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Experimental Investigation on Gear Manufacturing for Improved Quality

Nitesh Kumar¹, Dr. Pawan Kumar Yadav^{2*}

¹PG Student, Department of Mechanical Engineering, RIMT University, Mandi - Gobindgarh (PB), India

²Assistant Professor, Department of Mechanical Engineering, RIMT University, Mandi - Gobindgarh (PB), India

ABSTRACT: Manufacturing of gears has a significant role in the automotive sector. One of the best ways to boost production without compromising quality is to improve the hob tool's support structure. The variables that influence the procedure of cutting ought to be known and manageable.

With the use of theoretical research and experimental analysis, speed, efficiency, and flexibility are important factors influencing the productivity feed, surface quality, hob diameter, and cost of the hob. The parameters should be chosen carefully to minimize the increase in output by reducing the cycle time. The investigation has been conducted by utilizing the hob speed, feed, diameter, and material parameters and the various levels of each. Regarding the experiment, carbide was utilized for making hob tool/cutter material. Feed is shown to be more efficient for cutting material. The main aim of this research is to reduce the cycle time as well as the quality of the gear more effectively than anything else. Another strategy to reduce tool wear and improve gear quality is adaptive control. The Syntec 5-axis controller in this regulates and monitors all parameters, eliminating the errors that can be caused by the conventional gear hobbing machine tool.

KEYWORDS: Gear, Machining, Hobbing, Adaptive control (ac), CNC Hobbing

1. INTRODUCTION

On a hobbing machine, a unique kind of milling machine, hobbing is a machining process for cutting gears, splines, and sprockets. A hob, a type of cutting tool, makes a series of cuts into the material (a flat, cylindrical piece of metal) to gradually shape the gear's teeth, or splines. It is utilised for a variety of parts and quantities since it is reasonably affordable but still quite accurate when compared to other gear manufacturing methods.

Hobbing is the most common method for cutting spur and helical gears and is the method most often employed since it is the quickest and least expensive. Although it was a modest machine, the basic components may be seen in the typical patent drawings. It is easy to see the hob cutting tool and the gear train that will produce the proper ratio. Hobbing was certainly known in the watchmaking trades prior to his patent. Examples of manual gear hobs that can contribute to the production of gear prior to the 19th century and earlier can be found in many manufacturing companies that keep museums of how items were made in the past. Along with entirely manual gear hobs, there will also be samples of some of the first gear hobs that were semi-automated, and finally, there will be demonstrations of more current technology that shows how modern gear hobs create gear fully automatically. A few gear hob manufacturers also provide intriguing literature about the history of gear hobs, which includes information on how contemporary gear hobs can create thousands of gears in just one hour.

Rough machining is a crucial stage in making cylindrical gears for the automotive transmission sector. The process of cutting metal involves complex kinematics of the cutting tools and the material being worked on, chip generation, and tool wear mechanisms. Furthermore, the material and shape of the cutting tools influence how cost-effectively they can be used. A manufacturer recently announced plans to replace case hardening with using induction hardening to boost output, save CO2 emissions, and get the desired hardness following induction hardening. To achieve this, they employed cutting tool evaluation. The wear type and wear mechanism are crucial in terms of tool life. A key factor in hob design for high speed dry machining is the use of varied cutting speeds in various steels. Consequently, a test technique including one-tooth milling is quite desirable to replicate the worn style of gear hobbing.

II. LITERATURE SURVEY

Raafat examines how changing certain factors affects the conventional hobbing process, analysing and testing the outcome in reality. He focused his research on vibrations, cutting torque, power consumption, and tooth surface



roughness [1]. The micro-geometric deviations or geometrical tolerances of a gear, as well as the surface roughness of its flank surfaces, are used to determine its quality [2].

Deviations in gear micro geometry are expressed in terms of form deviation parameters, such as profile (Fa) and lead (F), as well as location deviation parameters, such as cumulative pitch (Fp) and radial run out (Fr). Form deviations (i.e., Fa and F) pertain to deviations in gear tooth form or shape, whereas location deviation parameters (i.e., Fp and Fr) refer to deviations or mistakes in gear tooth position. Roughness characteristics on the gear flank surface, such as average roughness (Ra) and maximum roughness (Rmax), indicate the unevenness or coarseness of the gear flank surface, which affects the gear's performance[2] ,[3] .

It employs synthetic cutting fluids in conjunction with flood lubrication (FL) and cooling technology to reduce and control heat generation by enhancing the frictional behaviour at the machining zone and assisting in chip evacuation. Cutting fluids are also important for improving product quality, lowering power usage, and extending tool life [4] [5].

The accuracy of applied manufacturing processes defines the quality of a gear, as defined by its elements, in order to satisfy the geometrical and dimensional demands, as required by functional circumstances and use cycles, for each component of an assembly or subassembly [6]. Continuous attempts are being made to eliminate or reduce the use of synthetic cutting fluids and reduce the process chain by discovering potential alternatives to the current FL technique in order to improve the sustainability and performance of the gear hobbing process [7], [8].

