Educational Administration: Theory and Practice
2024, 30(5), 5209-5217
ISSN: 2148-2403
https://kuey.net/
Research Article

Navigating the path from Casing Design to Precision Inspection.

Sunil Shinde[1*], Soham Vyapari[2], Yuteeka Kamath[3], Vajreshwari Wagh[4], Arya Utage[5], Vedant Korke[6], Vishal Patil[7]

[1*,2,3,4,5,6,7]Department of Mechanical EngineeringVishwakarma Institute of Technology, Pune, India

Citation Sunil Shinde, et al (2024), Navigating the path from Casing Design to Precision Inspection, *Educational Administration: Theory and Practice, 30(5),* 5209-5217
Doi: 10.53555/kuey.v30i5.3766

ARTICLE INFO | **ABSTRACT**

This project will briefly explain methodology which must be followed from Design Considerations to Inspection of Rack-Pinion Casing. Our approach involves selecting suitable material considering different factors like strength, durability on dynamic conditions. Modelling considering the tolerance factor for bearing pressfit. Manufacturing the part using VMC machining, incorporating varieties of cutting tools. Inspection of finished part using CMM.

Keywords – Material Selection, CAD modelling, Vertical Machining Centre, Coordinate Measuring Machine

I. INTRODUCTION

Steering system works on the handling of vehicle. For a vehicle to move smooth and quick, the steering rack pinion case is essential. At its core, the steering casing is in charge of housing the vital steering components like rack and pinion that converts driver input into motion of the car's front wheels. It must therefore display unmatched structural integrity and dimensional correctness.

We have covered the journey from material selection and manufacturing to metrology i.e. CMM of Steering casing. VMC is a machine tool with a vertical spindle used in manufacturing operations to accurately shape and cut materials, which gives it importance in automobile sector. Coordinate Measuring Machines (CMM) is transforming the production and quality control processes so engineers and manufacturers may inspect and confirm the dimensional accuracy of critical components.

II. LITERATURE REVIEW

Design and Modification of Rack and Pinion Steering.

Santosh D. Giri, Aditya N. Bhavsat et al Presented a study, This paper discusses the design and simulation of rack and pinion steering using sphere gear. The concept aims to reduce driver effort during parking or sharp curve maneuvering. The steering ratio can be adjusted using the sun gear with the existing steering gear box. The project aims to design an efficient, durable rack and pinion mechanism for better maneuverability in difficult road conditions. SOLIDWORK software was used for design and manufacturing.

Machining of aluminum alloys: a review.

Mário C. Santos Jr1, Alisson R. Machado et al Presented a study, Aluminum alloys' use in manufacturing has grown due to their combination of lightness and strength. Machining volume has increased, with chip volume accounting for up to 80% of the original material volume in sectors like aerospace. Understanding machinability characteristics is crucial for industry and researchers. This review compiles relevant information.

Virtual Machining for CNC Milling and Turning Machine Tools: A Review.

Mohsen Soori, Behrooz Arezoo et al Presented a study, virtual manufacturing systems simulate real manufacturing processes in digital environments to improve part production accuracy and efficiency. These systems analyze and reduce errors, enhancing the accuracy of produced parts. Optimization methods can be applied to optimize cutting conditions, and machine tool elements can be simulated, analyzed, and modified. These systems can be used for training, monitoring, and error analysis, and can be selected using process planning methodologies. The paper reviews virtual machining systems for CNC milling and turning machine tools, suggesting future research.

Design and Manufacturing of 4th Axis VMC Fixture.

Apurva Vinay Patil Presented a study, paper discusses the design and manufacturing of a fixture for a 4 axis VMC machine, aimed at reducing individual marking positioning, increasing productivity efficiency, and minimizing setup costs. The fixture should withstand stresses during clamping, loading, and unloading, have high wear resistance, and require minimal setting time and force.

COORDINATE MEASURING MACHINE (CMM).

Rohit Raju Nikam Presented a study, The demand for numerically controlled machine tools has led to the need for faster first-piece and 100% dimensional inspections. Coordinate Measuring Machines (CMMs) play a crucial role in mechanizing inspection processes and can even be used as layout machines before and after machining. These versatile machines record measurements of complex profiles with high sensitivity and speed.

2010-03 Rack and Pinion Steering System Inspection.

This Inspection Bulletin outlines the process of inspecting trucks and truck tractors with rack and pinion steering, a system similar to the reciprocating ball system used in heavy-use vehicles. It emphasizes the need for clarification on system functions and proper inspection points.

