Design analysis and topology optimization of Vertical Machining Center Spindle Head structure

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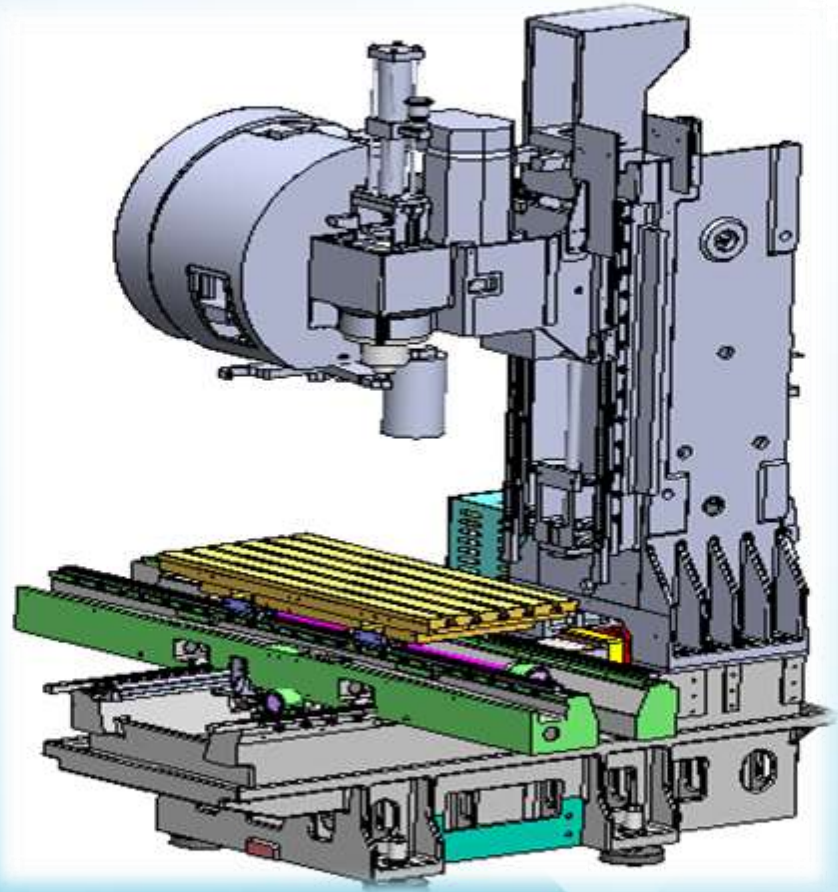
Milestones

- **1961** – Started our journey
- **1962** – Milling machines production started
- **1970** – Produced & supplied first Special Purpose Machine
- **1980** – Launched CNC Boring & Milling machines in India
- **1984** – Started Horizontal Machining Centers
- **1986** – **Silver Jubilee Year.** Exported Machining Centers to USSR
- **1990** – Started high-speed Vertical Machining Centers
- **1997** – Started foundry
- **2003** – Introduced Crankshaft Pin Milling machine
- **2004** – First Indian machine tool company to get ISO14001:2004 certification
- **2008** – Launched Vertical Turning Centers
- **2011** – **Golden Jubilee Year**
- **2012** – Introduced Front Axle Beam
- **2013** – Entered into Horizontal Turning business
- **2016** – Inaugurated Govt. Of India approved Dr. Kalam Center of Innovation
- **2017** – Launched IRIS
- **2018** – Inaugurated Hosur Manufacturing Facility

Introduction

- To meet the high precision and efficient development trends of modern CNC machine tool
  - Achieve structural lightweight design
  - Should have high dynamic performance
- Here, structural design of the CNC machine tool Spindle head is a multi-objective optimization issue



Objectives

- To obtain *VMC* dynamic characteristics using Tool tip FRF and Experimental Modal analysis (EMA)
- Validate FEA model of original Spindle head using EMA data
- To build light weight design of *Spindle head* by Topology Optimization
- Analyze optimized Spindle head for Static and Dynamic Characteristics

