Design Validation of an Individually Balanced Crankshaft

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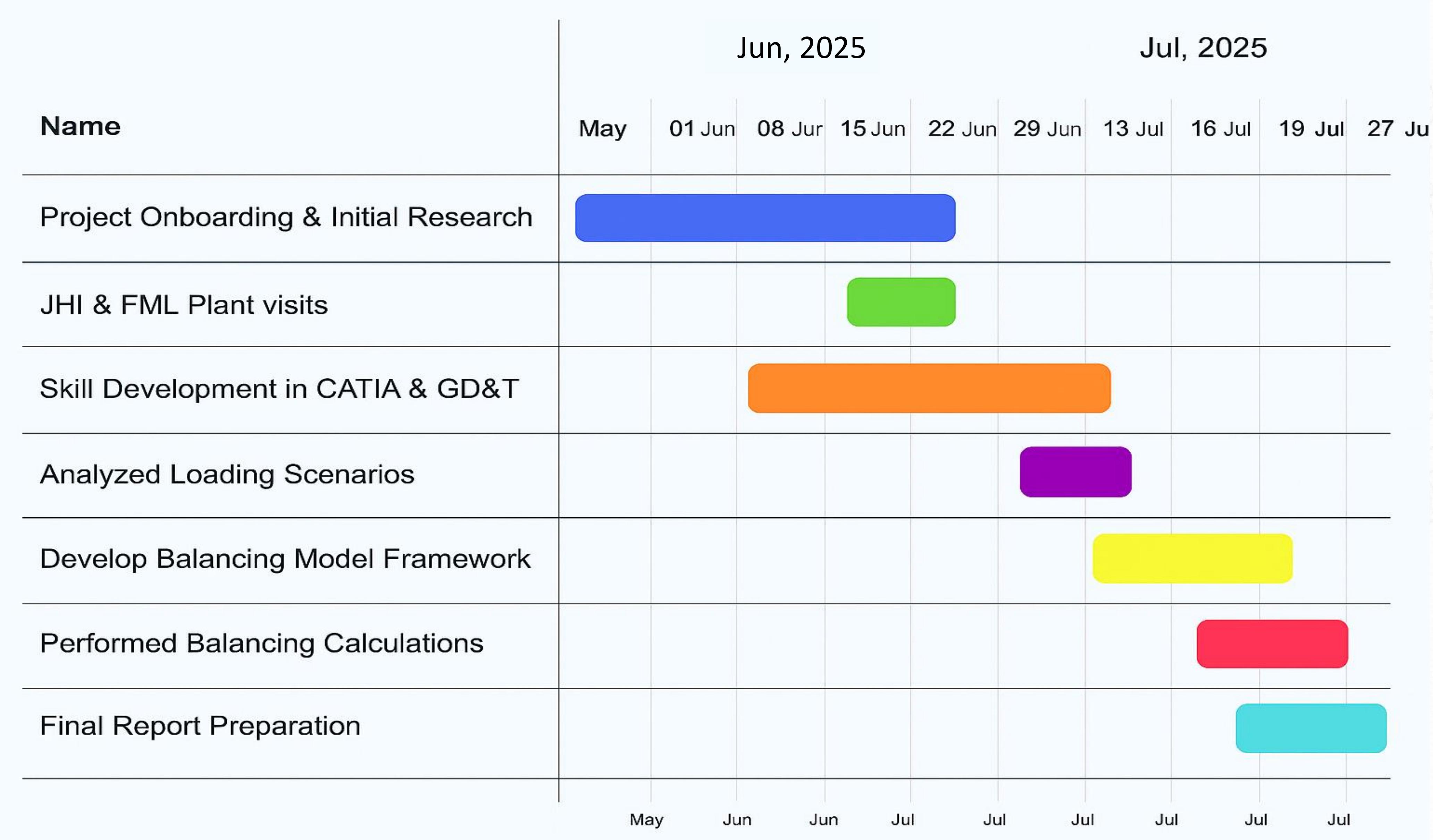
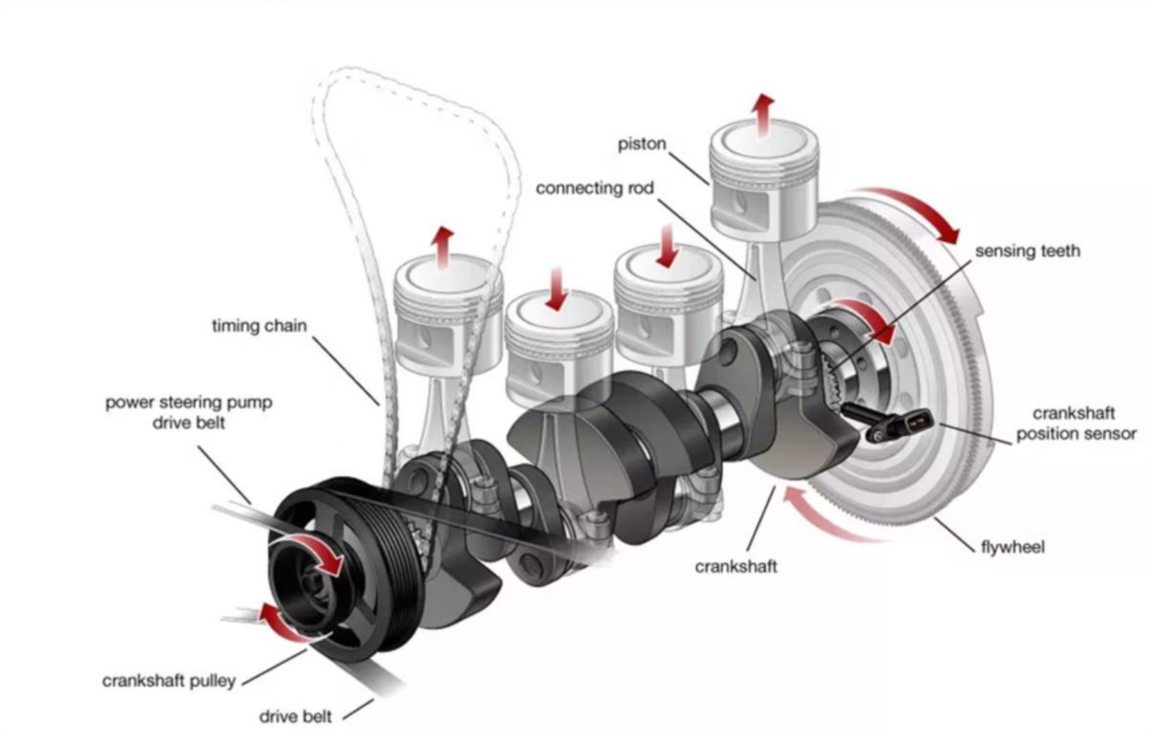
