Phase - 0 [Planning and learning]

Phase Breakdown

Phase 1: Core Geometry & Engineering Logic

- Implement gear parameter data structures
- Code mathematical gear design equations
- Generate involute tooth profiles
- Validate calculations against textbook examples

Phase 2: CAD Model Generation

- Learn CadQuery/OpenCascade basics
- Generate 3D tooth geometry from involute profiles
- Pattern teeth around pitch circle
- Export to STEP/STL formats

Phase 3: AI Parameter Extraction

- Design LLM prompts for structured JSON output
- Extract gear parameters from natural language
- Integrate AI → Engineering → CAD pipeline
- Build simple CLI interface

Core features of MVP

Feature	Components	Deliverable
Specification Input	- Parameter validation- Data class structure- Sanity checks	`GearParameters` class
Engineering Calculations	- Pitch diameter formulas- Involute curve generation- Tooth profile geometry- ISO/AGMA standard equations	`SpurGearCalculator` module

Feature	Components	Deliverable
CAD Generation	- 2D profile creation- 3D extrusion- Circular patterning- File export (STEP/STL)	`GearCADGenerator` class
AI Interface	- Prompt engineering- JSON schema enforcement- Parameter extraction- Error handling	LLM integration layer
Validation	- Unit tests for formulas- Visual inspection in CAD software- Dimension verification	Test suite

Essential Concepts to master :

Spur Gear Terminology :

Key formulas to identify and implement :

involute Curve mathematics :

Cadquery Basics

LLM integration

Gear type we are working on :

for mvp we will work on spur gear then we will work on other gear types

Gear Type	Complexity	Tooth Geometry	MVP Scope
Spur Gear ⭐	Low	Straight, parallel to axis	✅ **YES - Primary focus**
Helical Gear	Medium	Angled spiral around axis	❌ Future Phase 2
Bevel Gear	High	Conical, tapered teeth	❌ Future Phase 3
Worm Gear	High	螺旋 thread-like	❌ Future Phase 3
Planetary Gear	Very High	System of gears	❌ Future Phase 4
Rack & Pinion	Medium	Linear gear + spur gear	❌ Future Phase 2

Some important things regarding the project :

```
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│                        USER INPUT
```

```
│
│  "Create a spur gear with 20 teeth, module 2mm"              │
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                           │
                           ▼
┌────────────────────────────────────────────────────────────────────┐
│              AI LAYER (LLM)
│
│  Role: UNDERSTAND intent, EXTRACT parameters                       │
│  • Natural language → Structured data
│
│  • "20 teeth" → {"teeth": 20}                                      │
│  • Fill missing defaults intelligently
│
│  • Route to correct tool/component type                            │
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│         DETERMINISTIC ENGINEERING LAYER
│
│  Role: APPLY verified formulas (hard-coded)                        │
│  • Pitch diameter = module × teeth
│
│  • Base diameter = pitch × cos(pressure_angle)                     │
│  • No AI guessing - pure mathematics                               │
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│              CAD GENERATION LAYER
│
│  Role: BUILD geometry using CadQuery                               │
│  • Generate involute curves                                        │
│  • Create 3D models                                                │
│  • Export STEP/STL                                                 │
└────────────────────────────────────────────────────────────────────┘
```

▼ Scaling the System for Complex Geometries

Overview

The AI CAD agent does not require hard-coded formulas for every possible design. Instead, it uses a **three-tier architecture** that scales intelligently from simple components to complex systems like Kaplan turbines, IC engines, and custom assemblies.

Three-Tier Architecture

Tier 1: Fully Parametric Component Library (Core)

What it is: 150-200 primitive mechanical components with clear mathematical formulas.

Examples:

- Gears (spur, helical, bevel)
- Shafts and bushings
- Bearings (database lookup)
- Bolts and fasteners
- Springs and washers
- Cylinders, cones, and basic shapes

Tier 2: Parametric Template Library (Assemblies)

What it is: Pre-designed complex assemblies stored as parametric templates. Designed once by humans, modified infinitely by AI.

Examples:

- Kaplan turbine (micro, large, ultra-large variants)
- Francis turbine
- IC engine block
- Centrifugal pump

- Planetary gearbox

Tier 3: AI-Assisted Custom Design (Novel)

What it is: Designs not yet in the template library, handled through AI-orchestrated component composition.

[Full document continues...]

Open source component library for reference :

- freecad gear workbench
- freecad fasteners workbench
- mc-master-carr
- cad - query