BFW Bharat Fritz Werner

Phase 1: Machine tool Dynamic Analysis

- Measuring Tool Tip FRF
- Experimental Modal analysis

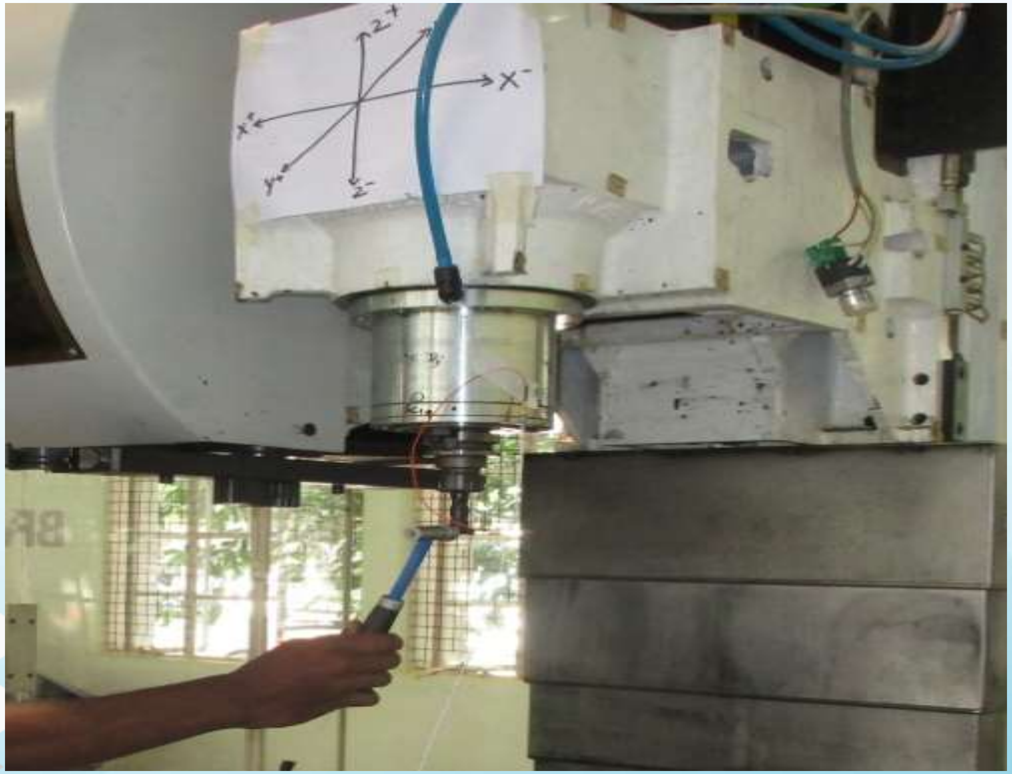


Fig. 1 Tool Tip FRF

Fig 2. Modal analysis

VMC Modal Analysis

Bharat Fritz Werner

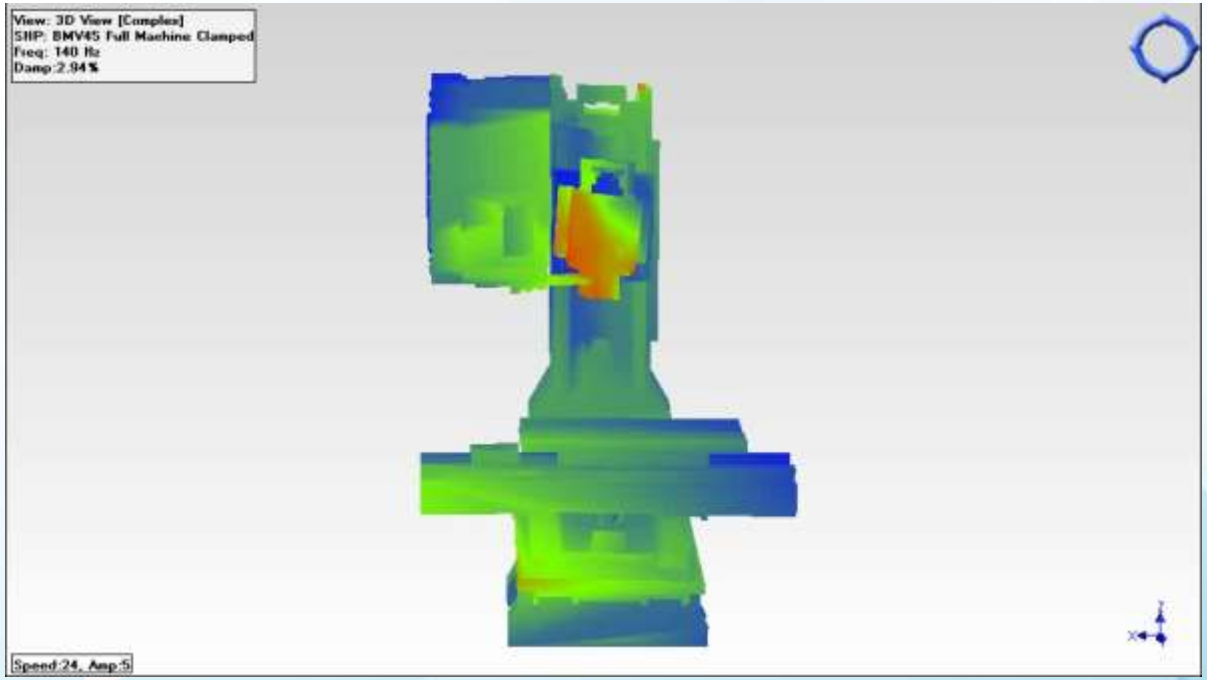


Fig.3. Mode shape for 140 Hz

Fig.4. Tool Tip FRF

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Phase 2: Numerical Analysis for Spindle head Using COMSOL Multiphysics

- Static analysis
- Dynamic analysis
  - Eigen Frequency analysis
  - Harmonic Response analysis