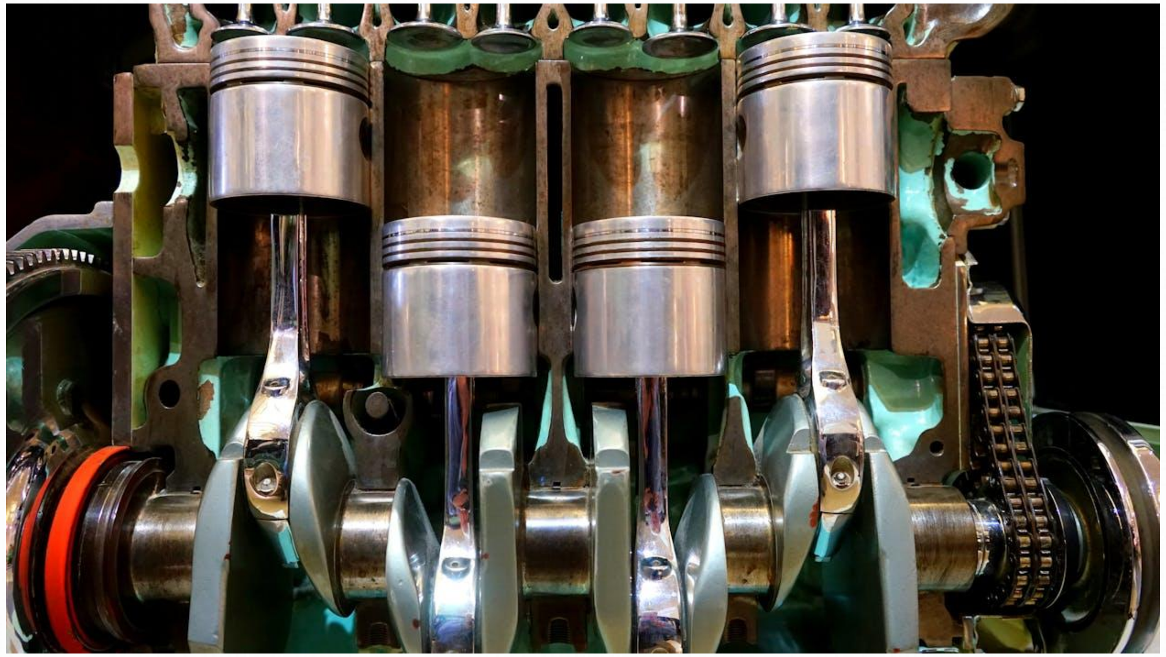
Internship Work Plan & Timeline

The project was structured into distinct phases, ensuring a systematic approach to model development and validation.