III. METHODOLOGY

1. Material Selection and Modelling.
2. Manufacturing using VMC Machining.
3. Inspection using CMM.
4. Results & discussions.

The methodology we employ for manufacturing and inspection of steering casing is a systematic approach with distinct phases. We initiate the process by selecting the most suitable materials, ensuring optimal performance and durability considering real life applications

This is followed by extensive design and understanding of the component using 3D CAD modelling software, SolidWorks.

The CAD model of the designed part is manufactured using VMC.

Furthermore, a thorough inspection is conducted using CMM, to identify and rectify manufacturing inaccuracies and misalignments in the manufactured component.

1. Material Selection and Modelling:

While selecting material for any component it is essential to calculate the amount of forces that will be acting in dynamic condition. The force needed to turn the front wheels will be applied by the driver and transmitted through the steering column to the rack-pinion.

Although force will be sent to the tires, there won't be much force acting on the steering casing. Hence, we concluded that we can move ahead with the material Aluminium 6061. The density of aluminium 6061 is approximately 2.7 g/cm3. Tensile strength ranges from 180 to 290 MPa and Yield strength ranges from 110 to 240 MPa. Because of its intermediate fatigue strength, it can be used in applications involving cyclic stress.

Aluminium 6061 has a great strength-to-weight ratio, which makes it ideal for applications that call for strength without a lot of weight. It demonstrates strong corrosion resistance, especially in air settings. It is well machinable, allowing for precise construction and machining. This alloy has a wide range of applications, from bicycle frames to aerospace parts. It is incredibly adaptable. We procured the billet of aluminium 6061 with dimensions (60mm * 60mm * 40mm) considering the tolerances for manufacturing error.

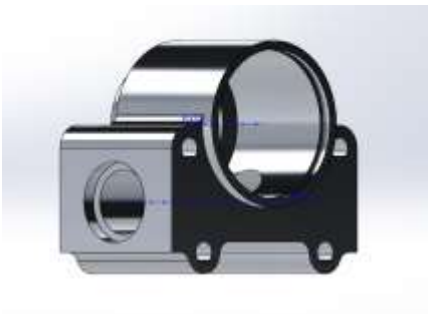

Fig-1. Isometric view of casing.

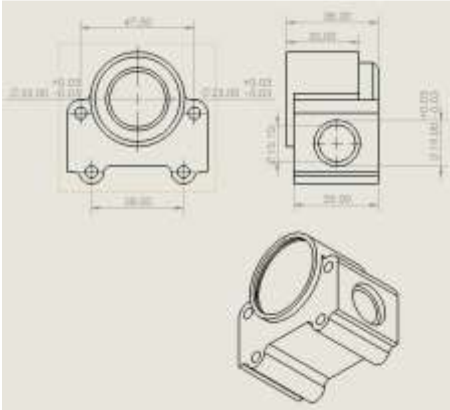

Fig-2. Drawing of casing processed in SolidWorks.

2. Manufacturing using VMC Machining:

When performing different machining operations including milling, drilling and tapping, a *vertical machining centre* (VMC) is a type of machine tool used in manufacturing and metalworking. VMCs are suited for a variety of applications since they have a vertically oriented spindle and a stationary worktable.
VMCs are extremely versatile machines that can handle a wide range of machining tasks. They can mill, drill, tap, contour, and pocket on a variety of materials, including metals, plastics, and composites. Multi-axis VMCs enable sophisticated and precise machining processes. They are capable of high precision and accuracy. VMCs' vertical spindle design allows for simple access to the workpiece from a variety of angles. VMCs can hold a variety of cutting instruments.

Fig. 3. Vertical Machining Centre

The methodology we employ for manufacturing and inspection of steering casing is a systematic approach with distinct phases. We initiate the process by meticulously selecting the most suitable materials, ensuring optimal performance and durability considering real life applications

This is followed by extensive design and understanding of the component using 3D CAD modelling software, SolidWorks.
The CAD model of the designed part is manufactured using VMC.
Furthermore, a thorough inspection is conducted using CMM, to identify and rectify manufacturing inaccuracies and misalignments in the manufactured component.