Structure simplification for FEA

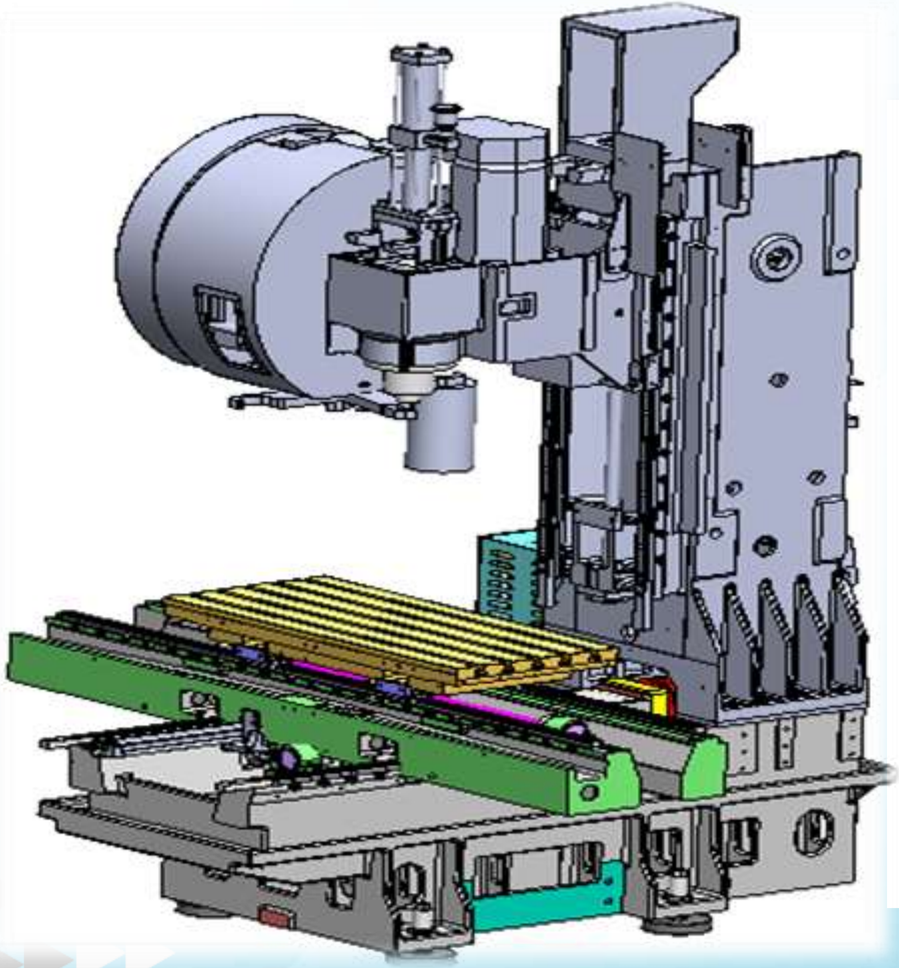


Fig.5. CNC VMC Assembly

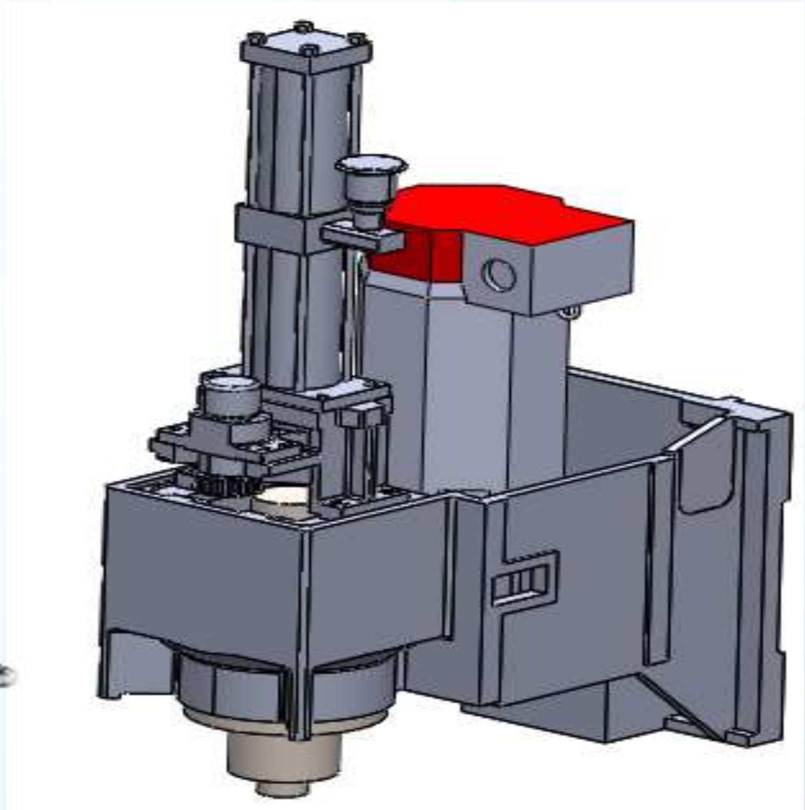


Fig.6. Spindle head Assembly

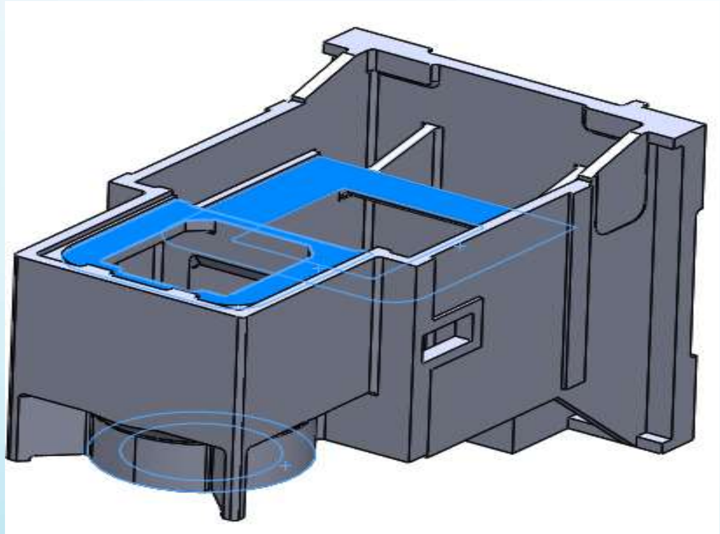


Fig.7. Spindle Head

Spindle head Loads and Boundary conditions

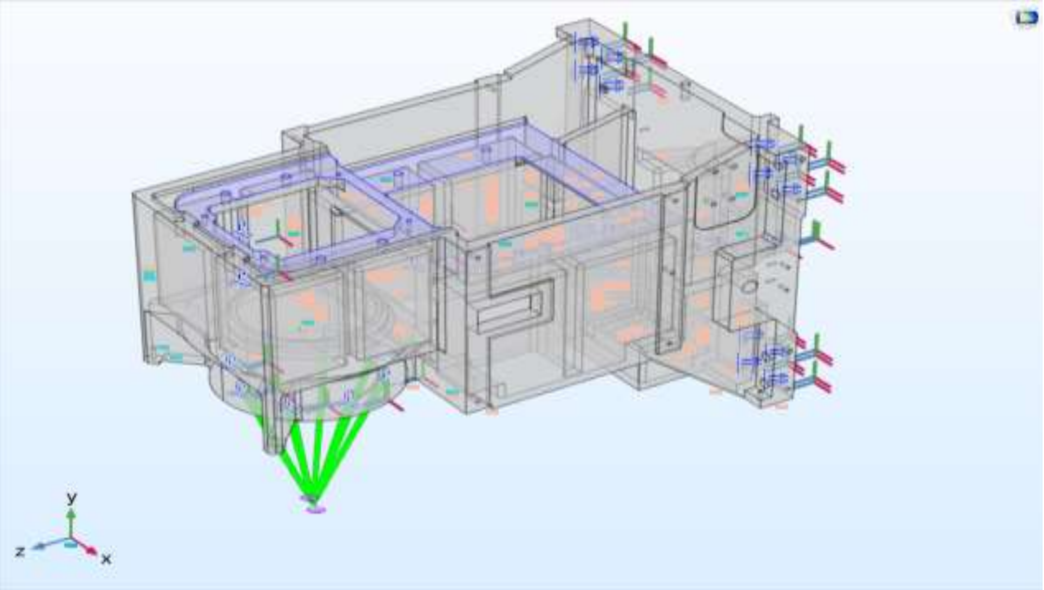


Fig.8. Loads and Boundary Conditions

Loads - Boundary condition and Material	
Loads	Instantaneous Cutting Loads •For Material Aluminium Fx = 200N Fy = 140N Fz = 20N •For Hardened Steel Fx = 540N Fy = 420N Fz = 25N
Dead weights	• Spindle (8000 Rpm) weight – 40 kg • Motor weight – 45 kg • Tool de-clamp weight - 30 kg • Spindle self weight – 165 kg
Constraints	Fixed at guide way block positions and counter balance
Material	Cast Iron (G4) Young's Mod- 145 Gpa Poissons ratio – 0.26 Density – 7250 kg/m^3