Introduction to the functions of a Crankshaft





Primary Function of the Crankshaft:

- Pistons move up and down due to combustion propelling them downwards.
- Converts piston's linear motion to rotary motion.
- Creates engine's primary torque output.

Primary Function of the Crankshaft:

- Drives camshaft for valve timing.
- Powers oil pump, water pump, alternator and ac.

Vital Role in Stability:

- Integrated counterweights balance dynamic forces during high-speed rotation.
- Minimizes engine vibration for smooth operation.

Crankshaft Materials & Manufacturing

FORCE

Crankshaft Types

- **4-web:** Typically for 4-cylinder assembly balanced crankshafts in compact engines.
- **8-web:** Used in 4-cylinder engines, for better balancing and power delivery. This is currently the project being worked on.

Material Selection

- **38MnVs6:** High strength, good machinability, often used for forged crankshafts. Used at FML
- **42CrMo4:** Excellent strength, toughness, and fatigue resistance.
- **CK45:** A common carbon steel, good for general purpose applications where cost is a factor.

Manufacturing Processes

- **Forging:** Creates a strong, continuous grain flow, enhancing fatigue strength. Used at FML
- **Casting:** More cost-effective for complex shapes, but generally lower strength than forged.

Heat Treatment

- **Induction Hardening:** Localized heating and quenching to increase surface hardness and wear resistance on journals and pins.
- **Controlled Cooling:** Used after forging or casting to achieve desired microstructure and mechanical properties.

The Types of Crankshaft Balancing

	Assembly Balancing	Individual Balancing
Definition	Entire rotating system balanced as a single unit. Including flywheel and damper	Crankshaft balanced independently before assembly.
Benefits	Common and cost-effective for mass production.	Addresses vibration at the source, allowing interchangeability and higher precision.
Drawbacks	Can cause high torsion, leading to increased stress and reduced durability.	Potentially more complex design, requiring meticulous production and validation.
Cost	Requires additional machinery post assembly; added cost	Cheaper manufacturing as it requires lesser tooling time after being produced

Project Objectives

This project can be divided into two core analytical frameworks:

1

Mechanical Design Guideline Framework

Create a robust design guideline to ensure the balanced design meets performance and durability criteria for future iterations.