Components of VMC:
1. Base: The base is the foundation of the VMC and provides stability to the entire machine. It is typically made of heavy cast iron or other materials with high rigidity to dampen vibrations during machining.
2. Worktable: The worktable is a flat, horizontal surface that holds the workpiece. It can move along the X and Y axes to position the workpiece under the cutting tool accurately. Some VMCs also have a rotary table or a fourth axis (A-axis) for more complex machining tasks.
3. Guideways: Guideways are precision tracks that allow the movement of the spindle head, worktable, and other components along the X, Y, and Z axes. They must be carefully designed and maintained to ensure accurate and smooth movements.
4. Tool Holder: The tool holder is a component that securely holds the cutting tools, such as end mills, drills, or taps. It is attached to the spindle and allows for easy tool changes when needed.
5. Tool Carousel / Tool Change: Many VMCs are equipped with an automatic tool changer (ATC), which is a carousel or a magazine that holds multiple cutting tools. The ATC can automatically select and replace tools during machining operations, reducing downtime.
Firstly, we provide CAD model in the format of .STEP. The WorkNC software was used to generate code by using the CAD model. Code is generated by considering x, y, z co-ordinates by taking a specific reference point.

Commands for machining are generated by software which contains various factors like Tool, RPM, Holder, feed, time, diameter etc. STM-VL850 is used for precise and accurate manufacturing. As a 3-axis VMC machine it required 4 Settings, on 5 axis VMC same job is possible in single setting saving the time.

Fig. 4. STM-VL850

The manufacturing process is described step by step:

Operation No.	Description	Tool
	Setting – 01	
1.	Vertical Profile Milling	End Mill Cutter. (Teeth on peripheral and bottom)
2.	Face Milling Horizontal and Collar (Bore Face).	End Mill Cutter.
3.	Drilling (23mm)	Drill
4.	Boring collar (26mm) Bearing Seat.	Boring bar
5.	Boring (35mm)	Boring bar
6.	Drilling 4 holes (5mm diameter)	Drill
	Setting-02 (Job rotated 180deg)	
7.	Horizontal Face Milling (To maintain 38mm height)	End Mill Cutter.
8.	Profile Milling	End Mill Cutter.
9.	Profile Chamfer	Ball cutter
	Setting-03 (Indexing and Gripping – 90deg)	
10.	Drilling (8mm)	Drill
11.	Drilling (Again 14.5mm)	Drill
12.	Reaming (15 H7 as diameter of rack is 15 f6)	Reamer
13.	Counter Bore (19mm)	Boring Bar
14.	Face Milling	End Mill Cutter.
	Setting-04 (Reverse)	
15.	Counter Bore (19mm)	Boring Bar
16.	Face Milling.	End Mill Cutter.

Table. 1. Manufacturing process

We have made some calculations to justify RPM of tools,
RPM(n) = (1000*V)/(Pie*D).
Take D = 16mm , V = 180mm/min ,
n = (1000*180) / (3.142 * 16).
= 3581
= nearly 3600.
Dia is inversely proportional to RPM.
Job was made in material al-6061 and tool used was of material Tungsten Carbide with cubic boron nitride. Feed value was 0.05 mm/rev with depth of cut 0.1 mm.

3. Inspection using CMM:

Introduction to CMM:

A Coordinate Measuring Machine (CMM) is a metrology equipment that accurately measures the physical dimensions of an object using a three-dimensional Cartesian coordinate system. It is used in industries like automotive, aerospace, and medical device manufacturing, where precision and accuracy are crucial for product quality. CMMs use probes like tactile, optical, or laser sensors to measure geometric characteristics, such as dimensions, angles, roundness, straightness, and flatness. They are also used in reverse engineering to create a 3D model of an object. The accuracy of a CMM is determined by factors such as the machine's design, probe type, and calibration. The least count, which is the smallest distance the machine can measure, can have a least count of up to 0.1 micro meter.

Components of CMM machine
A CMM's multiple moving elements work together to allow the machine to evaluate a given object. There are several varieties of CMMs with varying measuring capabilities, but they all have four major components:

i. A Structure.
ii. A Probing System.
iii. A Controller.
iv. A Metrology Software.

Probe
The most common and crucial part of a conventional CMM machine that measures action is the probe. Other CMM devices make use of lasers, cameras, and optical light, among other things. The probes are made of a stable, inflexible substance by nature. It must also be resistant to temperature changes so that the size remains constant. Zirconia and rubies are often used materials. Additionally, the tip may resemble a needle or be spherical.

Fig. 5. Probe

Granite Table
Because granite is so stable, it is a crucial part of the CMM machine. It also has a lower rate of wear and tear than other materials and is not impacted by temperature. Granite's constant form makes it perfect for extremely precise measurements.

Fig-6. Granite table

Fixtures
Fixtures are also highly significant instruments utilized in most manufacturing activities as agents of stability and support. They are CMM machine components that serve to hold the parts in place. Because a moving item can cause measurement inaccuracies, it must be repaired. Fixing equipment such as fixture plates, clamps, and magnets are also available.