Spindle head Static analysis

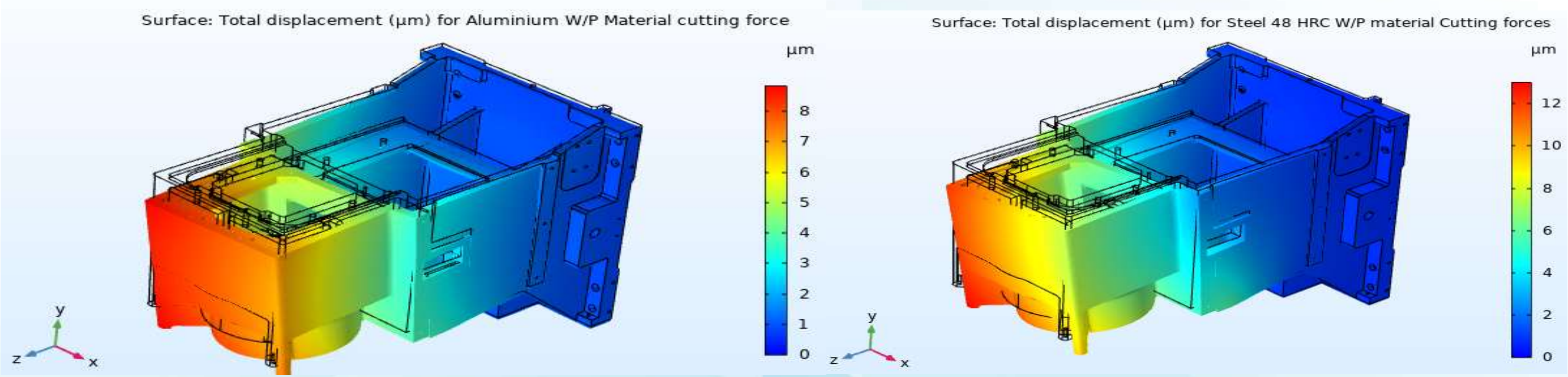


Fig.9. Total Displacement

Spindle head Frequency analysis

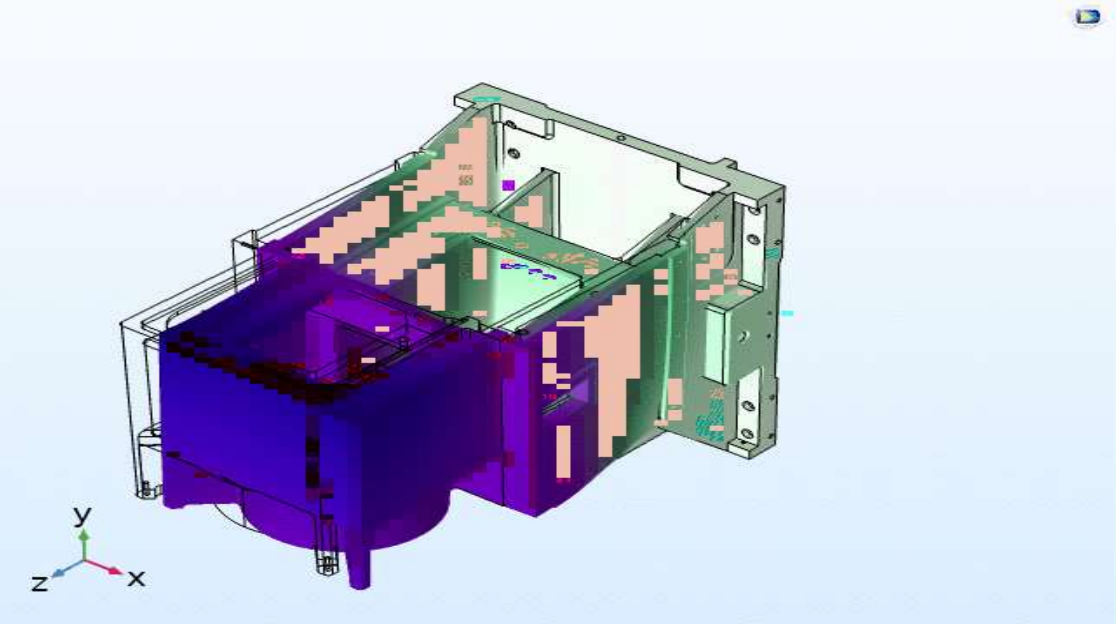
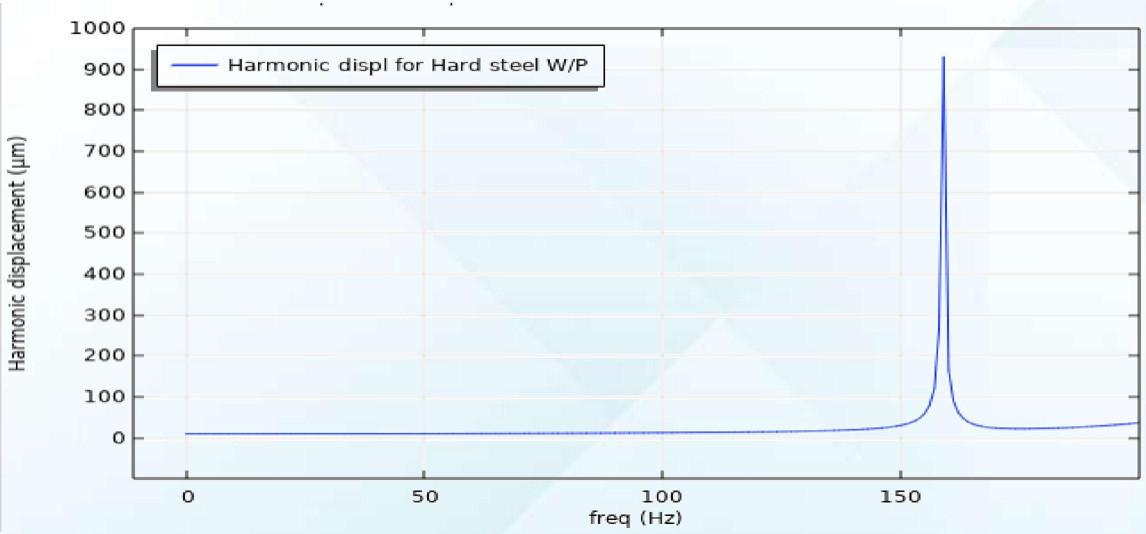
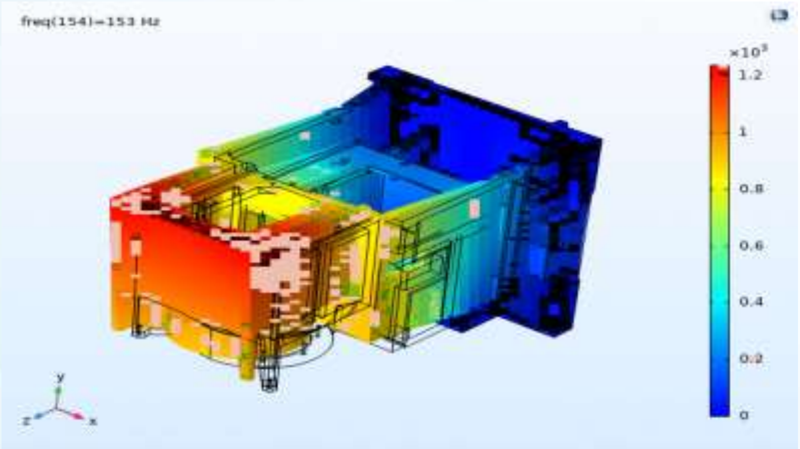


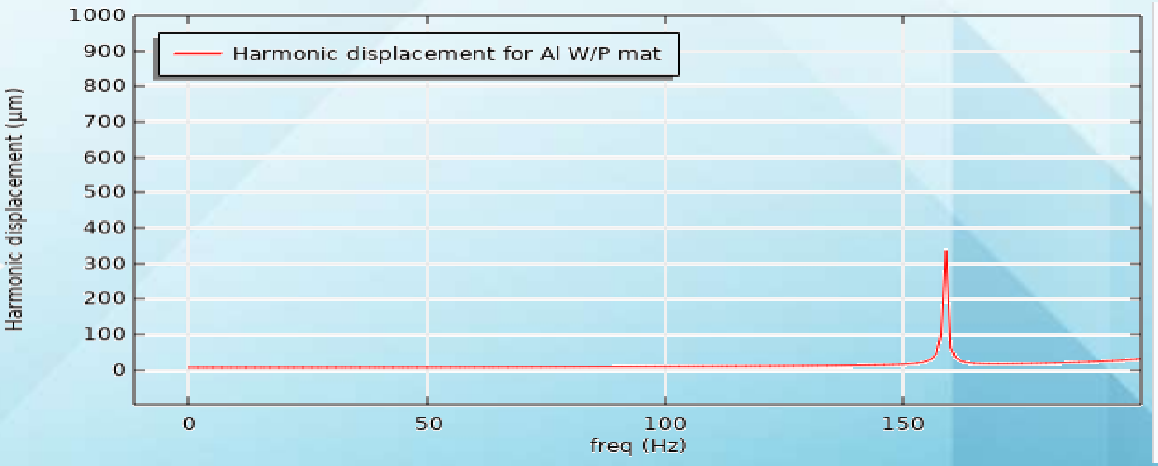
Fig.10. Mode shape (153 Hz)