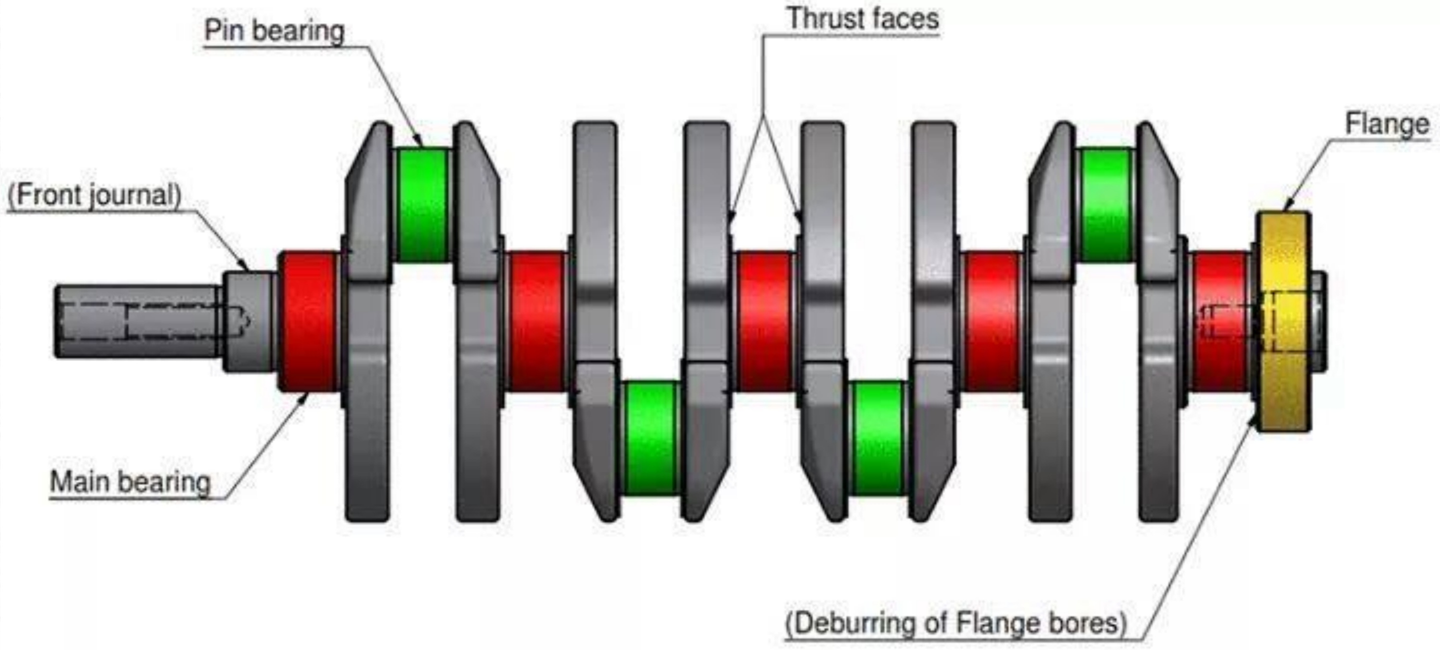
2

Analytical Model for Individual Balancing

Develop a mathematical model to predict the optimal counterweight parameters for individual crankshaft balancing.

Anatomy of a Crankshaft

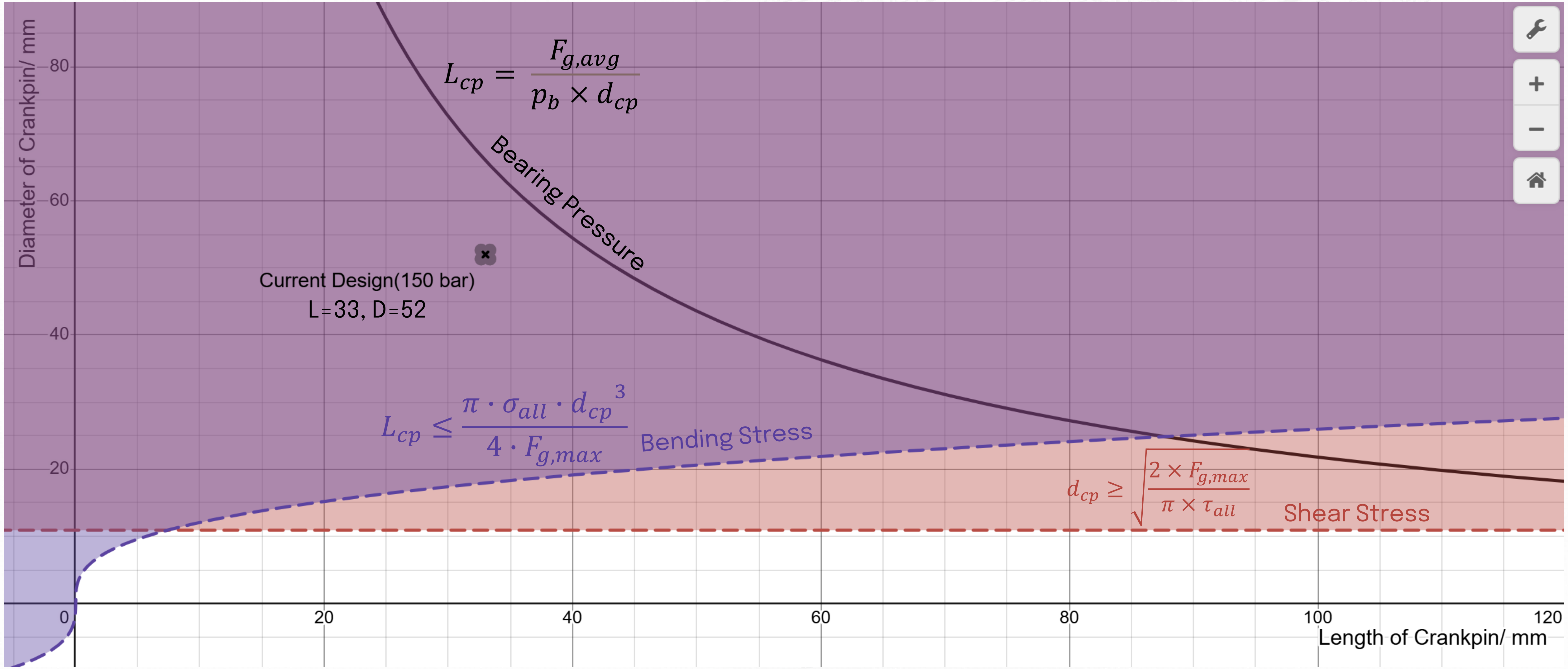
- **Main Journals:**
  - It forms the central axis of rotation and are supported by the main bearings on the engine block.
  - Marked in red
- **Crankpins:**
  - The offset journals where connecting rods attach, responsible for converting the piston's force into torque.
  - Marked in green
- **Crank Webs:**
  - Web: The section that connects the main journal to the crank pin. This forms the throw.
  - Counter Web: The section that is added to the opposite side, creating a counter moment, helping in balancing.
- **Fillet Edges:**
  - Right angled edges tend to be failure points. To reduce the change of failure, a fillet is added.
- **Flywheel**
  - A disc bolted to the rear flange that stores rotational energy (inertia) to smooth out power delivery between combustion strokes.