Although removing cutting fluids has its own set of drawbacks, gear hobbing without one causes more variations in gear micro geometry due to thermal expansion produced by severe heat accumulation in the machining zone, resulting in poor gear quality [9] .

MQL [Minimum Quantity Lubrication] delivers a precise amount of lubricant in aerosol form to the machining zone, reducing the detrimental effects of huge amounts of synthetic-based cutting fluids used in traditional FL techniques [8]. More effective lubrication and penetration of the lubricant, as well as improved frictional behaviour at the work-tool and tool-chip interfaces, can be achieved by supplying a precise amount of lubricant combined with compressed air [10].

[11] used a fly tool cutter to replicate hobbing for spur gear production in MQL and a dry lubrication environment. The tool wear rate and cutting forces obtained in MQL aided hobbing (MQLAH) were found to be lower than those obtained in dry hobbing. Matsuoka et al. conducted experimental research to manufacture spur gears by hobbing using coated tools in dry and MQL lubrication environments.

Zhang et al. [12] examined the performance of flood, dry, MQL, and cryogenic lubrication assisted hobbing of helical gears and found that MQLAH [Minimum Quantity Lubrication assisted hobbing] outperformed other lubrication systems in terms of tool life. There is a lack of research on MQLAH using environmentally friendly lubricants with the goal of determining the best ranges of MQLAH process parameters (i.e. hob cutter speed, axial feed, depth of cut, lube flow rate, and nozzle angle) for commercial production of superior quality spur gears. This is where the latest research fills in the gap.

The majority of earlier studies on sustainable gear manufacture used fly tool cutters and synthetic cutting fluids, and they concentrated on analyzing metrics including tool wear rate, thermal variations, and cutting forces.

Scholars have performed substantial research on the subject, with numerous positive outcomes documented in the literature. Hsu et al. [13] suggested a five-axis machine tool adjustment approach that was experimentally tested. An integrated positioning dependent geometric error (PIGE) identification and compensation method was suggested by Yang et al. [14]. Servo system errors were investigated by Andolfatto et al. [15]. Abukhshim et al. [16] looked into heat generation and heat transmission patterns in a high-speed gear hobbing machine.

As a result, the tooth design process, particularly in the automotive industry, focuses on optimum micro-geometry [17]. The goal is to cut down on transmission mistakes and, as a result, vibration excitation. This micro-geometry is influenced by gear manufacturing processes, particularly finishing operations [18], and this paper presents a case study to demonstrate the impact of two of these parameters, profile angle deviation (fH) and tooth trace angle deviation (fH), on the run-off cycle on test benches for high-performance automatic transmissions designed for passenger vehicles [19] [20] proposes a method for getting optimal cutting torque in the context of gear hobbing,

III. RESEARCH OBJECTIVE

As we already know, the CNC gear hobbing machine reduces the production time with an increase in quality of gears. But this paper helps to increase the quality of gear and reduce tool wear with continuous monitoring of the vibrations of the machine with the help of an adaptive control system.

Adaptive control helps to improve cutting speed and enhance the tool life. reduction in minor accidents, which is



caused by work material impurities.

IV. EXPERIMENTAL SETUP OF GEAR MANUFACTURING

The experiments were accomplished on an 8-axis (rotational + linear) CNC gear hobbing machine at Pa Pinions (H.P). In this, the whole trial is done on SS440C, which is work material with the help of carbide hob. Material SS-440C material is being widely used for various industrial applications, so experiments have been carried out by hobbing SS-440C blank gear of diameter 21.30 mm and width of 8 mm on a hobbing machine at different speeds and feeds.

4.1 Chemical Composition of SS440 C

Tooth profile per	:	86-108-870
Diametral pitch	:	60
Pressure angle	:	20.00
Number of teeth	:	47
Pitch diameter	theo.:	19.896
Outside diameter	max.:	21.178
	min.:	21.095
A.G.M.A. Quality class	:	10
Wire diameter	:	0.813
Measurement over wire	max.:	21.559
	min.:	21.496
Tooth to tooth comp. error	:	0.013
Total composite error	:	0.025
Testing radius ref.	max.:	10.160
Circular tooth thk.	max.:	0.823
	min.:	0.794
Helix angle	:	
Hand of helix	:	
Top hob / Non topping	:	Top hob
Tight mesh center dist. with standard master gear	max.:	29.210
	min.:	29.172