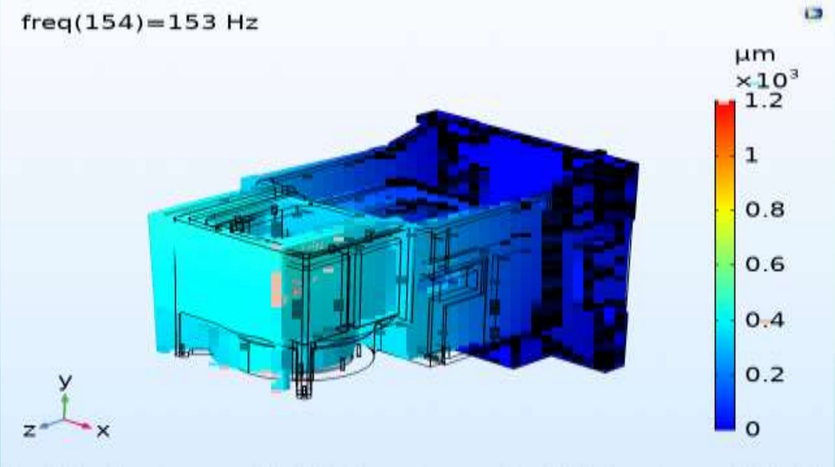
Frequencies (Hz)	Mode shape
153	Bending

Spindle head Frequency response analysis









Spindle head FEA Validation

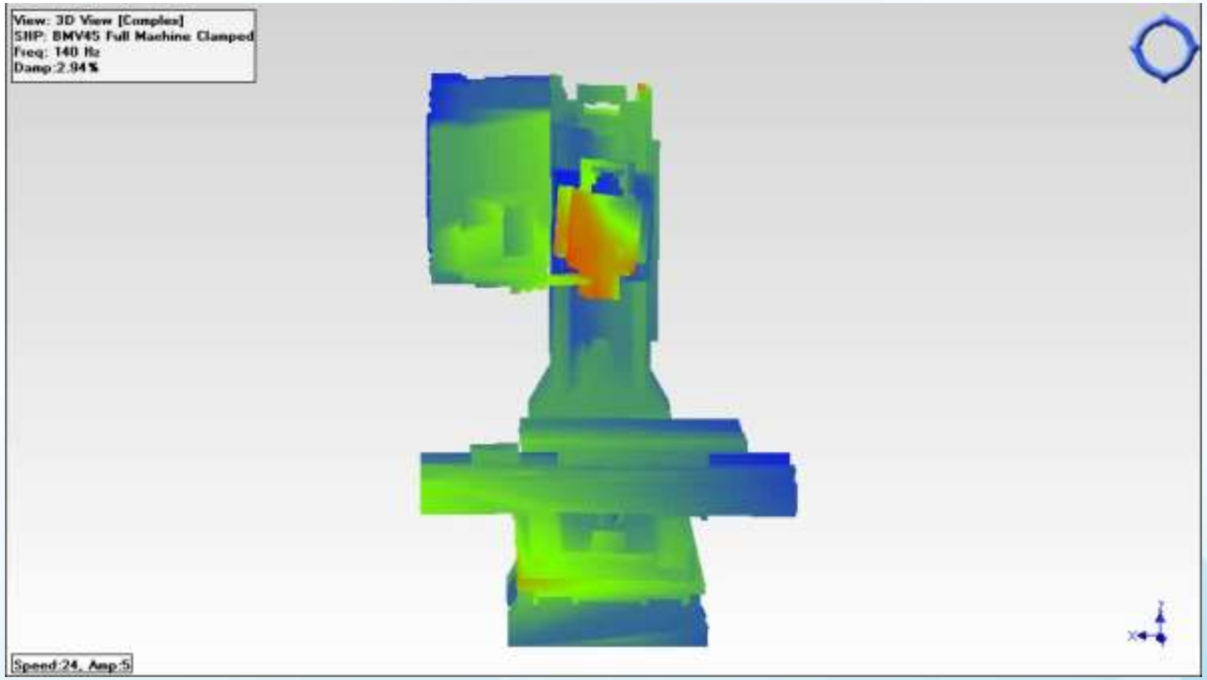


Fig.13. Mode shape for 140 Hz

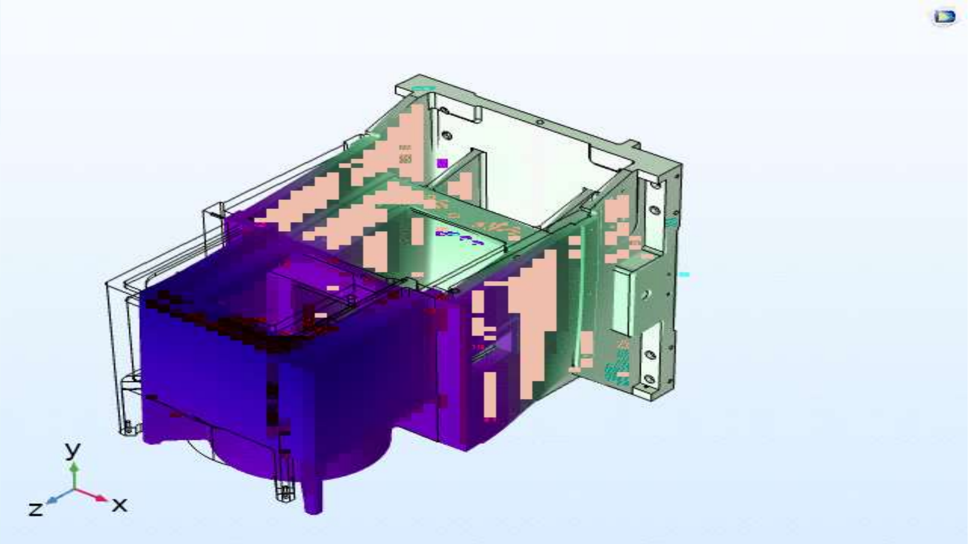


Fig.14. Mode shape for 153 Hz

There is a 9% deviation in numerical analysis data to experimental data

Spindle head Design Analysis

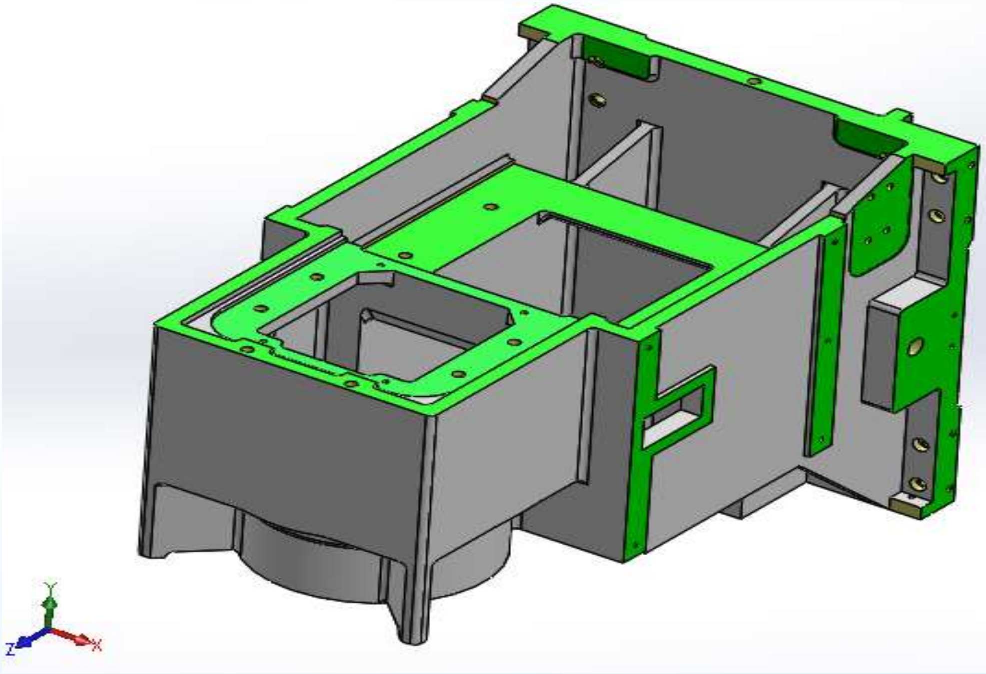


Fig.15. Original Spindle head