Crankshaft Design Guidelines

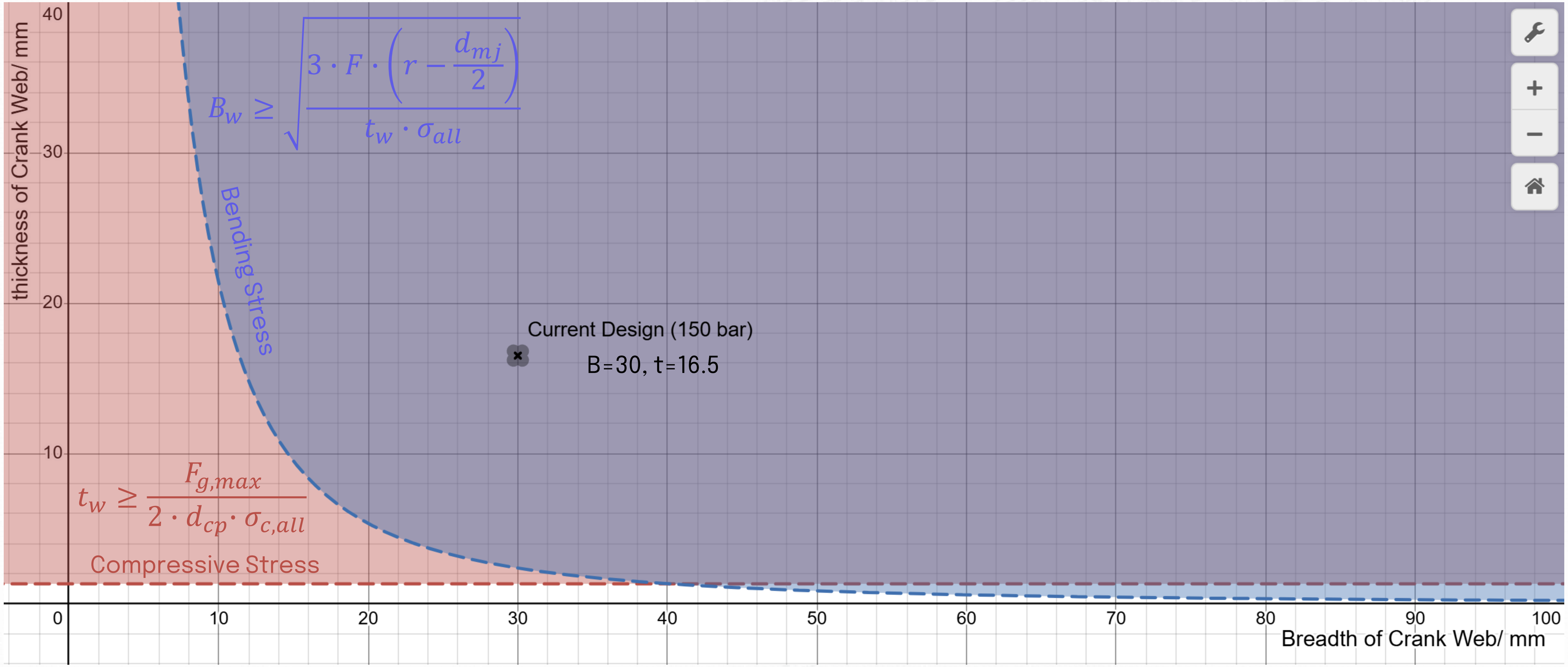
Allowable ranges for critical dimensions were determined through calculations to ensure proper function and optimize material usage. The following graphs illustrate the permissible variation. The colored regions are considered OK. The current design can be seen to be in safe region.