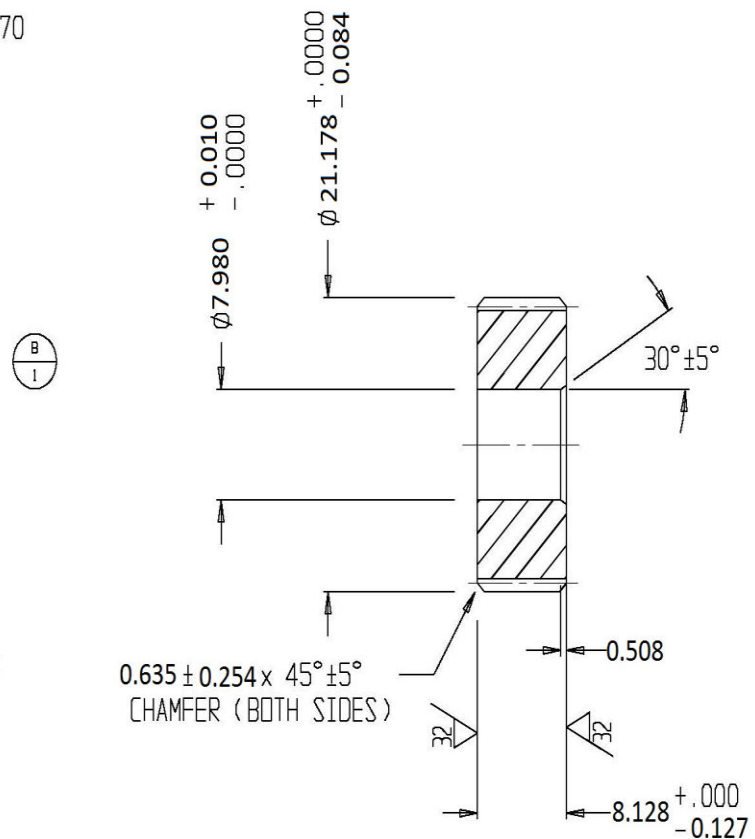


Fig.1 PART Drawing of Gear

Table 1 Composition of PART (SS440C)

Property	Value
Density	7.8 g/cm ³ at 20 °C
Elastic modulus	200 - 210 GPa at 20 °C
Poisson's ratio	0.27 – 0.30
Melting point	1483 °C
Mean Coefficient of Thermal Expansion	10.1 µm/m°C at 0 – 100 °C
Thermal Conductivity	24.2 W/m.K at 0 – 100 °C



Specific Heat Capacity	460 J/kg.K at 0 – 100 °C
Electrical Resistivity	600 nW.m
Elongation	13 % at 20 °C
Hardness, Brinell	285 at 20 °C
Hardness, Rockwell	B97
Tensile strength	740 - 755 MPa at 20 °C
Yield strength	445 MPa at 20 °C

Ref.:- <https://matmatch.com/learn/material/440c-stainless-steel>

4.2 Cutter/Hob

Carbide hobs involute are logarithmically relief ground. The following design is available from stock: DIN867-U2/Class AA / DIN3968 or 7/DIN58413/1 ggright hand. Special dimensions and design (e.g. Multi – start mills/ quality AAA).

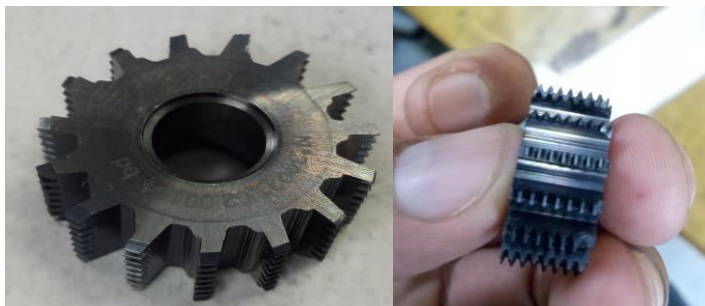
Material = Carbide

DP of HOB = DP60

Class = AA

Standard number of teeth of the cutter = 15

Outer diameter (OD) = 24mm



Helix angle = 1.02 Degree

Fig. 2 Carbide Gear hob

4.3 Instruments for measuring performance characteristics

Hob wear, surface roughness, chip thickness, tool life, and cutting power have all been measured during the studies. An instrument maker's microscope was used to gauge tool wear.

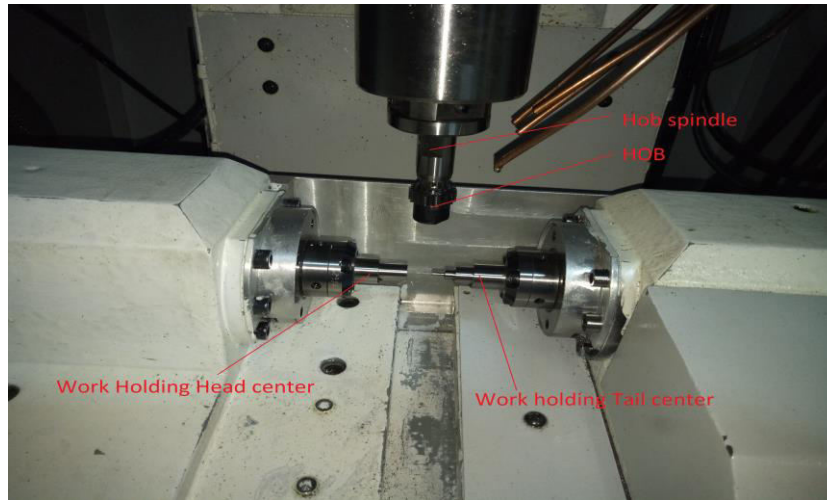


Fig. 3 CNC GH part and hob position

The commonly used instruments are follows:-

-Toolmaker microscope

- 1) Surface roughness tester
- 2) Micro Hardness tester
- 3) Double gear flank tester
- 4) Pyrometer
- 5) VMS