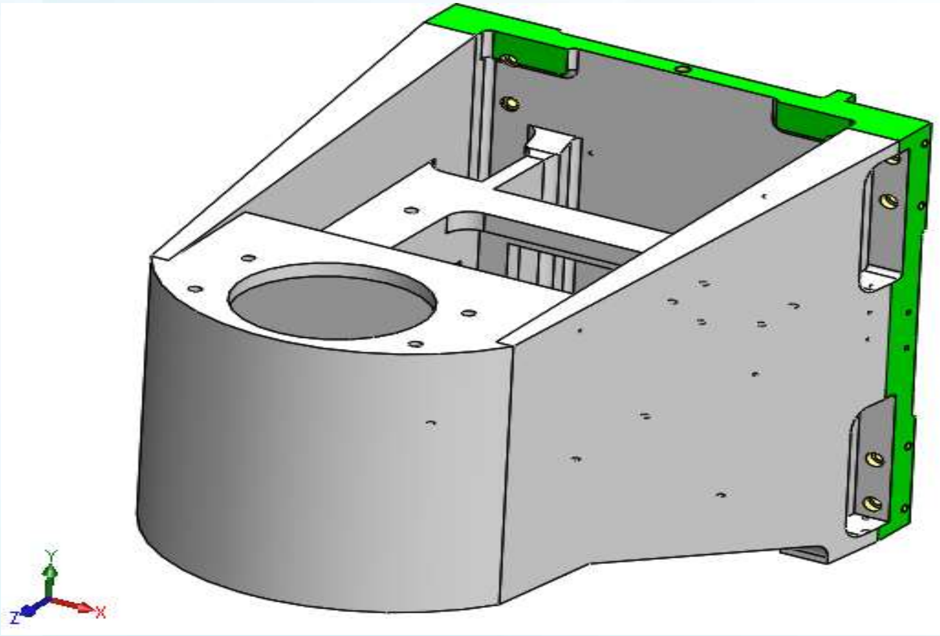


Fig.16. Primary design for Spindle head

Structure Type	Weight (kg)
Original Spindle head	165
Primary Spindle head	172

Spindle head Topology Optimization

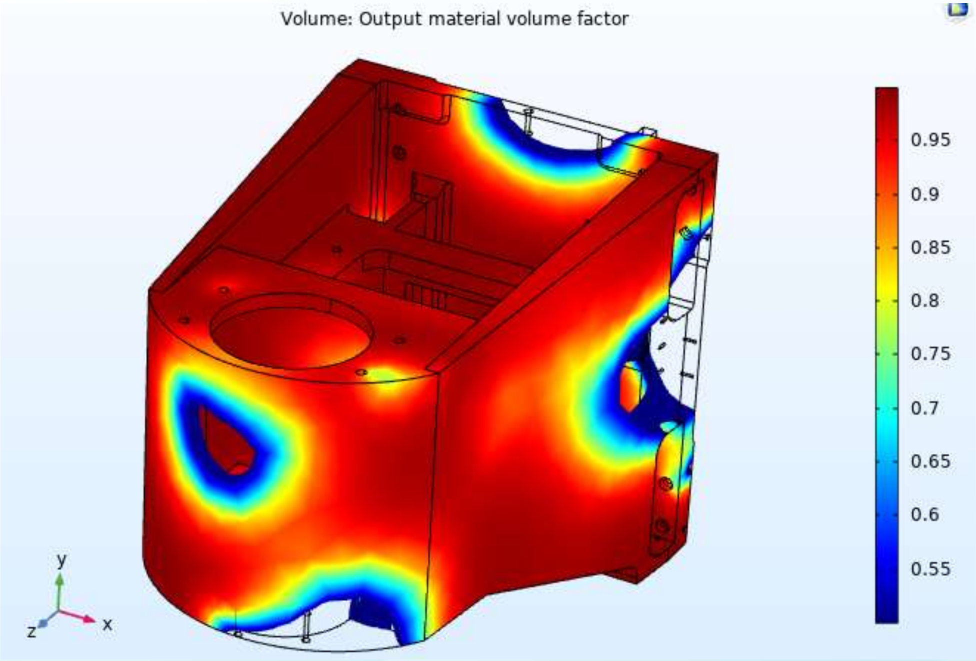


Fig.17. Optimized Spindle head

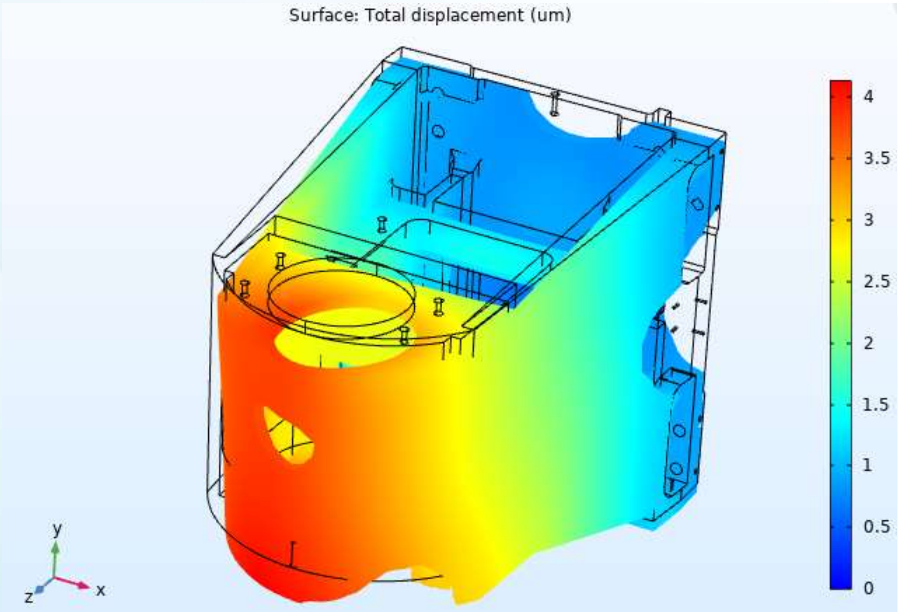


Fig.18. Total Displacement

Purpose: To improve the static stiffness
Objective: Minimization of structure mass by 15%
Constraints: Static displacement of spindle head need to be < 5 micron

