06
13	310	0.025	107.3	2.028	3.189	5.47	4.85
14	310	0.05	100.85	1.919	3.122	10.94	9.49
15	310	0.075	88.4	1.707	2.571	11.19	7.99
16	310	0.1	87.6	1.694	2.571	14.92	10.65

Results presented in Figure 3 show the influence of tool radius of rotation on the average surface roughness and power consumption at varied spindle speeds. It is apparent from the graph plot that, at spindle speeds 125 rpm and 170 rpm, as the tool radius of rotation increased the surface texture (surface roughness, R_a) of the cylinder liner also tended to increase. Whereas, at spindle speeds of 230 rpm and 310 rpm respectively, as the tool radius of rotation increases the surface texture quality also tended to get smoother.

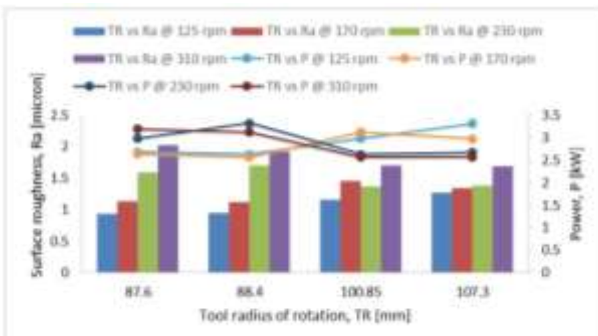

Figure 3. Surface roughness as a function of tool radius

Figure 4 show results plot of the influence of tool rotation radius on machining energy. It is apparent from the graph plot that as the tool radius of rotation increase the machining energy also tended to increase, however the increase of the machining energy tended to occur at a diminishing rate. The profile of the machining energy increase with increasing tool rotation radius tend to suggest the existence of an optimal operating tool rotation radius or machining energy operating point.

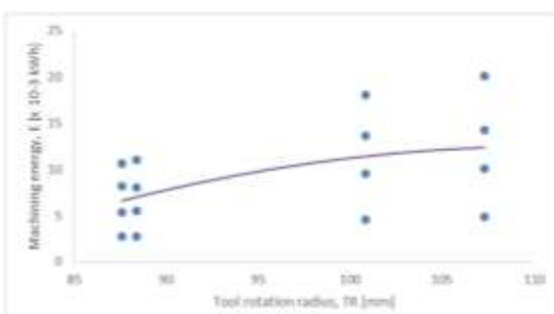

Figure 4. Tool radius of rotation influence on machining energy

Results presented in Figure 5 show the influence of spindle speed change on, respectively, surface texture of the sleeve liners and the cutting power. It is apparent from the results plot that as spindle speed increases surface roughness also increases whereas the cutting power marginally decrease with the increase in spindle speed.

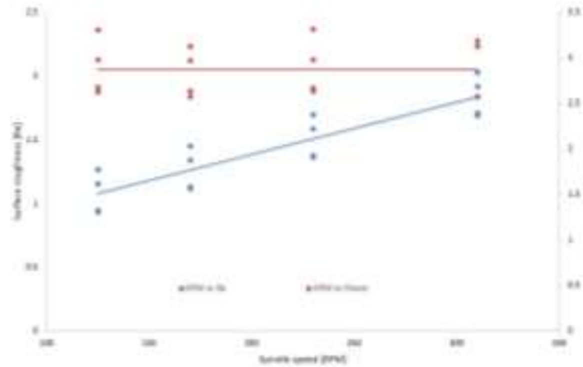

Figure 5. Spindle speed influence on surface roughness and power consumption

Graph results presented in Figure 6 is a plot showing the response of surface roughness (texture) and machining power to the influence of the changing increase in the depth of cut at varied spindle speeds. It is apparent from the graph plot that at spindle speeds of, respectively 125 rpm and 170 rpm, an increase in the depth of cut generally results in marginal increase in both the surface texture and the cutting power. On the other hand, at spindle speeds of 230 rpm and 310 rpm an increase in depth of cut also has an effect of resulting in general marginal decreasing in both surface roughness and cutting power respectively.