Fig-7. Fixture

Controller
The controller of a CMM maintains precision through aiming and houses the machine's mathematical error map. It supports various running speeds and circulator interpretation. The controller serves as the measurement system's traffic cop, directing data from the motor's scales and probe to the software.

Fig-8. Controller

Specifications of CMM machine of our project :
Make: **Hexagon**
Model: **Global**
Software: **PCDMIS2017**
Measuring Length: **X: 900mm Y: 1500mm Z:800mm**
Accuracy: **0.0018mm**

Fig-9. Coordinate Measuring Machine.

CMM inspections enhance the driving experience by ensuring the reliability of the steering system. By identifying deviations and rectifying them, manufacturers can guarantee optimal performance and consistency, reinforcing their commitment to producing high-quality, dependable automotive products.
The CMM process is described step by step:

1. **Concentricity**

Fig-10. Concentricity

In CMM inspection, concentricity assesses the alignment of a feature's central axis with a reference axis, which is critical for component quality. This measurement is vital for maintaining optimal component alignment and quality, especially in applications requiring precise fits, such as bearings, shafts, or mating parts.

CMMs check concentricity by comparing the measured feature's center to the reference axis, helping manufacturers to keep tight dimensional and geometric tolerances.

Here, we have measured concentricity in 2 cases; lower and upper bearing seat and inner, outer circle of rack entry. This concentricity will ensure proper bearing assembly and rack-pinion meshing.

2. C to C distance between holes of bolting points

Fig-11. C to C distance

The "C to C" distance in Coordinate Measuring Machine (CMM) inspection is crucial for verifying proper positioning and alignment of features, using precision probing and mathematical algorithms.

This distance is vital in quality control and manufacturing processes, especially for component assembly and interlocking features.

Here, we have measure C to C distance between bolting points of casing on mount. Accuracy in this measurement will ensure proper assembly of casing on mount, avoiding error in assembly point of view.

3. Parallelism of bolting and working face

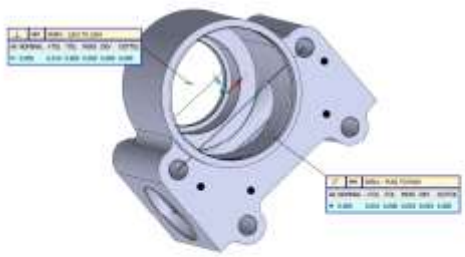

Fig-12. Feature Measured Parallelism

Inspection refers to the assessment of parallel manner alignment between surfaces or features on an object, using specialized probes to gather data on relative positions. This measurement is crucial in quality control and manufacturing, ensuring component dimensional accuracy.

4. Perpendicularity

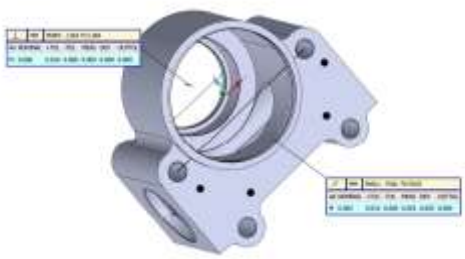

Fig-13. Perpendicularity

In CMM (Coordinate Measuring Machine) inspection, perpendicularity measurement assesses the degree to which a surface or feature is orientated at a 90-degree angle relative to a reference plane or axis. It guarantees that the inspected surface is completely square or perpendicular to the stated reference, such as the coordinate system of the CMM.

This measurement is critical for preserving component alignment and orientation, ensuring the quality and performance of manufactured parts, particularly in applications such as assembly and structures where right angles are critical.

5. Diameter of Inner Circle.

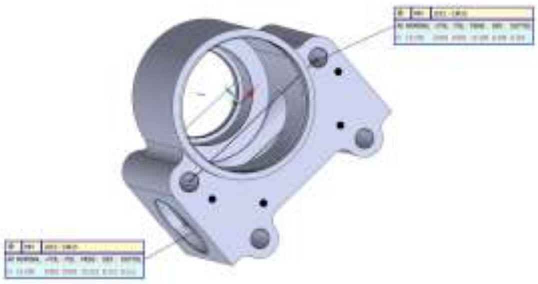

Fig-14. Inner Diameter

In CMM (Coordinate Measuring Machine) inspection, diameter measurement entails precisely determining the size of a circular or cylindrical feature, such as the diameter of a hole or a shaft. It is often used in manufacturing operations to examine the accuracy of drilled holes or the dimensions of cylindrical pieces, for example.