Spindle head Topology Optimization

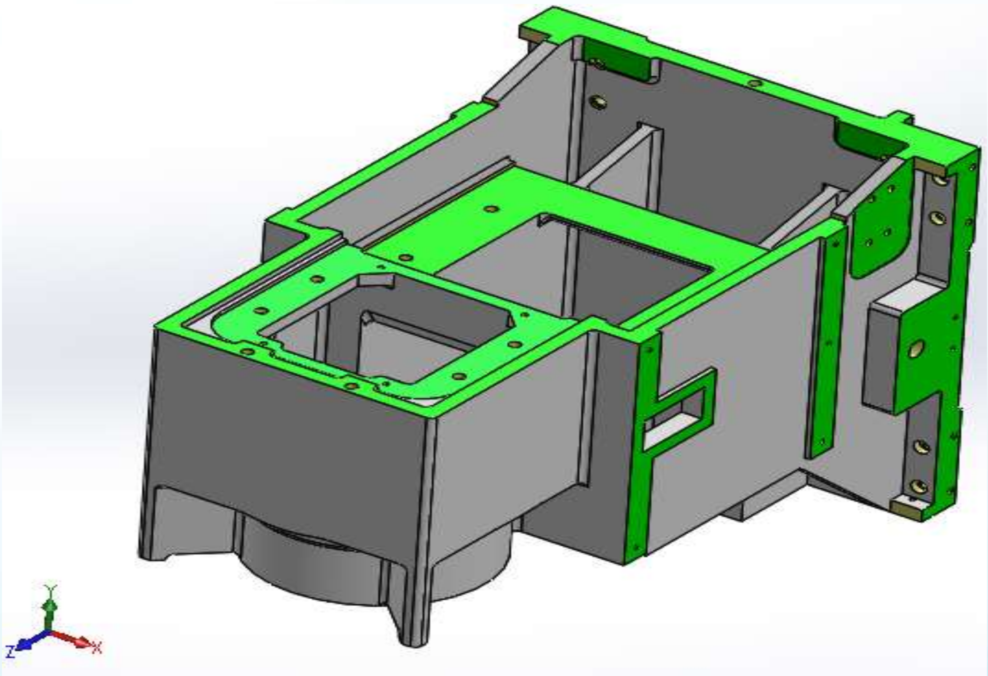


Fig.19. Original Spindle head

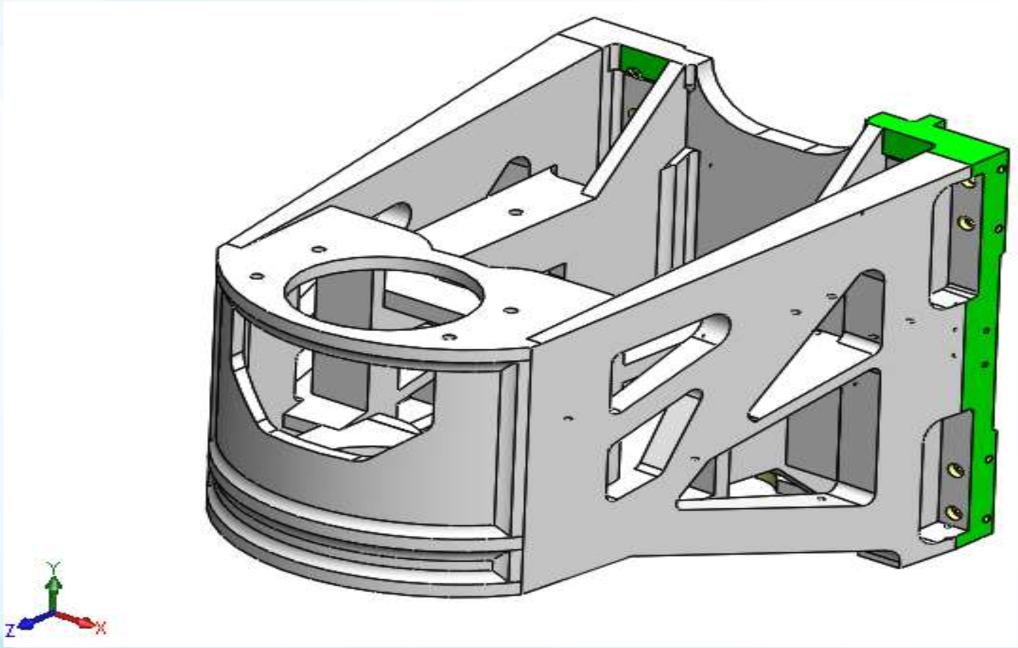
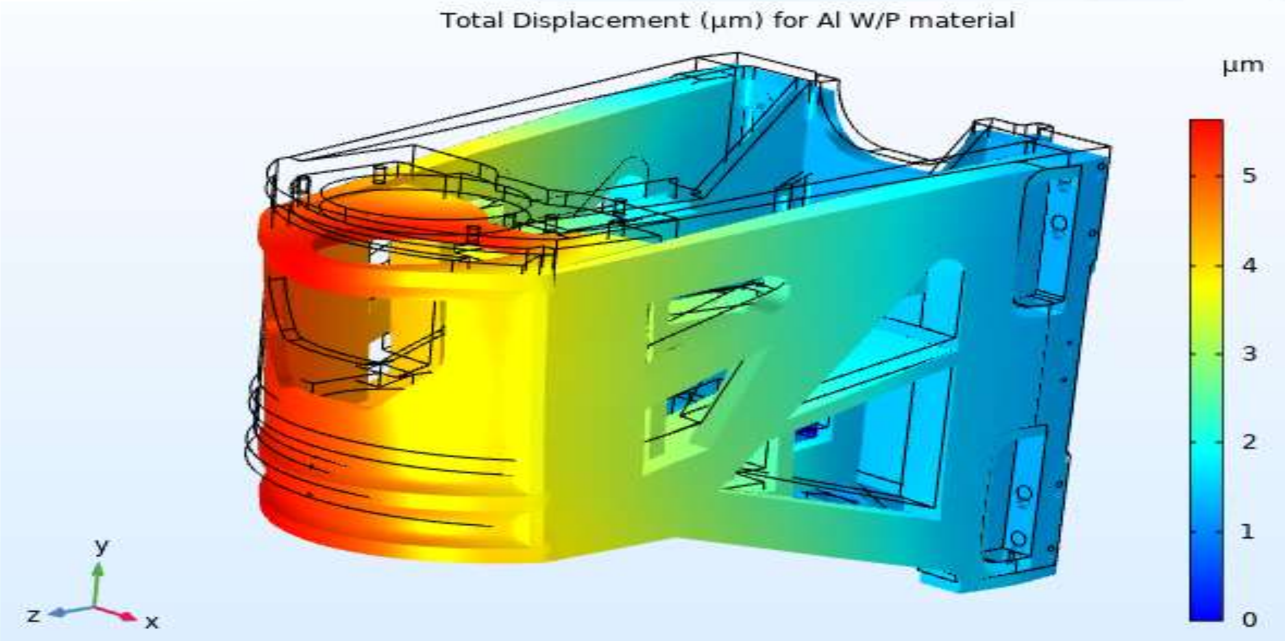


Fig.20. Optimized Spindle head

Structure Type	Weight (kg)
Original Spindle head	165
Primary Spindle head	172
Optimized Spindle head	145