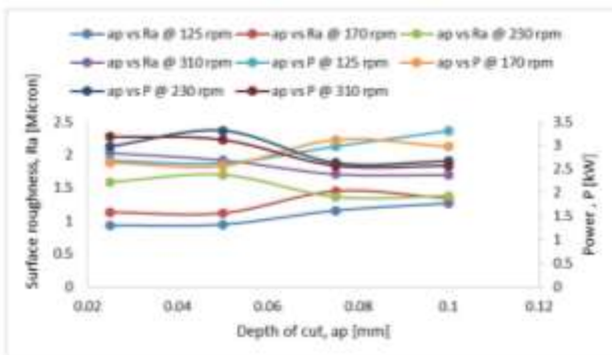

Figure 6. Surface roughness and power use as functions of depth of cut

Results of the influence of depth of cut on the machining energy are presented in Figure 7. It is apparent, from the graph plot, that an increase in the depth of cut is associated with a marginal increase in the machining energy. The profile curvature however seem to suggest the subsistence of an optimal level of energy use at some point in the increasing range of the depth of cut.

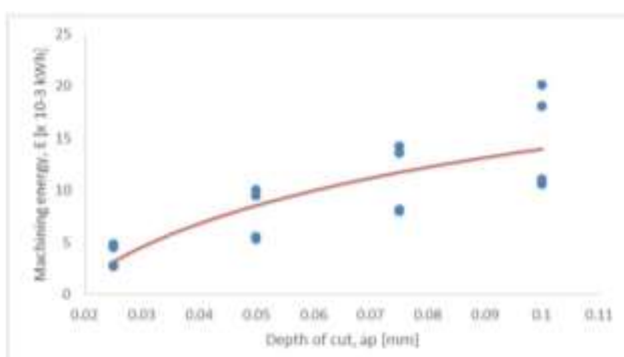

Figure 7. Effect of depth of cut on machining energy

Figure 8 present the results plot of the effect of spindle speed increase on the machining energy. The plot show that spindle speed increase is associated with a decrease in the machining energy. These results are in agreement with earlier findings by Tayisepi, Samambgwa & Madyira (2020) in a research on the dry machining of EN19 steel material.

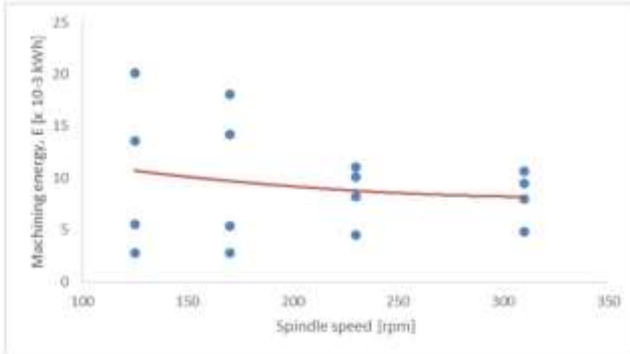

Figure 8. Spindle speed influence on machining energy

4.0 Conclusion

Taguchi Design of experiments (DOE) was utilised to plan the 16 plateau honing experiments carried out on motor vehicle internal combustion engine block cylinder relining sleeves. The goal was to establish the trend extent to which variation of three input process parameters – spindle speed, tool radius of rotation and depth of cut – influence the response parameters - energy consumption of the machining process and surface roughness quality generated in the relining sleeves. Results were analysed and parameter interrelationships were plotted to reflect on and understand the input parameters effect on the response parameters under consideration.

The following conclusions were reached after data analysis from the experimental study:

- Plateau honing is a significant finishing process in the development of appropriate surface quality standard during the machining of cylinder relining sleeves of motor vehicle engine blocks.
- Significant changes were observed on increasing of machining energy with changed tool radius of rotation, increase in surface roughness as a function of spindle speed and change of machining energy as influenced by increase in the depth of cut.
- There subsist an optimal operating point on the plots of machining energy, respectively, as affected by the increase in tool radius of rotation, depth of cut and spindle speed.
- Further studies would be recommended to establish the optimum operating point of these parameters as they influence the machining energy and surface quality standard of the cylinder liner sleeves.

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