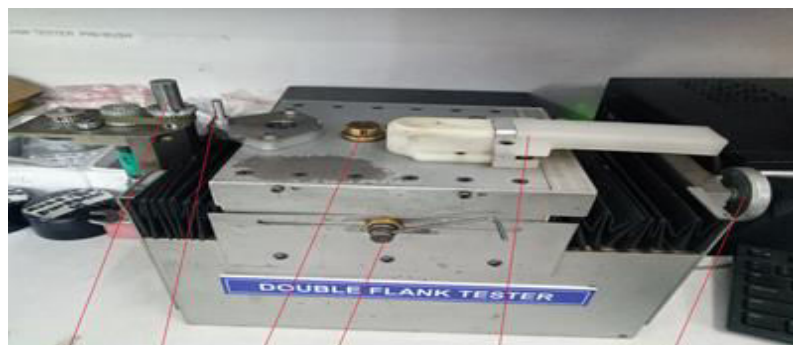


Fig. 4 Double Flank tester

V. CAPABILITIES OF MACHINE

Machine is capable of storing large no. of programs. Once program is made, next time we can directly execute it on single click after changing the hob & centers according to part requirement.

- Machine is capable of hobbing components of large diameters up-to 40 mm.
- Capable of hobbing large modules i.e. > 0.8mm
- Capable of executing Double Side Cutting strategy.



Double Side Cutting Procedure

Objective:- To eliminate the burr on chamfer angle.

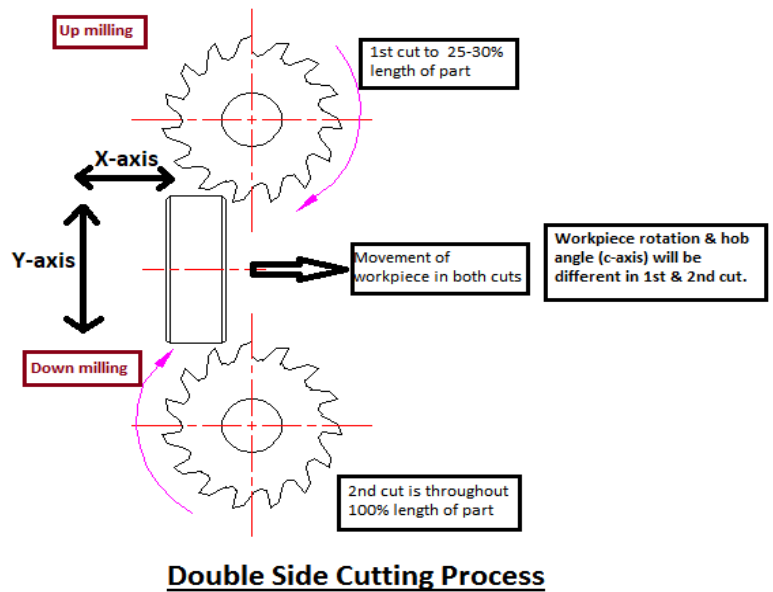
5.1 Part program Used for double side hobbing

Part No. 03-111-673 No. of Teeth= 47

Explained Program of Double side cutting

```

$1
M46 (clamping)
G0A5.70
M8
M6C1.033 {Hob spindle (c-axis) angle for 1st cut}
M41 (De-coupling)
M43 (De-coupling)
M80 (Axis-mode)
G0B0 (Hob spindle position)
G0B1=0 (Centers position)
G4X.1
M40 (Coupling for 1st cut)
M3S0
M81
M3S1000
G1Y5.0X0.0Z-39.329F1.5
G1Y-6.50F1.0
G1Y-9.338F.2
G1X-4.50F.005
G1Y-4.0F.2
G1Y5.0F.9
M3S0
M01
G94
G1Z-1.0F1500
M6C-1.033 {Hob spindle (c-axis) angle for 2nd cut}
G1Z6.0F1500
G1Y-62.0F1500
M41 (De-coupling)
G95
M80
    
```



- Rotate the hob spindle & centers through 180° to start hobbing in 2nd cut from position same as 1st cut

```

G0B180 (Hob spindle position for second cut)
G0B1=180 (Centers position)
G4X.1
M81
M42 {Coupling for 2nd cut (in 2nd cut workpiece will rotate in opposite direction of 1st cut)}
M3S0
M81
M3S1000
    
```



VI. OPTIMIZATION OF PROCESS PARAMETERS BY USING SYNTAX CONTROLLER WITH AC SYSTEM

6.1 Problem Defined / Hypothesis

The proposed system is based on a system of adaptive control. A significant number of calculations and experiments have found that the cutting force of the gear hobbing operation fluctuates violently.