Optimized Spindle head Static analysis



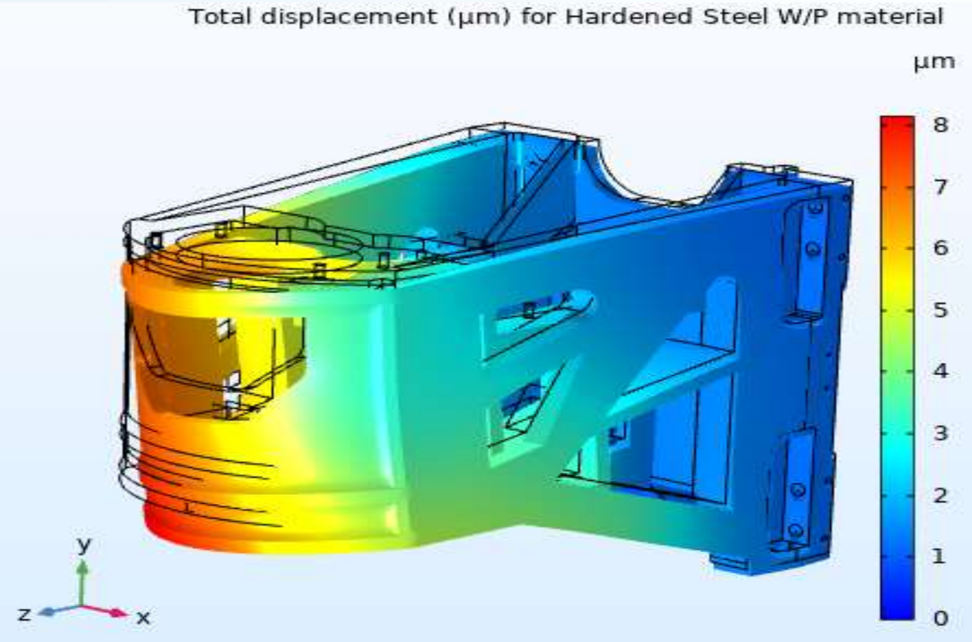


Fig.21. Total Displacement

Optimized Spindle head Frequency analysis

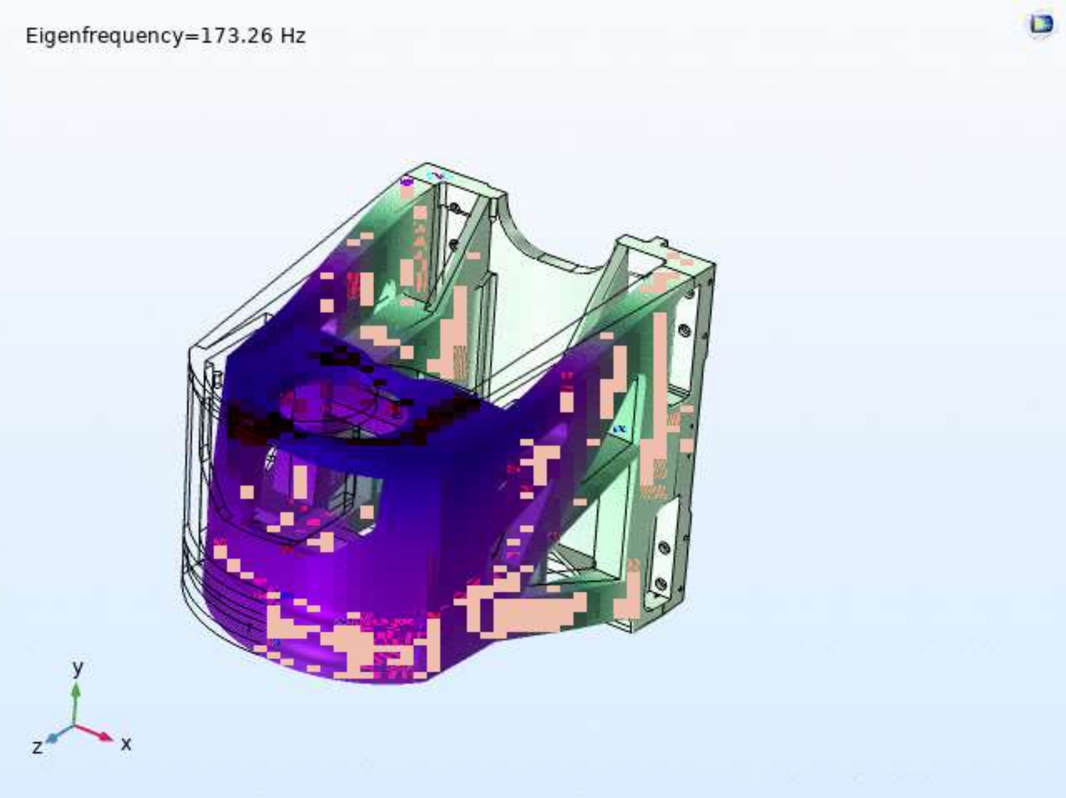
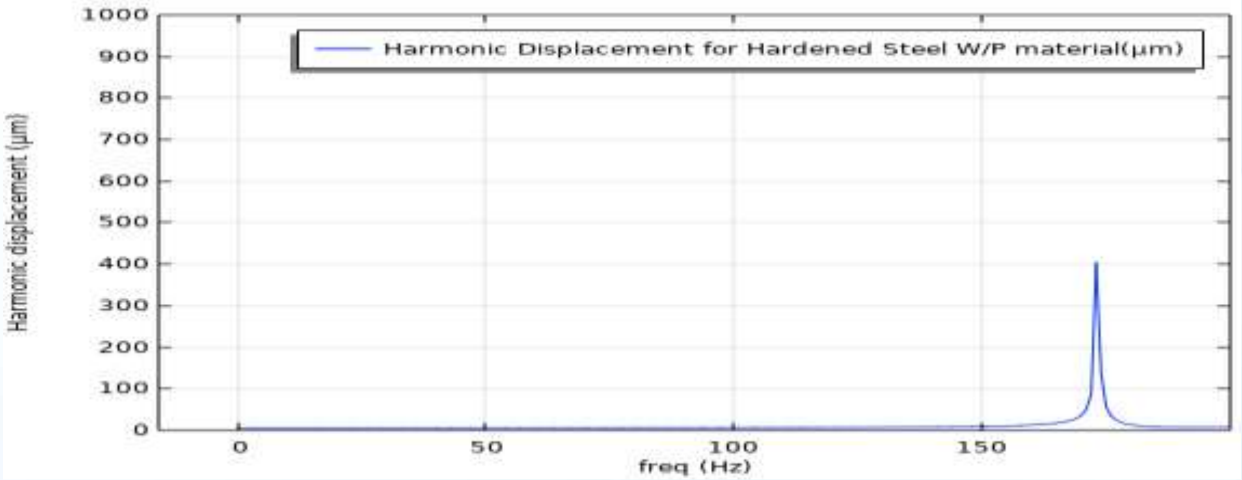
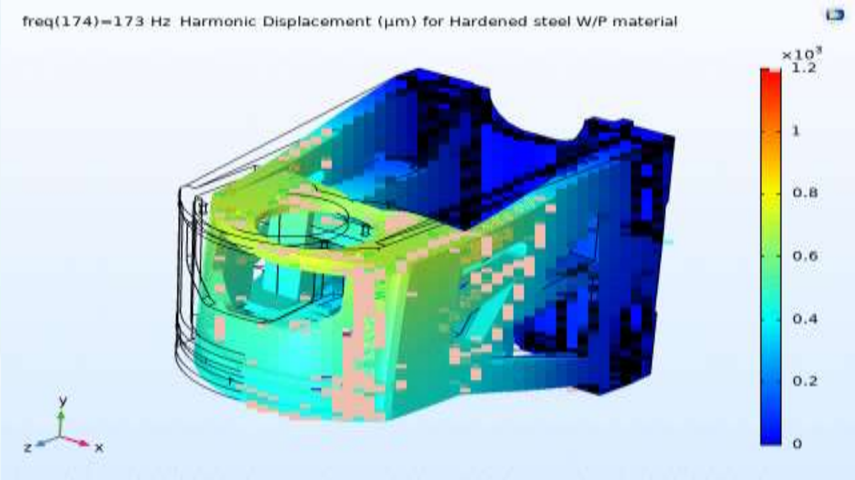


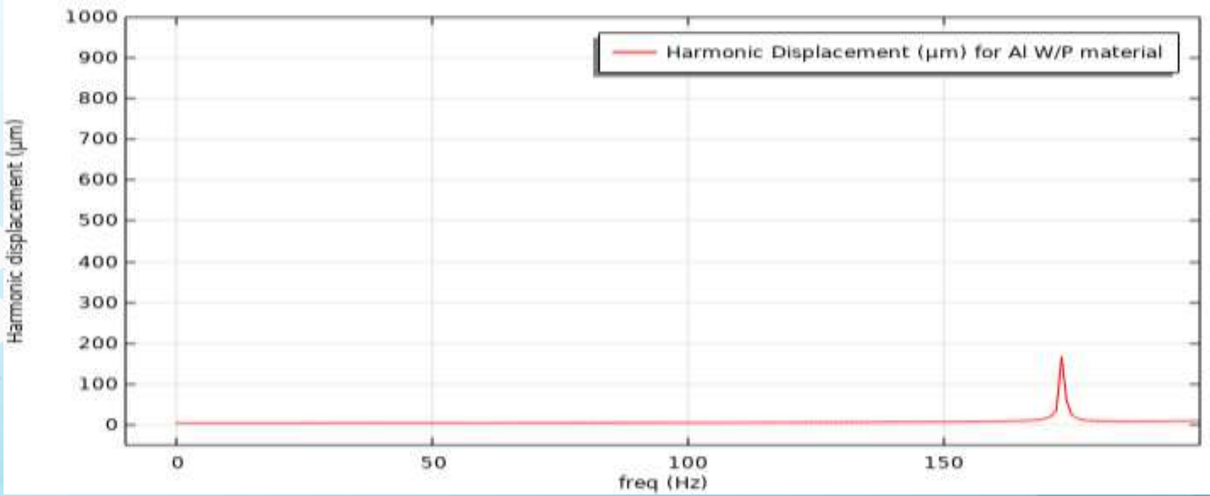
Fig.22. Mode shape for frequency 173.26 Hz

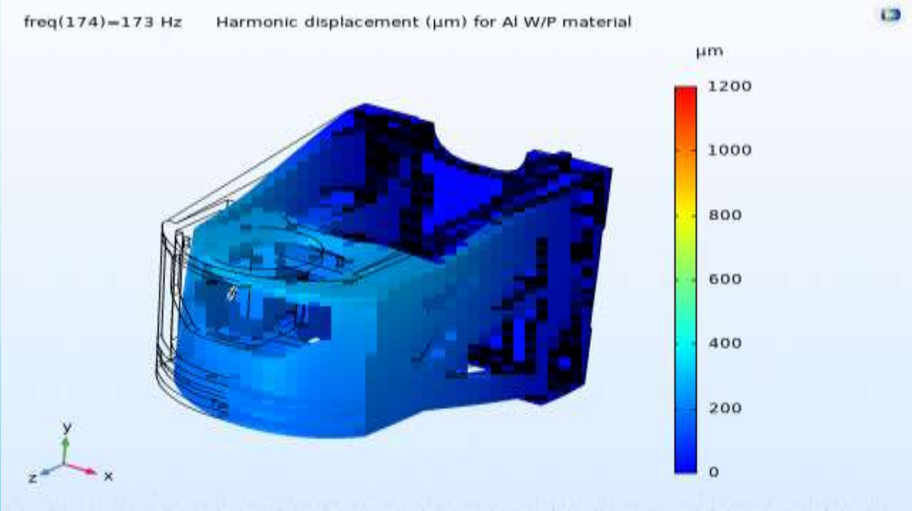
Frequencies (Hz)	Mode shape
173.26	Bending

Spindle head Frequency response analysis









Results and Discussion

	Parameters	W/P Material	Original Spindle head	Optimized Spindle head	Improvement(%)
Topology Optimization	Mass of structure (kg)	-	165	145	**12**
Static analysis	Static Displacement (µm)	Aluminium	8	5	**37**
		Hardened Steel	12	8	**34**
Frequency response analysis	Frequencies (Hz)	-	153	173	**13**
	Harmonic Displacement (µm)	Aluminium	330	160	**52**
		Hardened Steel	930	420	**54**

Conclusion

- The Experimental Modal Analysis and Tool Tip FRF of the machine, helps to determine the weak stiffness and redundant mass
- Dynamic and Static stiffness increased 50 & 35 % respectively, by reducing mass with the help of Topology Optimization by 12%

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