Crank Pin Dimensions

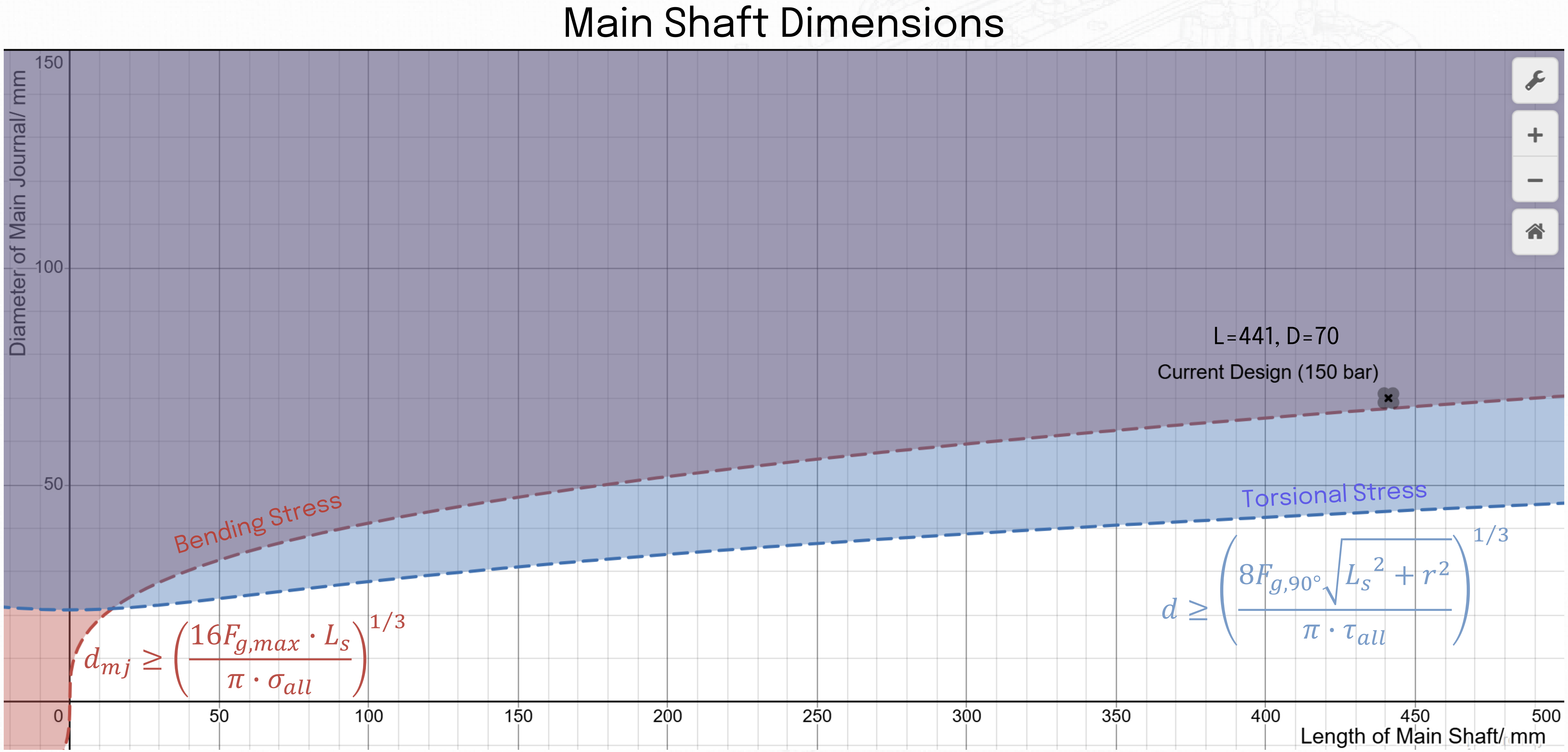


The colored regions are considered OK. The current design can be seen to be in safe region. Although, according to calculations, it would still be 'safe' even if dimensions were reduced.

Crank Web Dimensions



The colored regions are considered OK. The current design can be seen to be in safe region. Although, according to calculations, it is on the very end of the allowed region.



The Analytical Balancing Model

The analytical model utilizes a series of equations to calculate the optimal mass distribution for perfect balance. This includes factors such as connecting rod mass, piston mass, and crank throw radius. The target value is 50%

$$\text{Balancing Rate (\%)} = \left(1 - \frac{\sum_{i=1}^{n} M_i'}{\sum_{i=1}^{n} M_i}\right) \times 100$$

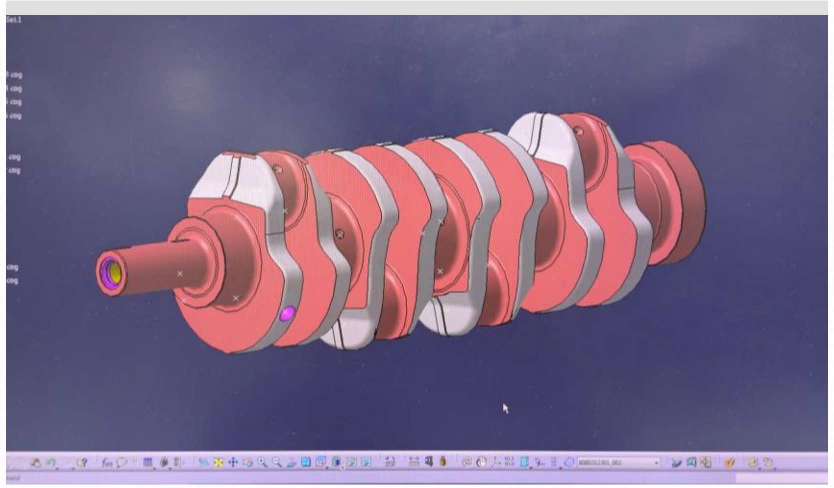
Where Mi is the unbalanced couple moment and Mi' is the residual couple moment after balancing efforts.