As a result, the process cutting conditions are quite poor. Conservative cutting parameters (e.g., feed rate and spindle speed) are frequently selected in the gear hobbing operation to avoid tool breakage and machine overload. As a result, while employing constant cutting parameters, productivity will be minimal. As a result, the adaptive control technique is well suited to the process of increasing efficiency while simultaneously protecting the machine and cutting tool by adjusting the machining settings.

6.2 Methodology

The experimental apparatus for proposed idea on a manual/CNC gear hobbing machine by the help of advance syntec controller. Environment friendly and biodegradable oil based lubricant was used to manufacture spur gears using solid type single start hob cutter made of Carbide.

Specifications of the hob cutter and manufactured spur gears are shown in [Table 2](#).

Table 2 Specifications of hob cutter and manufactured spur gear

Specification of the spur gear	Specifications of the hob cutter
Material: SS440c	Material: Carbide
Chemical composition: Above ment.	Chemical composition: Gen.
Module: 0.4233	Module:0.4233
Profile: involute	Helix angle:1.02 degree
Number of teeth: 47	Number of starts: 1
Pitch circle diameter: 19.896 mm	Number of gashes:14
Pressure angle: 20°	Outer diameter: 24 mm
Face width: 8.00mm	Bore diameter: 8 mm
Tip diameter: 21.112-21.178mm	Length: ~20mm

[Table 3](#) lists the variable input parameters and their levels, as well as the fixed parameters and responses employed in this study.

6.3 Experimental investigation procedure with conventional and CNC hobbing results

Experiment 1:- Initially, I will evaluate the increases in gear quality (while keeping all other parameters the same, such as feed, cutting speed, and depth of cut) on an 8-axis CNC gear hobbing machine vs. an old conventional gear hobbing machine In this scenario, we'll change the cutting settings one by one and note any variations in the previous outcome.



Table 3 Details of variable input parameters and responses used in the experimentation

Variable parameters	I	II	III	IV
Hob cutter speed (m/min)	<u>1000rpm</u>	<u>1000 rpm</u>	<u>1200rpm</u>	<u>1000 rpm</u>
Axial feed (mm/rev)	<u>0.01 mm/rev.</u>	<u>0.005 mm/rev.</u>	<u>0.005 mm/ rev.</u>	<u>0.005 mm/ rev.</u>
Depth of cut (mm)	<u>1.014mm</u>	<u>1.014 mm</u>	<u>1.014 mm</u>	<u>1.014 mm</u>
Lube flow rate (L/mint.)	10	<u>10</u>	<u>10</u>	<u>10</u>
Nozzle angle (degrees)	<u>30 degree</u>	<u>30 degree</u>	<u>30 degree</u>	<u>40 degree</u>

6.4 OUTCOMES

Table 4 Comparison Results with Taper centers of CNC and conventional machine

Comparison of CNC gear hobbing and Conventional hobbing machine			
S.No	Parameter	CNC Gear Hobbing	Conventional Machine
1	Stability	Due to higher rigidity results are stable.	There is problem of dia variation in conventional machines.
2	Yeild	100% yeild.	Less than 100%.
3	Accuracy	More (Around 50% parts have TCE around 10 microns)	Less
4	Surface Finish	Better than conventional machine.	Less than CNC machine.
5	Suitability for hard parts	Due to higher rigidity, it is preferable to hobb the components with higher hardness on CNC hobbing machine (i.e 35-40 HRC).	Not suitable to hobb components of higher hardness. (i.e 35-40 HRC)
6	Diameter	Capable to hob the component of diameter upto 40mm	Capable upto 25mm only
7	Module	Greater than 0.8mm (Part of 1mm module made on machine for trial purpose)	Capable upto 0.8 mm only.
8	User Friendly	Due to semi-automation, chances of error are less for trained operator.	Need to change the parameters manually. So, the chances of mistake are higher.
9	Burr	Burrless hobbing is possible	De-burring tool is required or manual deburring need to done.
10	Taper Centers	Suitable	Not suitable due to less rigidity.
11	Type of gears	Suitable to hob different type of gears	Only spur gears can be hob.
12	Length	CNC machine is capable to hob component of larger length than conventional machine.	



Conclusion of Experiment 1

Results on large diameters (diameter more than 15mm) & tough materials are better on CNC gear hobbing machine.