The CMM delivers accurate and repeatable diameter measurements, which helps to ensure product consistency and compliance. Diameter of inner circle is important considering the rack entry in casing.

IV. RESULTS & DISCUSSIONS

Fig-15. Operating CMM through Controller

Firstly, a material suitable for manufacturing of steering casing was selected based on different factors like durability, strength, market availability and cost efficiency.

The steering casing has been intricately designed using SolidWorks software. The CAD model was provided in .STEP format for manufacturing. STM-VL850 machine is used for precise and efficient manufacturing of the component with minimal errors. The job was completed in 4 settings which included, profile milling, face milling, drilling, boring, chamfering and reaming.

Finally, the CMM inspection of the steering rack pinion holder shell proved to be an excellent quality control tool during the manufacturing process of this critical automobile component. We have got a thorough understanding of the casing's dimensional correctness and geometric features through accurate measurements and analysis.

The collected data has provided critical insights into features such as alignment, concentricity, diameter, and perpendicularity, guaranteeing that the holder casing meets the rigorous tolerances and specifications required for its position in the steering system.

V. Conclusion

Vertical Machining Center (VMC) technology has revolutionized the production of rack pinion casings, enhancing precision and efficiency in machining processes. This technology ensures that casings meet precise dimensions and surface polish demands, reducing lead times and increasing overall output. Computerized Measurement Machines (CMM) complement VMC manufacture by ensuring dimensional integrity and quality control. Combining VMC manufacturing with CMM inspection improves the durability and performance of rack pinion casings for various industrial applications. VMC machining capabilities enable the creation of complex geometries, while CMM inspections ensure compatibility and performance within larger mechanical systems.

VI. References

1. Santosh D. Giri, Aditya N. Bhavsat "Design and Modification of Rack and Pinion Steering." Volume 2, Issue 7, May 2022, IJARSCT.
2. Mário C. Santos Jr1, Alisson R. Machado "Machining of aluminum alloys: a review." Article in International Journal of Engineering and Technology · July 2020.
3. Mohsen Soori, Behrooz Arezoo "Virtual Machining for CNC Milling and Turning Machine Tools: A Review."
4. Apurva Vinay Patil "Design and Manufacturing of 4th Axis VMC Fixture."
6. 2010-03 Rack and Pinion Steering System Inspection.
7. Large Y-Axis VMC Enables Complete
1. Machining in Single Setup, Case Study.
2. 7.S.R. Shankapal, "Development of four wheel steering system for a car" SAS Tech journal volume 12, Issue 1, April 2013.
3. 8.R. Masilamani, S.Arun Kumar "Design and analysis of steering mechanism using planetary gear" IJAER, volume 10, Number 19, 2015.
8. Ing. T. Schulze and Dipl. Ing. C. Hartmann Gerlach, and Prof.Ing. B. Schlecht, "Calculation of load distribution in planetary gears for an effective gear design process" ISSN 2250-2450 volume 2, Issue 2, Jan 2011.
9. Bhushan Akhare and Sanjeev S Chouhan "Performance and value analysis of power steering system" IJEMTAE, volume 2, Issue 8, August 2012.
10. S.H.Yadav, "Failure investigation of planetary gear train due to pitting" ISSN volume, Issue 2, 2013.
11. Masilamani R ,Saravanakuamr J, Deepak S Gowtham K Mohammed Ansal M, "A Review Of Vehicle Roof Structure Analysis Using CFRP"(ISBN: 978-93- 84943-19- 6), National Conference on "Recent Trends in Engineering, Technology and Management"
12. Ya-Li Feng, Yi-Ting Kang, Wen-Ming Zhang and Jie Zhang, "Steady state characteristic analysis of deep-sea running mechanism with planetary gear wheel based on articulated steering radius" Journal of Marine Science and Technology, volume 18 No5 pp 780-784, 2010.
13. Masilamani. R, Krishnaraj C, Sivabalaji S "Enhancing the Passenger's Safety by Automatic Door Locking System and Self Locking of Starter Motor" International Journal of Innovative Research in Science, Engineering and Technology, ISSN 23198753, Volume 5, Issue 7, pp 13-17, 2016
14. Dinesh. N. Kamble "An over active front steering system" Internal journal of scientific and engineering research, volume 3, Issue 6, June 2012.
15. Nalecz A G and Bindemann A C, "Analysis of the dynamic response of four wheel steering vehicles at high speed." International journal of vehicle design, Vol 9, No 2, 1988, pp. 179-202.