Value Obtained: 49.8%

The Current Design & Validation Process

1

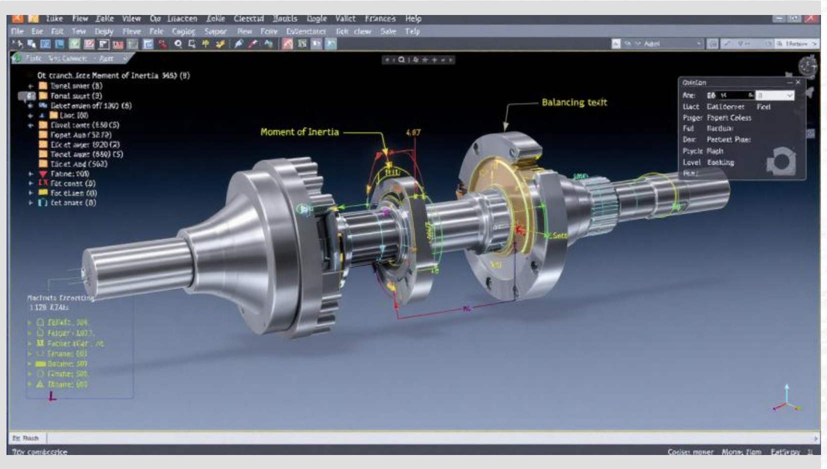
Design



Initial design conceptualization and 3D modeling using CAD software.

2

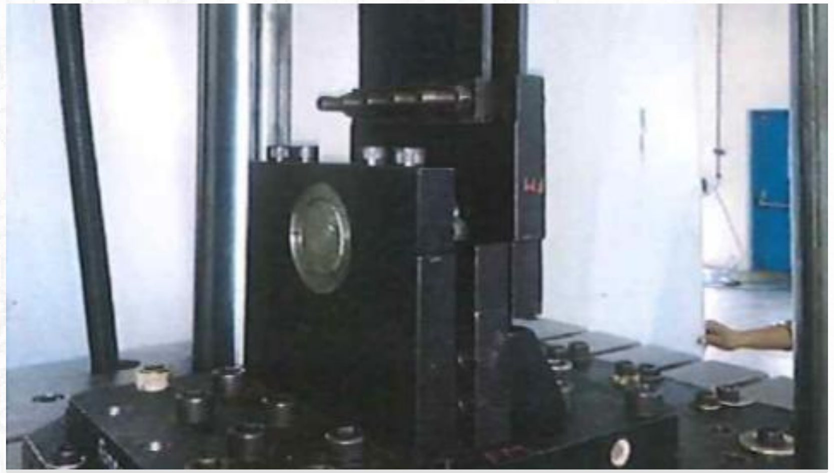
Simulation



FEA and multi-body dynamics simulations to predict performance under load and evaluate balance.

3

Proto-Testing



Physical prototyping and fatigue testing to validate simulation results and identify potential weaknesses.

Validation of Crankshaft Design

- **Endurance Testing:**
  - Objective: To assess long-term durability and wear characteristics.
  - Method: The crankshaft is tested in a fully assembled engine, run for a standard duration of 1000 hours under various operating conditions.

- **Fatigue Testing:**
  - Objective: To validate the design's resistance to high-cycle fatigue failure.
  - Method: An accelerated component-level test that subjects a section of the crankshaft to millions of simulated, high-load cycles. This test was a key focus for this project.