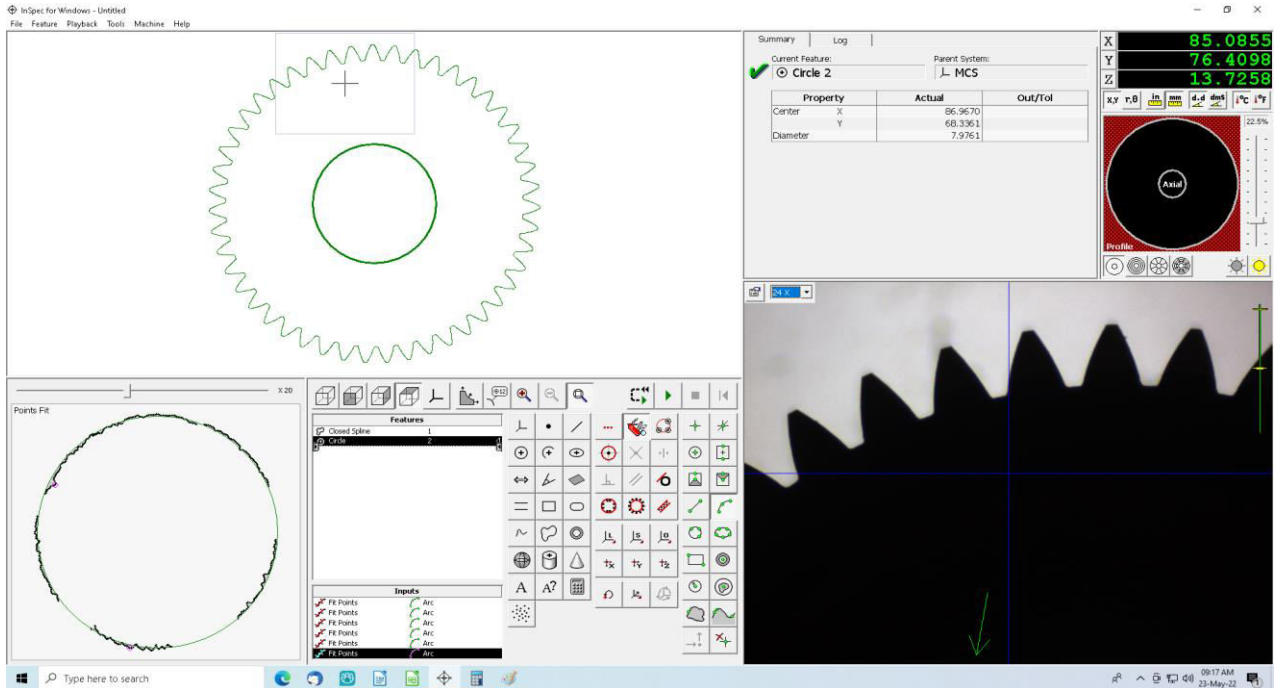


Fig. 5: Vms Checking of gear profile and comparison with original

- Gear parameter results for large parts are same.
- Results on small components (Dia less than 5mm) are almost same in both machines (report made).
- Double cut hobbing strategy proved beneficial for large parts, tough materials and in soft materials like peek etc.
- Better surface finish achieved in large parts.
- As per current data, there is no such benefit for small parts, even there is productivity loss in CNC machine as compare to old machine.
 - Easy loading of parts having length more than 20mm. So, CNC gear hobbing machine proved beneficial for shafts of length >20mm.

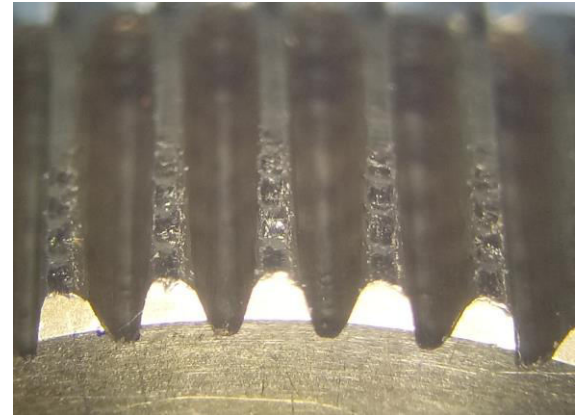
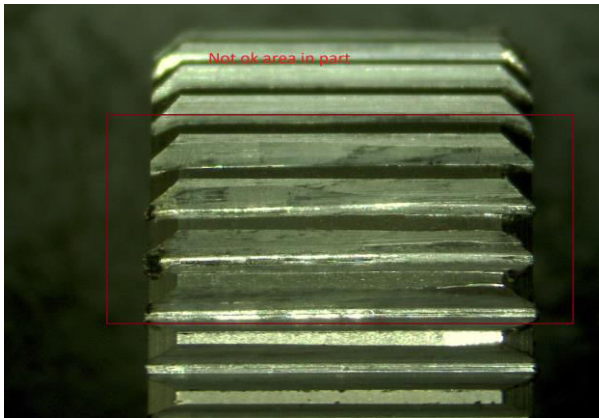


Fig. 6 Gear with burr problem (not ok)

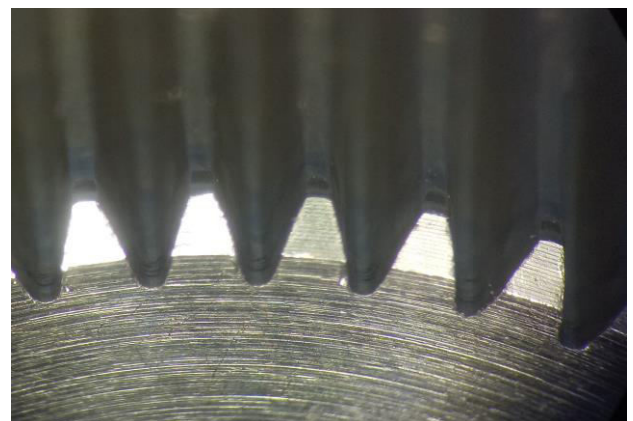


Fig. 7 Gear with burr Free (ok)

VII. OPTIMIZATION OF PROCESS PARAMETERS BY USING ADAPTIVE CONTROL

Experiment 2:- Select the optimal cutting parameters for additional adaptive control system trials based on prior trials (feed will be automatically altered based on cutting load and vibration conditions). Using vibration sensors, a pyrometer and an inbuilt dynamometer during gear hobbing. The output of all these instruments works as a feedback system to control and maintain the feed and cutting speed in all conditions.

As shown in Fig.8, the load was selected by the help of the hit and trial method as per the required cutting speed in SS 440C material. The cutting load on the spindle was set with a tolerance band of +/-10%. During hobbing, when the cutting load on the spindle increases, the automatic feed is decreased to maintain the cutting load on the spindles.

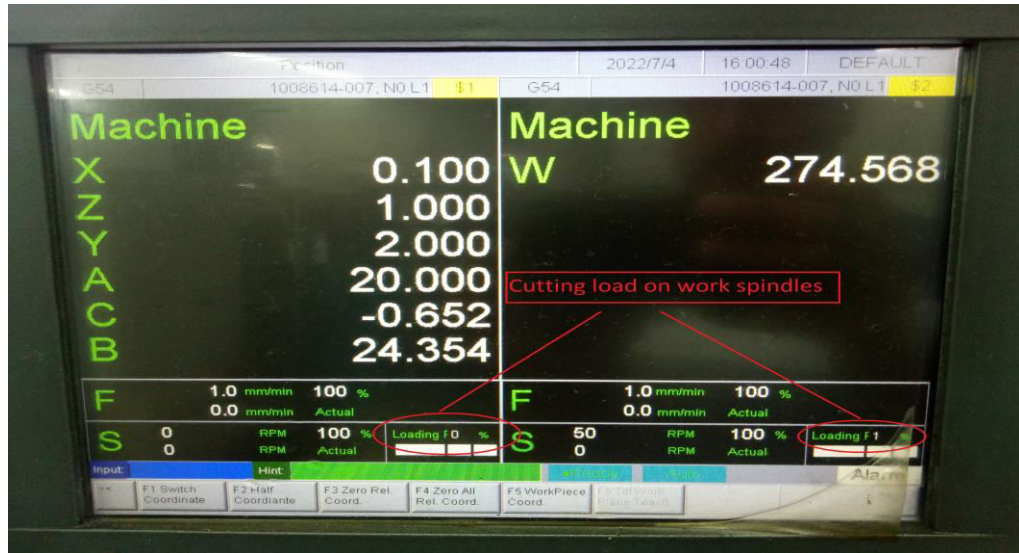


Fig. 8 Cutting Load percentage digital output

The strategy of implementation of ADAPTIVE CONTROL system is little bit different.

- Firstly I set all the cutting parameters (spindle speed, hob spindle speed, and feed) in a previous experiment no.1/2.
- After that make few parts on the same setting and record all the results on checking.
- Now time to change to adaptive control system by collecting all the data from feedback system & all the sensors.
- During machining we set the loading percentage on work spindles, if load is increased then cutting load is decreased automatically by reducing the speed of work spindle to maintaining cutting load thoroughly same.
- Record all the data by adaptive control system and compare with the previous one experiment.

7.1 Results and Comparison of Adaptive control system

The results with adaptive control system are looks better.