Validation of Crankshaft Design: Fatigue Test

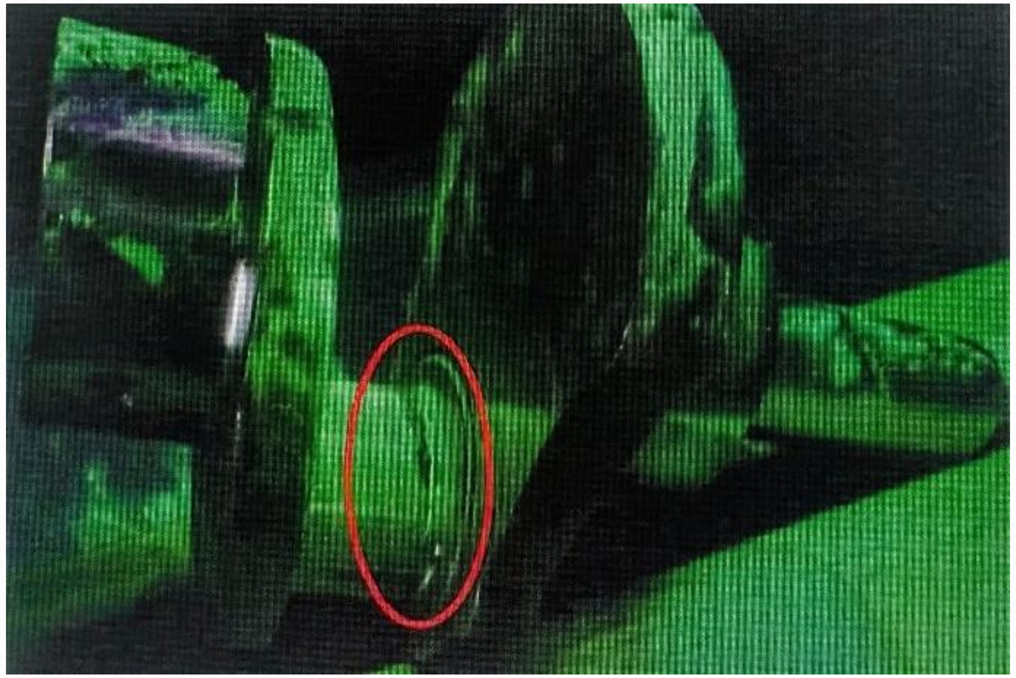
Test Parameters

- A single crankpin and two adjacent main journals are sectioned from a prototype crankshaft.

- The specimen is mounted in a fixture and loaded by a spring-powered, high-frequency mechanical pulsator.

- Load:
  - Cycle: Alternating load from 18 kN (Tensile) to 55 kN (Compressive).
  - Frequency: 52 Hz
  - Duration: 5 Million Cycles or unit failure is detected

Validation of Crankshaft Design: Fatigue Test



Analysis and Outcomes

- Inspection Method:
    - Post-test examination for micro-cracks using Non-Destructive Testing (NDT) methods like Dye Penetrant Inspection.
    - Real-time monitoring of the pulsator's frequency indicates component fracture.
- Decision Criteria Based on Factor of Safety (FS) at Failure:
    - **FS < 1.5 (FAIL):** The design is insufficient. The failure location is analyzed and compared to FEA to reinforce weak points.
    - **1.5 < FS < 2.5 (PASS):** The design is validated as safe and robust. This is the green light for manufacturing.
    - **FS > 3.0 (OPTIMIZE):** The component is over-engineered. This presents an opportunity to reduce weight and cost.

An Interim report on Fatigue testing

Sr. No.	Pin No.	FOS	Tensile Load (kN)	Compressive Load (kN)	Target Cycles	Test Status
1	3	1	18	-55	5 Million	Test completed
2	1	1	18	-55	5 Million	Test completed
3	2	1.5	27	-82.5	5 Million	Test completed
4	4	1.5	27	-82.5	5 Million	Test completed
5	3	2	36	-110	5 Million	Test completed
6	4	2	36	-110	5 Million	Test completed
7	2	2.5	45	-137	5 Million	Test completed
8	2	2.5	45	-137	5 Million	Test completed
9	2	3	54	-165	5 Million	Test completed
10	3	3	54	-165	5 Million	Sample failed at 175,284 cycles
11	3	3	54	-165	5 Million	Sample failed at 514,096 cycles
12	3	2.75	49.5	-151.25	5 Million	Test running

Conclusion & Recommendation

- **Design Validation:**
  - The analytical framework for establishing dimensional constraints has been successfully applied, ensuring the design's structural integrity under peak loads.
  - Physical fatigue testing at ARAI further validated the design, which successfully endured 5 million cycles without failure.
- **Superior Balancing Methodology:**
  - The developed analytical model confirms that an individually balanced design effectively neutralizes unbalance forces at their source.
  - This method eliminates the internal torsional flex inherent in assembly-balanced crankshafts, leading to higher durability and smoother engine operation.
- **Manufacturing & Cost Advantages:**
  - Individual balancing simplifies the engine assembly process by allowing for fully interchangeable flywheels and dampers, reducing production time and complexity.
- **Final Recommendation:**
  - Given its validated durability, superior dynamic performance, and manufacturing advantages, it is recommended that Force Motors adopt the individually balanced crankshaft design for future engine platforms.

Thank you