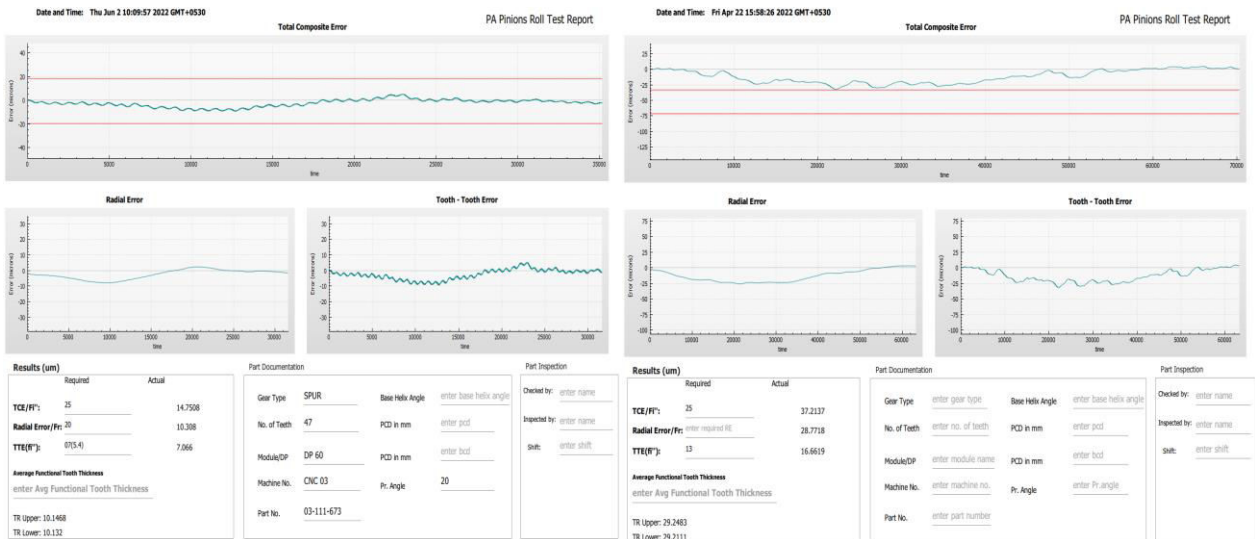
Table 5 comparison of DFT report & improved quality percentage

Part no. 03-111-673
Mat :- SS 440C
Total no. of Parts = 1305

TCE (in microns)	No. of Parts	Percentage
<10	566	43.37%
10 to 15	652	49.96%
15 to 20	84	6.40%
20 to 25	3	0.23%
>25	-	-



If we compare the repeatability of quality in both the cases, the AC system doesn't more effect on repeatability but it improves the quality of gear.



The percentage of parts having TCE is less than 10 microns is increased from 15 to ~43%.

Fig. 9 DFT checking report CNC & conventional machine

7.2 Conclusion of Experiment 2

Stable & improved Results with adaptive control of feed during machining was obtained. When the cutting load start increase on work spindle and hob spindle, the controller give the output to servo motors and maintained the cutting load throughout machining of gear.

- Can do hobbing of large diameter (up to 40-50mm) parts.
- Can cut gears of module >0.8mm.
- Capable of cut different type of gears.
- Capable of burr less hobbing.

VIII. CONCLUSIONS AND FUTURE SCOPE OF WORK

1. Stable results were observed on a CNC hobbing machine with an adaptive control system. The mass production part should be run on a CNC hobbing machine.
2. The machine is highly efficient for burrless hobbing. So, it is preferable to run the parts on a CNC hobbing machine that has a chamfer. No extra manpower is required for removing burrs on the lathe machine.
3. Due to the advantage of high rigidity, better results can be achieved with tapered centers. So, it is preferable to



use only taper centres wherever possible.

4. The problem of taper alignment disturbance is significant in conventional hobbing machines, while there is no such problem in CNC hobbing machines. So, it is preferable to run the parts on a CNC machine prone to this problem.
5. Trials on small components need to be conducted to explore the benefits of adaptive control systems.
6. In this case, the whole experiment is done on spur gear. But in the future, the author can do the same trials on splines, worm screws and other customised gears. In the future, the author could use smart industrial intelligence to build adaptive control methods. This will help to improve the quality of gears, machine/tool life, and manufacturing gear productivity.

Symbols

Fa	–	Profile
F_{β}	–	Lead
Fp	–	cumulative pitch
Fr	–	radial run out
T	–	Temperature
V	–	Cutting speed
f	–	Feed rate
d	–	Depth-of-cut
gm	–	Gram
TW	–	Tool wear
AC	–	Adaptive control
CO2	–	Carbon dioxide
MQL	–	Minimum Quantity Lubrication
TCE	–	Total composite error
Ra	–	Average roughness
Rmax	–	Maximum roughness
FL	–	Flood lubrication
MQLH	–	Minimum Quantity Lubrication assisted hobbing
PIGE	–	Integrated positioning dependent geometric error
SS-440	–	Stainless steel 440 grade
GPA	–	Gega pascal
MPA	–	Mega Pascal
DIN	–	Director Identification Number
DP	–	Diametrical Pitch
VMS	–	Video Measuring system



FEM	–	Finite element method
IR	–	Infra Red
Iso	–	International organization for standardization
DFT	–	Double flank tester

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BIOGRAPHY

Nitesh Kumar is an M.Tech student in the Department of Mechanical Engineering, RIMT University Mandi-Gobindgarh, Punjab, India. His research area is Quality improvement of gear .

Dr. Pawan Kumar Yadav, B.Tech (Mechanical), M.Tech (Design & Production Engineering), NIT Durgapur, Ph.D (IIT BHU) on Performance measurement of Heavy Vehicles is presently working as an Assistant Professor in RIMT University Mandi-Gobindgarh, Punjab. His research areas are Performance Analysis of heavy vehicles, production improvement of heavy vehicles, and Quality improvement of gears. Pawan Kumar Yadav is corresponding author and can be contacted at pawankuaryadav@rimt.ac.in



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